UNIVERSITY OF SOUTHAMPTON
Faculty of Engineering, Science and Mathematics
School of Geography

# Palaeoecology of human impact in Northwest England during the early medieval period: investigating 'cultural decline' in the Dark Ages.

Emily E. Forster

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UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS
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Doctor of Philosophy

PALAEOECOLOGY OF HUMAN IMPACT IN NORTHWEST ENGLAND DURING THE EARLY MEDIEVAL PERIOD: INVESTIGATING 'CULTURAL DECLINE' IN THE DARK AGES.

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The period following the Roman withdrawal from England in AD 410 has long been considered a time of 'cultural decline', owing to the relative paucity of archaeological evidence relating to this time and the dismal state of affairs described by the Dark Age historians Gildas (*c* AD 540) and Bede (AD 731). Traditionally this period has been viewed as a time of chaos in which farmland was abandoned and the population declined, leading to woodland regeneration in many areas. In Northwest England, archaeological remains for the early medieval period (*c* AD 410-1066) are sparse. Early palynological studies in Cumbria, for which radiocarbon dates were often lacking or imprecise, frequently assigned major 'woodland clearances' to the Romano-British period, woodland regeneration phases to the early Dark Ages, 'subdued' agriculture to Anglo-Saxon farmers and pastoral clearances to the actions of Norse settlers.

The overarching aim of this study has been to question the validity of the above interpretations through analysis of pollen and diatom records from six tarns within the English Lake District. Of the sites investigated, both Loughrigg and Barfield Tarns produced good records for the study period. The pollen curves for Loughrigg Tarn appear to support the traditional interpretation of woodland regeneration in the early post-Romano-British period, while at Barfield Tarn the pollen indicates a largely open landscape with limited evidence for agriculture. Drawing together the data from these sites with the small body of extant palaeoecological research relating to this period, it is clear that the timing and nature of land-use varied across the region. This highlights the importance of localised pollen studies, particularly as regards the relationship between vegetation records and archaeological remains. Pollen-vegetation simulation experiments using HUMPOL (Bunting & Middleton, 2005) were a useful aid to interpretation, raising important questions regarding 'woodland regeneration' signals in pollen diagrams.

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[1] Dates are based on the oldest archaeological remains in the area (Mesolithic) and the earliest date for the Roman invasion of Northwest England respectively.

**Appendices**

# LIST OF FIGURES, IMAGES, MAPS AND TABLES

**All diagrams, maps and photographs are by the author unless otherwise stated.**

The first number for each figure denotes the chapter within which it is found (page numbers in brackets), or in the case of appendices ('A'), that in which it is first mentioned.

## Figures

[1] Maximum presence of 2% or more of the TLP
[2] Maximum presence of 2% or more of the TDC

## Images

## Maps

## Tables

# DECLARATION OF AUTHORSHIP

I, Emily E. Forster, declare that the thesis entitled

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- none of this work has been published before submission

**Signed:** E.E. Forster

**Date:** 21/09/2010

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## Abbreviations and conventions used in the text

**Site codes:**

BFT: Barfield Tarn

BLT: Blelham Tarn

BYT: Burney Tarn

BYB: Burney Bog

LLT: Little Langdale Tarn

LGT: Loughrigg Tarn

TWT: Tewet Tarn

**Modelling:**

RSAP – Relative Source Area for Pollen (*sensu* Sugita, 1994)

LRA – Landscape Reconstruction Algorithm

MSA – Multiple Scenario Approach

**General:**

References contained within curly brackets {} refer to diatom authorities or creators of software programs.

sp. – species (singular)

spp. – species (plural)

p – page

pp – pages

# INTRODUCTION

Traditionally, historians and archaeologists have viewed the Roman withdrawal from Britain as a cultural catastrophe. The Roman invasion in AD 43 had brought with it stone architecture, written texts, fine pottery and a system of government. Trade links were forged with continental Europe, facilitating the import of exotic goods. When the Romans deserted the westernmost part of their empire in AD 410, they left the Britons to the mercy of heathen invaders, condemning them to centuries of barbaric raids and cultural decline. The Roman system collapsed, buildings were abandoned and trees reclaimed the farmland. These were the Dark Ages.

In recent decades this pessimistic view of post-Roman life has been challenged. The progression of archaeological theory has resulted in a reappraisal of concepts such as 'value' and 'sophistication' as applied to artefactual evidence. Our own experiences and preconceptions influence our interpretation of archaeological remains, meaning that our assessment of the value of an object may be quite different to that of past peoples with belief systems and world views completely alien to us. Bearing this in mind, it is necessary to reconsider our evaluation of periods such as the Dark Ages relative to the preceding and following periods; we have to be aware that the cessation of mosaic and samien-ware production may have occurred as the result of socio-cultural change as opposed to a collapse of trade or a loss of expertise.

The importance of differential survival, visibility and representation within the archaeological record is also recognised. Wooden structures and artefacts are far more vulnerable to decay than stone buildings and durable pottery, biasing the record in favour of cultures producing the latter. As new artefactual evidence comes to light and earthworks and postholes of previously indeterminate age are attributed increasingly to the Dark Ages, it is necessary to reconsider the negative view of this period of history. With the decline of empires the glorification of Rome has been called into question; if imperialism is viewed as an instrument of oppression and exploitation rather than a means of 'enlightening' and bringing culture to other peoples, our perceptions of the Roman occupation need to be re-examined. An improved understanding of the biases inherent in historical accounts has also helped to deconstruct negative views of the Dark Ages, acknowledging that the portrayal of the period by contemporary authors such as Bede (writing in AD 731) was influenced heavily by their political and religious standpoint and that of their intended audiences. The early to middle medieval period (approximately the $5^{th}$ – $11^{th}$ centuries AD) has now come to be seen by some authors not as a time of darkness and degeneration, but as one of cultural change and the formation of the English nation (Wood, 1981).

Despite these developments in archaeological and historical thought, when interpreting palaeoecological data the established sequence of glorious Roman civilisation followed by decline and chaos prevails. The Romano-British period is often described as a time of clearance and agricultural intensification, with the Romans introducing new crops to some parts of the country (*e.g.* Rye, *Secale cereale*) and covering the land in fields to feed the army. In contrast, the Dark Ages (approximately the $5^{th}$ - $8^{th}$ centuries AD) are viewed as a time of violence, cultural degeneration and abandonment of farmland, when crop-fields deteriorated and were overgrown with woodland. Unfortunately, in Britain there is currently insufficient palaeoecological work covering this period for us to be able to draw these conclusions with confidence. Painting such a picture of vegetation change at the end of the Roman occupation undermines the assertion that the Dark Ages were a time of socio-cultural development in Britain; further work is required to either refute or support this theory.

The aim of this project is to elucidate the nature of landscape and vegetation change from the late Roman to the early/middle medieval period in the English Lake District. The need for this investigation springs from a paucity of historical and archaeological information relating to the period, combined with sparse palaeoecological data covering this time span. As an area at the edge of the Roman Empire and a point of contention between Scotland and England for centuries, the history of this mountainous region has been tempestuous. Owing to the prevalence of cold, wet weather and the rocky terrain, the Lake District is today considered to be a marginal landscape. It is difficult to imagine crops thriving on the rugged mountainsides or lush pastures in the valleys, yet the present landscape has been shaped by thousands of years of human activity. Although a great deal of palaeoecological work has been carried out in the area, there is little focusing on the period in question; further investigation is required if events at this time are to be understood.

The hypothesis to be tested here is that farming (and presumably other economic activity) was maintained after the Roman withdrawal, in opposition to the traditional view of cultural collapse, abandonment of farmland and woodland regeneration. If this is the case, we may expect continuity in landscape management rather than change, reflected in the pollen record by the continued presence of agricultural and pastoral indicator species. Conversely, evidence for woodland regeneration and the disappearance of these taxa would suggest abandonment of agricultural land, supporting the traditional view of this period and perhaps signifying cultural change. The findings of this research may have wider implications for the way in which the period of Roman domination is viewed, both in terms of socio-cultural influences and as an agent of landscape development. A combination of pollen and diatom analyses and radiocarbon dating of significant changes in these records is here presented as a means of determining the nature of landscape development in Dark Age Lakeland. Simulation software (HUMPOL v3, Bunting & Middleton, 2005) was employed to aid interpretation of the palynological data.

The subsequent chapter begins with a summary of the key issues affecting early medieval history and archaeology (1.1-1.3), followed by an overview of the landscape and human history of the Lake District (1.4). Although this research focuses on the later Romano-British and early medieval periods, a brief history of the prehistoric, later medieval and post-medieval periods is provided in order to demonstrate both the longevity of land-use in the region and the dearth of Dark Age archaeological material in comparison with that for other time periods. Palaeoecological techniques for investigating human impact are then discussed, followed by a synopsis of the available pollen and diatom data relating to early medieval Cumbria. The chapter concludes with a breakdown of the research aims of this project.

# CHAPTER 1: BACKGROUND TO THE PROJECT AND A REVIEW OF THE LITERATURE

## 1.1. Cultural decline in the Dark Ages? Readdressing the evidence

The post-Roman and early medieval periods[1] (approximately the 5$^{th}$ to 10$^{th}$ centuries AD), derogatorily known as 'the Dark Ages' have long been depicted by historians and archaeologists as a time of cultural decline and limited progress in England. Historical texts conjure up images of noble, Christian Romano-Britons, abandoned by the Roman army and deprived suddenly of the culture, technology, government and protection to which they had grown accustomed (*e.g.* Bede, AD 731; Marsh, 1970; Faulkner, 2004). In the aftermath of the Roman exodus, Germanic pagans took advantage of the vulnerability of the deserted Britons, raiding coastal settlements and eventually invading the lands that evolved into English kingdoms under their rule. The paucity of archaeological records from the early Dark Ages (*c* 5$^{th}$ to 7$^{th}$ centuries AD) seems to betray a loss of cultural and technological sophistication achieved during the Roman occupation, and the lack of contemporary written evidence shrouds the period in mystery. As Marsh states (1970: 15), 'continental writers knew little of...the lost island and recorded only rumours and fables'.

The negative views outlined above have been to a large extent questioned by changes in the way that archaeological evidence is interpreted, combined with a reassessment of the material culture of the Dark Ages (*e.g.* Wood, 1981; Hodges, 1982; Arnold, 1997; Barrett *et al.*, 2004, Pryor, 2005). Although historical and archaeological data pertaining to this era remain scarce, changes in the theoretical grounding of archaeological interpretation necessitate a reconsideration of assumptions made about the Dark Ages. The differences between schools of archaeological theory are explained briefly below, followed by outlines of the contending views of early medieval England. This section is divided into the early and later Dark Age periods (post-Roman/early Anglo-Saxon and late Anglo-Saxon/Viking) as these are generally (though perhaps incorrectly) treated as distinct periods in the literature, often falling into separate research themes.

[1] Two less commonly used terms are 'Late Antiquity' and 'the early Middle Ages'.

### 1.1.1. Views of the past: theoretical considerations

It is generally acknowledged that the interpretation of archaeological remains is highly subjective and influenced by the prevailing academic and political climate. For example, during the twentieth century the origin myth wherein England was founded by Anglo-Saxon settlers fell out of favour, on account of associations with Germany and her part in the two World Wars (MacDougall, 1982). Similarly, during the period of British imperialism the Romans were viewed in a positive light, as bringers of culture and civilisation to the barbarian populations of Europe. This portrayal of Rome as an educating, civilising force is linked closely to the Victorian outlook, in which Britain was seen as the saviour of 'savage' peoples around the world (*cf.* Bowler, 1992). As in the case of the British Empire, this romantic view of Rome as a spreader of enlightenment has been challenged in recent years; Roman campaigns abroad were driven largely by a search for resources, power and wealth and not by a desire to educate 'the barbarians' in Roman ways (Faulkner, 2004).

Changes in historical thought may seem to have little bearing on the archaeological process, but implicit assumptions about the peoples whose cultural remains are being excavated and the relative value of different artefacts or structures affect the treatment and interpretation of sites and artefacts. A basic example of this is seen in the decision-making processes of an individual excavator. Items that are considered 'valuable' or rare such as jewellery and weapons are treated with care and patience, while rough sherds of pottery and fragments of animal bone are often tossed aside; in some cases material that is deemed 'worthless' may be discarded.[2] In extreme cases this decision-making process has led to the destruction of all archaeological deposits overlying those in which the excavators are interested; tales of site directors instructing archaeologists to dig through everything until they reach Roman (or equivalent) levels are not uncommon, and in one case workers were told to 'dig until they hit skulls' underlying a villa complex (Martin Brown, pers. comm.). The intrinsic value of Roman artefacts compared to Dark Age archaeological remains combined with the lack of interest in the archaeology of this period among early excavators has almost certainly led to the loss of a considerable body of material evidence at many sites. Recognition of the arbitrary nature of measures of 'value' and 'sophistication' attached to artefacts and buildings and the degree to which these factors are seen to reflect on cultural development, have led to a reconsideration of material evidence from the Dark Ages (*cf.* Wood, 1981; Pryor, 2005).

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[2] A common example is the decision not to retain 19th or 20th century pottery during excavation. This is in part owing to the time-consuming process of cleaning, cataloguing and storing all collected items, but also stems from the assumption that little will be gained by studying these materials.

Documentary evidence tends to support positive views of Rome, but contemporary records were written almost exclusively by the conquerors or their sympathisers and as such were unlikely to portray them in an unfavourable light, although Tacitus (*c* AD 98) is surprisingly scathing about Roman imperialism. The biases inherent in written sources have long been recognised by historians; the personality, knowledge, experiences and motivations of the author all have a bearing on the version of events recounted (*cf.* Marsh, 1970). A key problem in historical (as opposed to prehistoric) archaeology has been the assumption that archaeological investigation serves merely to supplement knowledge gained from documentary evidence. This approach assumes implicitly that the historical sources provide an accurate, practically complete record of history that the archaeological evidence is incapable of contradicting (Moreland, 2003). Documentary evidence from early medieval England is very limited, but that which is available has been the basis for the reverence of Rome and the negative views of Dark Age Britain described above (*e.g.* Gildas, *c* AD 540; Bede, AD 731). Recognition of the incomplete, subjective nature of these records is vital to the reappraisal of Dark Age history.

The difficulty of separating fact from propaganda in historical records is compounded by the poor representativity of archaeological remains. The archaeological record is thought to retain only a tiny percentage of the objects and materials used in daily life. Perishable items such as textiles, food and wooden objects are rarely preserved; consequently there are large aspects of material culture for which we are frequently without evidence (Drewett, 1999; Renfrew & Bahn, 2000). In the Dark Ages most dwellings were constructed from wood, normally reduced to a series of postholes over the centuries and invisible in unexcavated areas. As such remains are not readily observed in the landscape, any associated artefacts, animal or plant remains are also unlikely to be found except by chance (*e.g.* brought to the surface by ploughing) or excavation. In addition, many villages originating from this period probably continued to exist in the same locations and were eventually rebuilt in stone, obscuring remnants of earlier, wooden buildings (*cf.* Fell, 1973c; Lloyd, 2008). As Fulford states (2001), 'The sample of evidence available to us is limited to the vagaries of a variety of excavation and finds conservation strategies.' This could be said of the entire archaeological record, but is exaggerated with regard to periods such as the Dark Ages where the material remains are sparse and poorly preserved. Growth of the disciplines of zooarchaeology (or archaeozoology) and archaeobotany since the late 1960s has also led archaeologists to realise the value of animal bone and plant remains in revealing past diets and husbandry practices (*e.g.* Payne, 1973; Klein & Cruz-Uribe, 1984; Jones, 1987; van der Veen, 1992; Driver, 2001). This has resulted in more rigorous collection of these materials during excavation; for periods such as the Dark Ages where the remains of buildings and artefacts are scarce, the knowledge gleaned from examination of animal and plant remains makes a valuable contribution to our understanding.

Owing to the above-mentioned changes in archaeological and historical thought, a growing body of material evidence from the time and recognition of the preservation biases affecting Dark Age archaeology, the much maligned post-Roman period has now come to be considered an important and formative time in Britain's developmental history (Wood, 1981; Pryor, 2005). Nevertheless, the traditional view prevails in local histories and more often than not in the palaeoecological literature. Competing interpretations of the situation in Dark Age Britain are here presented with their supporting evidence. With regard to the current project, the question of which hypothesis is closest to the truth is an important one; the potential impact in terms of land-use history could be expected to vary substantially for the different scenarios, ranging from continuity in land management to total abandonment of farming practices. As with many theories about the past where the answers are uncertain, the way in which evidence is interpreted, governed by the preconceptions and preconditioning of the analyst, has a significant effect on the conclusions reached. For this reason it is important to consider all available lines of evidence as objectively as possible.

Greater emphasis is placed upon the post-Roman and early Anglo-Saxon periods than on the later, less contentious, Anglo-Saxon and Norse 'settlement' phases in the following synopsis. This is because the impact of the Roman withdrawal and ensuing Germanic invasions/migrations is the focus of many of the arguments surrounding early medieval England (*e.g.* Stenton 1947; Arnold, 1984; Higham, 1992; Dark, K., 2000; Faulkner, 2004; Pryor, 2005), while the relatively peaceful phase conjectured for the latter part of the first millennium AD (with the notable exception of the late 8$^{th}$ to mid-9$^{th}$ century AD period of Viking raiding) generally receives less attention.

**1.2. The early Dark Ages: post-Roman and Anglo-Saxon England**

The earliest phase of the 'Dark Age' period featured the end of Roman Britain and the arrival of the Anglo-Saxons. Traditionally, this period has been portrayed as the most dismal part of the Dark Ages on account of the disruption of the Roman departure and subsequent Anglo-Saxon attacks. The writings of Gildas (*c* AD 540) and Bede (AD 731) paint a bleak picture of life in Britain (comprising approximately the area of present-day England) during the early

Dark Ages. Archaeological evidence has been employed to support or refute their claims to varying degrees and the history of this period remains debateable.

### 1.2.1. The traditional view: abandonment, cultural impoverishment and Anglo-Saxon invasion

The impressive material culture of the Romano-British period provides a stark contrast to pre- and post-Roman archaeological remains, and has often been construed as representing a cultural highpoint sandwiched between the murkier Iron and Dark Ages (Faulkner, 2004; Pryor, 2005). Mosaic-decorated villas with hypocausts and atria, fine pottery, written texts and exotic foods from continental Europe appeared during the three and a half centuries of Roman occupation, although Faulkner (2004) suggests that the most impressive developments in material culture were confined to the 1st and 2nd centuries AD. While in some places there appears to be continuity in the mid-/late-Romano-British period, in much of Britain the disappearance of Roman artefacts, presumably because of the disruption of trade networks as the empire declined, is dramatic (Faulkner, 2004). Abandonment of military forts in northern England is thought to have begun from the early-to-mid-4th century AD onwards, although archaeological evidence suggests continued (possibly civilian) occupation at some sites (Breeze & Dobson, 1985; Faulkner, 2004). The removal of a large number of soldiers as forts were deserted must have reduced demand for natural resources. This would have had a noticeable impact on landscapes in the vicinity of the forts; under the *Pax Romana* (Roman peace) Britain's standing army consisted of 40 000 men, requiring a considerable amount of food, metal and other supplies, as seen in tablets recovered from *Vindolanda* (Northumberland, south of Hadrian's Wall) (Bowman & Thomas; 1987; Dark, P., 2000; Faulkner, 2004). The sheer number of soldiers stationed at the forts along Hadrian's Wall necessitated substantial clearance of woodland for farming, evinced by palynological evidence for large-scale woodland clearances in the area during the Romano-British period (Dumayne, 1994; Dumayne & Barber, 1994). However, once the soldiers were gone there would be little value in continuing the upkeep of (for example) large areas of cultivated land when the crops produced were no longer required (*cf.* Dark, P., 2000). Pollen records show substantial woodland regeneration at several localities along Hadrian's Wall in the Dark Ages, suggesting that the farming landscape was abandoned (Barber, 1981; Barber *et al.*, 1994; Dumayne & Barber, 1994; Dumayne-Peaty & Barber, 1998; Dumayne-Peaty, 1999).

The loss of Roman authority and depopulation of some areas is also thought to have left Britain vulnerable to attackers from continental Europe, who were wreaking havoc on coastal settlements as early as the 3rd century AD. Germanic groups raided the eastern coastline, prompting the construction of numerous fortifications such as those at Pevensey (East Sussex), Dover (Kent) and Brancaster (Norfolk) (Cunliffe, 1973). Raiding almost certainly occurred, but the severity, frequency and eventual outcome of the attacks is debatable (see Sections 1.2.2 & 1.2.3). The desolate portrayal of the early Dark Ages in documentary records is to some extent supported by archaeological evidence; deposits containing silver objects and coins, thought to be 'hoards' buried for temporary protection and future retrieval (as opposed to permanent burials or 'offerings') are common from this period, often interpreted as evidence of raiding (Hill, 1981; Pryor, 2005). Traditionally, it was assumed that hordes of invaders destroyed or drove out and replaced the sparse Romano-British population, forming a new Anglo-Saxon nation that later became England (*e.g.* Bede, AD 731; Stenton, 1947). This is based on limited written evidence from the period, the Germanic roots of the English language, widespread occurrences of Anglo-Saxon pottery and the presence of Germanic styles of jewellery accompanying burials (*cf.* Wood, 1981; Hamerow, 1997; Lucy, 1998). In the 1980s a slightly different theory arose, suggesting a smaller-scale, elite immigration, whereby Romano-Britons were subjugated by Saxon military leaders and forced to adopt the culture of their conquerors (Arnold, 1984; Higham, 1992). The latter theory is now more widely accepted as there is evidence for continuity at numerous sites in the post-Roman period, suggesting that the vision of a depopulated landscape for Saxon migrants to colonise should be rejected. It has been postulated that the initial movement of high status authority figures was followed by a larger scale migration over time, which is probable given the corresponding evidence for depopulation of areas such as Angeln (Schleswig-Holstein, Germany) (Hamerow, 1994; Montgomery *et al.*, 2005). Attempts to assess the number of migrants have been carried out with varying success (Section 1.2.4) and the scale of the Anglo-Saxon invasion remains an unknown factor (Lloyd, 2008).

The Germanic invasions are documented in many medieval and later historical sources concerning the Dark Ages, but as with the majority of textual records these were written with pronounced socio-political biases and must be interpreted with care (Marsh, 1970; Wood, 1981; Pryor, 2005). Unfortunately there are no extant, written records from Britain dating to the period immediately following the Roman withdrawal; the closest thing to a contemporary

English account is *The Ruin of Britain* written by Gildas in *c* AD 540, more than a century after the departure of the Roman army.

#### 1.2.1.1. Gildas: *The Ruin of Britain* (*De Excidium Britonum*)

Gildas' work is a tirade against the ruling kings and clergy in 6th century Britain and includes a brief history of that time (Winterbottom, 1978). According to *De Excidium*, early post-Roman attacks were repelled successfully by the Romano-Britons. However, free from the constraints of Roman authority, the Britons are said to have become increasingly 'evil' (rejecting Christianity), with the result that 'God, meanwhile, wished to purge his family, and to cleanse it from such an infection of evil by the mere news of trouble.' (Gildas, *c* AD 540 (reproduced in Winterbottom, 1978: 25)). The resulting 'divine punishments' began with a plague and culminated in brutal and repeated Saxon attacks, until a council of Britons 'of their own free will…invited under the same roof a people they feared worse than death' (Gildas, *c* AD 540 (Winterbottom, 1978: 26)). The Saxons are described as mercenaries hired to fight off invaders from the north. When their work was done they demanded further payment and eventually turned on their British employers, attacking towns and slaughtering Britons and any remaining Romans. The survivors, hiding in the hills, banded together and fought the Saxons repeatedly, eventually triumphing at the Battle of Badon Hill, when the Saxons were driven out of England. Despite this victory, Gildas describes 6th century AD Britain as a land ravaged by civil wars, with the towns deserted and unkempt and the power held by tyrannical kings and sinful clergymen.

The strong religious overtones of Gildas' text render it highly questionable as an historical account (*cf.* Stenton, 1947; Marsh, 1970; Higham, 1992). The mixture of sensational religious propaganda and historical 'facts' is difficult to pick apart, and the prime objective of the author necessitates exaggeration of the horrors of 'divine retribution'. *The ruin of Britain* is littered with biblical quotations and repeated assertions that the sins of the British are the cause of all their suffering. The deadly plague and brutal 'heathen' attacks are portrayed as manifestations of the wrath of God, and the intent of the author is clear; he wishes to impress upon 6th century Britons the importance of religion, and repeatedly describes the torments they will face in hell should they fail to amend their ways. The tone of the text is exemplified by Gildas' reprimand of Constantine of Dumnonia, who had planted 'a slip of unbelieving folly in the soil of his heart' and subsequently committed various crimes that Gildas recounts with vehemence and in detail.  He concludes with the warning, 'if you turn your back on this, know that you will soon be whirled and burnt by dark torrents of hellfire that you can never escape' (Gildas, *c* AD 540, in Winterbottom, 1978: 30).

Aside from the propagandist nature of the text, Gildas was writing at least a century after many of the events he describes; there may have been earlier written works (now lost) on which he based his tale, but if not he would have heard the stories by word of mouth, presumably changed and elaborated upon over the years.  Higham (1992) argues that some of the historical facts in the text must be true, as the impact of *De Excidio*'s message would have been reduced had the introduction been thought inaccurate.  He also suggests that Gildas was personally acquainted with Saxons as the text demonstrates his knowledge of their language and practices, and goes on to infer separate settlements of Saxon 'English' and British peoples in England (interpreting the 'home' to which the Saxons went after the Battle of Badon Hill as their settlements in eastern England, rather than continental Europe) (Higham, 1992).  Considering the archaeological and linguistic evidence in favour of Anglo-Saxon immigration, this seems more likely than a total retreat, especially if the decimation of the British population by illness and Saxon attacks is to be given any credence.  It is possible that a temporary withdrawal occurred, followed by renewed attacks in the later 6th century AD; in his 'Historical introduction' to Gildas, Winterbottom (1978) states that the Saxons rebelled and 'subdued' the Britons at this time, but as he provides no source for this information it is difficult to assess its accuracy.

Gildas provides a *version* of history, written by one man with strong, religiously motivated bias, recounting events that were beyond living memory (though not beyond 'folk memory'); there is probably some truth buried in the text, but the style of writing and interweaving of historical 'fact' and religious fiction render this difficult to identify.  The nature and scale of the Saxon invasion/migration remains a matter for debate amongst scholars, many of whom (as suggested above) are dubious as to the accuracy of Gildas' account[3] and the subsequent work of Bede (AD 731), discussed below.

[3] Interestingly, in terms of changing historical consensus, Stenton (1947) stated the failure to mention King Arthur, 'whose **claim to historic existence** rests upon the ninth century [*i.e.* even further removed from the period described] compilation of…Nennius' as the principal reason to question the accuracy of Gildas' account (Stenton, 1947: 3).

#### 1.2.1.2. Bede: *The Ecclesiastical History of the English Nation*

The Venerable Bede, writing over three hundred years after the Roman departure, painted a picture of multiple invasions by hordes of marauding Saxons, Jutes and Angles, redeemed only by their conversion from 'a barbarous, fierce and unbelieving nation' to a Christian one in AD 597 (Bede, AD 731 (in Giles, 1847: 34)). Pryor describes Bede as a priest with Saxon sympathies who spent many years living in monasteries (Monkwearmouth and Jarrow), writing for 'the salvation of his people' (Pryor, 2005: 26). In addition, it is thought that much of Bede's *Ecclesiastical History* is gleaned from Gildas' earlier work, maintaining similar religious overtones throughout the text (Marsh, 1970). The latter is evident in Bede's dedication of the book; 'To the most glorious King Ceolwulph[4], Bede, the servant of Christ and priest' (Bede, AD 731: 1 (in Giles, 1874)). As with Gildas, it is difficult to assess the accuracy of Bede's history; he was born long after many of the events he describes, and his strong religious views necessitate the worst possible portrayal of the earlier 'heathens', in contrast with the pious Christian Saxons of his time. He considers the Saxons to be God's 'chosen' people (Gildas favours the Britons despite their wickedness), to whom the wanton Britons failed to spread Christianity (Bede, AD 731: Chapter 22 (Penguin Edition, 1990: 72)). The length of time elapsed between the early Dark Ages and the writing of Bede's account, in addition to the similarity between his version of events and that portrayed by Gildas, suggests that Bede's work is derived from the latter and should be considered with equal scepticism. While it is *possible* that both accounts accurately report the same series of events, the highly negative view of the post-Roman era presented by both authors is thought to be, at best, a dramatic exaggeration of the truth (*e.g.* Wood, 1981; Pryor, 2005).

#### 1.2.1.3. *The Gallic Chronicle*

As mentioned previously, there are no contemporary *British* accounts of the early post-Roman period. However, two versions of *The Gallic Chronicle* written in France in AD 452 and 511 contain references to England at this time, and state that 'the provinces of Britain were laid waste by the incursions of the Saxons' (cited in Cunliffe, 1973). The chronicles place Saxon invasions in AD 410-11 and AD 441, the latter of which is referred to as the conquest of Britain. Unfortunately, entries in the chronicles are often ambiguous; as Burgess (1990) explains, the attack dated AD 410-11 may not refer to an invasion as the Saxons had been

[4] King of Northumbria AD 729-737. Following a difficult period in power during which he was captured (AD 731), tonsured and subsequently released, he ended his reign by retiring to a monastery (Fisher, 1973).

raiding the coast for centuries. Doubt has been cast on the accuracy of the text owing to the incompatibility of certain dated events in the chronicles with those provided by other contemporary sources (Burgess, 1990). As mentioned previously, contact between Britain and the continent is thought to have been very limited after the Roman withdrawal; if this is the case, the authors of the chronicle would have had little information on which to base their accounts, and to repeat Marsh's quote, 'recorded only rumours and fables' (1970: 15). A further problem encountered by Burgess (though disputed by those whom he accuses (Jones & Casey, 1991)) is the propensity of scholars of the chronicles to 'correct' them, making them fit our understanding of the period more accurately (Burgess, 1990). This action is justified by the assumption that the chronicles were originally very accurate; mistakes are therefore attributed to later scribes copying the texts carelessly. Although it is probable that this occurred, as Burgess states, it is not possible to distinguish 'original' and 'corrupted' information when the chronicle itself is the primary source of information for the period. This can only be justified if older versions of the manuscript are found not to contain the errors.

As the closest thing we have to contemporary written records from Dark Age England, the three texts summarised above have been influential in the formation of theories about the nature of post-Roman England. The resulting vision of a people abandoned by their protectors (or oppressors) and set upon by barbarians is a bleak one. In *Dark Age Britain: some sources of history*, Marsh laments 'the fog of war, the clouds of despair, the boastful glare of triumphant armies and the mourning candles of the defeated' (Marsh, 1970: 195). Although there is archaeological evidence to support some aspects of the accounts (*e.g.* hoarding, construction of coastal forts) (Cunliffe, 1973; Hill, 1981), a closer examination of archaeological remains has led archaeologists to question the scale of the desolation suggested by traditional depictions of Dark Age England.

### 1.2.2. Post-imperial Romano-British rule: continuity in a Romanised land

In some ways the Roman withdrawal from Britain undoubtedly had a significant impact; as suggested above, the removal of a large number of soldiers (those who were still in active service) reduced the demand for resources, and loss of power structures probably disrupted trade with the continent (Faulkner, 2004). However, it could be argued that the army did not constitute all of the Romans in England. Many of those retiring from the army during the 367 years of occupation would have settled and raised families near where they were stationed, and their descendants are unlikely to have fled for their ancestral homelands with the retreating army.  In addition, many Britons adopted aspects of the Roman lifestyle and might have considered themselves to be more Roman than British (*cf.* Dark, K., 2000).  Winterbottom (1978) claims that all Britons born in the last two centuries of Roman rule were officially 'Roman', heightening the feeling of abandonment when their rulers withdrew.  This is difficult to assess and opinions vary within the field; traditionally, villas were viewed as the houses of wealthy Romans, but evidence from sites such as Fishbourne indicates that Britons of high status adopted Roman styles of architecture and decoration as a display of social standing (*cf.* Walthew, 1975; Pryor, 2005).  This suggests that the villas' occupants upheld positions of power, either as puppets of the Roman administration or as leaders in their own right.  The latter is supported by evidence that the invasion was 'invited' by leaders of southern British tribes (namely King Verica of the Atre-Bates), who benefited from the Roman system and continued to uphold positions of power under the blanket of Roman administration (Henig, 1998).  If the latter is the case, the removal of Roman troops may have had little impact on social order within the regions; with continuity in leadership the chaotic political collapse that is often envisaged may not have occurred (Dark, K., 2000; Lloyd, 2008).

The situation described above accords with that envisioned by Ken Dark (2000), wherein militarily strong political units of the late Roman period retained power into the 6$^{th}$ century AD, holding off the Anglo-Saxons and retaining aspects of Roman culture and Christianity.  This is supported by evidence for re-occupation of fortifications in the 5$^{th}$ century AD and the absence of recognisably Anglo-Saxon artefacts at many sites (Dark, K., 2000; Pryor, 2005; Lloyd, 2008), and is not wholly incompatible with Gildas and Bede's accounts.  As mentioned previously, there are some sites where the archaeological remains suggest continuity rather than change at the end of the Roman occupation (*e.g.* Birdoswald) (Wilmott, 1997; Dark, K., 2000), but these are usually considered to be exceptional rather than representative of the overall state of affairs (Faulkner, 2004).  Evidence for continuity and limited Anglo-Saxon influence is also cited by Francis Pryor in *Britain AD* (2005), but Pryor's vision of Romano- and post-Roman Britain is quite different to that of Ken Dark.

### 1.2.3. Limited Roman influence and no Anglo-Saxon invasion: continuity from Iron Age Britain through to early medieval England

In a logical extension of Dark's arguments for Romano-British continuity in the Dark Ages, Pryor postulates an uninterrupted line of population and cultural development from the pre-Roman Iron Age to the medieval period (Pryor, 2005). Excavations at some sites, such as Orton Hall Farm in Peterborough revealed a consistency in the development of structures, ditches and pits. This is thought to reflect continuity in the organisation of activities at the site, which Pryor believes would not have occurred if there were changes in ownership following the Roman withdrawal (Pryor, 2005). The persistence of Iron Age groups is also supported by archaeological evidence for continuation of pre-Roman religious rites in southern England, embodied by the symbolic deposition of artefacts in water (Fulford, 2001; Pryor, 2005). This demonstrates continuity in belief systems and implies that indigenous populations were not destroyed, replaced or indoctrinated completely with Roman ideology (Pryor, 2005). The importance of this is unclear as the Romans often tolerated or even adopted aspects of religions in the areas they conquered (*e.g.* renaming of ancient Greek gods; Zeus became Jupiter, Athena became Minerva, etc). It is difficult to establish whether circumstances differed in the North and South of England; the Roman invasion of the North occurred almost 30 years after that of the South (Section 1.4.2) and met with stark resistance in most areas (Faulkner, 2004). It is probable that in this case defeated local leaders were replaced by imported Romans or Roman-friendly Britons; if this occurred we should expect greater changes in these areas as measures are likely to have been taken to crush resistance and ensure future compliance. Further archaeological investigation of the Iron Age/Romano-British transition at non-military (*i.e.* domestic or ecclesiastical), northern sites may elucidate this issue.

Although the persistence of Iron Age/Romano-British groups at some sites goes against the theory of Dark Age collapse and population replacement, it does not preclude smaller scale Anglo-Saxon migrations. Adopting an extreme stance, Pryor (2005) insists that the Anglo-Saxon migration may not have occurred at all, and argues convincingly that there was not a significant influx of people at the end of the Roman period. The switch to hand-made pottery and appearance of continental-style jewellery and houses, often cited as evidence of migration (*e.g.* Hill, 1981; Arnold, 1997), are dismissed as the result of contact with continental Europe rather than a movement of people. As Pryor states, a change in material culture and socio-cultural/religious beliefs does not require a change in population; new ideas also arise from contact with other groups or internal innovation (*cf.* Pryor, 2005). To draw a modern comparison, the presence of Coca cola machines in England does not prove that the country has been invaded by North Americans. The system of trade and exchange of ideas in the Dark Ages is likely to have been very different to that in the modern, globalised world. However, the diffusion of Roman pottery styles and architecture throughout the empire without the replacement of native populations supports the theory that mass immigration was not a requirement for cultural change in early historical Europe.

Contemporary written records describing Anglo-Saxon attacks in the centuries after the Roman collapse, corroborated by evidence of hoarding and the construction of coastal defences, are not so easily dismissed. In addition, it seems highly unlikely that the Britons would have adopted a Germanic language through a relationship based on trade and exchange. Although it is difficult to judge the scale of the Germanic incursions (*cf.* Montgomery *et al.*, 2005), the fact that attacks occurred is practically indisputable. Pryor’s reasons for doubting the Anglo-Saxon invasion are therefore rejected by many archaeologists and historians; *Britain AD* was lambasted by the critics on account of Pryor’s dismissal of textual and linguistic evidence and his reliance on a small number of archaeological case studies (*e.g.* Spawton, 2004; Poole, 2006; Wiseman, 2007). One of the criticisms of Pryor is that his experience in prehistoric archaeology biases his approach to the historical period. Traditionally, major ‘advancements’ in prehistoric material culture were assumed to be the result of replacement of indigenous peoples by technologically more advanced newcomers. In the later twentieth and early twenty-first century, migration theories have become unpopular because of the implication that changes can not occur within a community without external forcing. This is also a reason for the rejection of environmentally deterministic theories, wherein environmental factors are viewed as the key to shaping cultural development (see Section 1.2.5). The most notable example of the migration/diffusion debate is in the Mesolithic/Neolithic transition. Early works concerning the spread of domestic plants and animals envisage farmers from the Near East moving out across the world, replacing or engulfing primitive, hunter-gatherer groups (*e.g.* Ammerman & Cavalli-Sforza’s ‘wave of advance’ model, 1979, 1984). In contrast, more recent works favour a gradual spread of ideas and cultigens through contact, rather than a mass movement of people (Zvelebil & Rowley-Conwy, 1984, 1986; Barker & Gamble, 1985; Bonsall *et al.*, 2002; Barker, 2006). Depending on the interpreter’s perspective it may be possible to argue in favour of either theory using the same set of evidence; the popularity of one version of events over another is determined partly by the available data, and partly by the interpretative approach of whichever school of thought dominates theoretical archaeology at the time (*e.g.* Marxist archaeology, the culture-historical approach, processualism and post-processualism) (Childe, 1925, 1936; 1942; Trigger, 1978; Binford, 1983; Gibbon, 1989; Renfrew & Bahn, 2000). Bearing this in mind, the presence of exclusively Anglo-Saxon style pottery at a site could be considered proof that only Anglo-Saxon people were present, thus supporting migration theories. Alternatively, the pottery may have reached a site through trade, theft (from Saxons, by indigenous groups) or Pryor's preferred method, exchange of ideas. It is practically impossible to distinguish these eventualities *for an individual site*. We can postulate that the change in material culture appears to be abrupt and therefore indicates an invasion, or that new styles (*e.g.* of pottery) appear similar to earlier designs and therefore represent development rather than replacement, but without a very large body of evidence there will always be some uncertainty and a degree of equifinality in the conclusions. In this particular case, the rejection of historical and linguistic records, not to mention the omission of countless archaeological sites and evidence from place-names in Pryor's account, gives the impression that he is keen to mould the evidence so that it fits the fashionable theory of spreading ideas as opposed to movement of people. Although this view is largely unsupported by the evidence, it forces us to re-examine the case for migration and reconsider the role of indigenous groups in the Dark Ages. It is plausible that the invasion was smaller in scale and achieved with less violence than is often assumed, but Pryor's vision of Romano-British people released from Roman oppression, rejecting the culture into which they had been born in favour of illiteracy, a new language and hand-made pottery is a little far-fetched. The contribution of scientific techniques to understanding the scale of migration had proved important in recent years and is discussed below.

### 1.2.4. Development of archaeological techniques

Methods for studying the archaeology of the Dark Ages have changed over time, developing rapidly in recent years on account of progress in related biological sciences. Traditionally, archaeologists of the Anglo-Saxon period concentrated on cemeteries and grave goods, as these were often more interesting and readily available than domestic objects or settlement remains (Arnold, 1997). Mapping the presence of artefacts and cemeteries of 'Continental type' was long considered an appropriate means of tracking the spread of Anglo-Saxon peoples (*e.g.* Leeds, 1913); the key problem with this method is in the assumption that Anglo-Saxon artefacts were possessed exclusively by Anglo-Saxon immigrants (*cf.* Arnold, 1997). As explained above, the native Romano-British population are not thought to have been displaced by the Anglo-Saxons; rather to have mixed with them, in which case many of those buried with Continental type weapons or jewellery may have been native Britons (or retired Roman soldiers).

In order to assess the degree of integration between the native and incoming populations, traditional methods have been supplemented with analysis of DNA and isotopes from skeletal remains, with the hope of distinguishing Romano-British from early Anglo-Saxon burials (Richards *et al.,* 1993; Montgomery *et al.,* 2005; Thomas *et al.,* 2006). Analysis of strontium isotopes in tooth enamel[5] at West Heslerton cemetery in North Yorkshire suggests a mixture of local and immigrant populations, though the data are inconclusive as to the origin of the immigrants (Montgomery *et al.,* 2005). A recent study of genetics by Thomas *et al.* (2006) appears to show a very significant input from Anglo-Saxon populations, which the authors claim as evidence of an effective system of apartheid at this time, whereby elite Anglo-Saxons were favoured genetically relative to natives. They suggest that the only alternative interpretation is that 'migration on a massive scale… [of] 500 000+ [Saxons]' occurred (Thomas *et al.,* 2006: 2651). Pattison's (2008) comment on the paper raises important issues regarding assumptions about British population levels prior to the Anglo-Saxon invasion; as links with the continent were far more advanced than has often been assumed in the Iron Age (Davies, 2000), there may have been significant migrations in the *pre-Roman* period. In addition, the Roman army consisted of a broad range of people from across the empire and it is likely that there was a substantial input to the English gene pool from Roman soldiers, many of whom may have been drawn from Germanic populations. In their response to Pattison's criticisms, Thomas *et al*. (2008) argue that many of the assertions in the article are not supported by genetic, linguistic, archaeological or textual evidence. One of the key points about which Thomas *et al.* are critical is the lack of pre-Norman population data upon which to base assertions, yet the very fact that so little is known about earlier population levels and migrations casts doubt upon their original hypothesis.

[5] Tooth enamel is laid down in early childhood and reflects the content of local water supplies during a person's early life. The minerals within water are obtained from the rock/soil over which it flows, so it is sometimes possible to establish the origins of a person by looking at the composition of their tooth enamel (in this case strontium isotopes) and that in the underlying geology of different areas (Montgomery *et al.,* 2005). In this case, first generation Anglo-Saxon immigrants who had grown up elsewhere in Europe should be expected to have different isotope levels to native Romano-Britons.

To summarise, determining the scale of Anglo-Saxon migration is fraught with difficulties; historical records are extremely limited, Anglo-Saxon archaeology is sparse in many areas, isotopic studies are only viable for the first generation migrants (not their descendants) and genetic/DNA analyses are problematic because of the complications introduced by earlier migrations about which very little is known. This is not to mention the likelihood that the separation of the population of Britain and continental Europe (assuming that human traffic from one to the other was relatively infrequent) may have occurred too recently for recognisable genetic differences to have emerged (*cf.* Richards *et al.*, 1993). Considering the artefactual, written, isotopic and linguistic evidence, the suggestion that the migration did not occur seems preposterous; whether it occurred on the scale that was traditionally imagined or as a smaller-scale, gradual movement of people is uncertain, but the latter is favoured at present.

### 1.2.5. Climatic worsening and environmental determinism

Various sources of evidence indicate a climatic deterioration in Britain during the early medieval period. Blackford & Chambers' (1991) peat humification work at five UK bog sites shows an increase in surface wetness in approximately AD 550, while peat and plant macrofossil records across the British Isles suggest a period of climatic cooling in the 6$^{th}$ and 7$^{th}$ centuries AD (*e.g.* Barber, 1981; Mauquoy & Barber, 1999; Wimble *et al.*, 2000; Hughes *et al.*, 2000; Barber *et al.*, 2003). The Dark Age decline in average temperatures has also been identified with a narrowing in Irish tree-rings (Baillie & Munro, 1988; Chambers & Blackford, 2001) and with signals in the oxygen isotope measurements from a speleothem in Crag Cave, Southwest Ireland (McDermott *et al.*, 2001). Similarly, accumulation rates in the GISP2 (Greenland Ice Sheet Project 2) icecore indicate a dramatic decline at this time, although this seems to be followed by significant warming in the latter part of the 6$^{th}$ century (Meese *et al.*, 1994).

The onset of cooler, wetter conditions might have resulted in changes in the landscape (*e.g.* expansion of heathland, inception of peat growth in some places), which could arguably lead to changes in farming practices or abandonment of certain areas. Although the way in which groups shape, utilise or create environments around themselves is rarely (if ever) determined by environmental conditions alone (*cf.* Coombes & Barber, 2005), the nature of the landscape in which people live limits their possibilities in terms of resources (*e.g.* fauna, flora, soils, minerals, rocks) (Dincauze, 2000). Traditionally, it was thought that the environment was not only a limiting factor, but also highly influential in the development of societies and cultures (Coombes & Barber, 2005). Archaeologists have moved away from this concept of 'environmental determinism' as anthropological studies have revealed the complexity of beliefs that may surround even mundane aspects of life (*e.g.* Fajans, 1997; Bray, 2003) and numerous internal (and possibly external) factors are thought to contribute to the course of socio-cultural development. Significant changes in weather patterns are, however, likely to have influenced people's way of living to some extent (*cf.* Bonsall *et al.,* 2002); for example, failure of wheat crops owing to heavy rain might lead to a decision to cultivate a hardier crop (*e.g.* oats), while persistent flooding could necessitate movement of livestock, or even settlement, to a new location. In more extreme cases, climatic worsening linked to large volcanic eruptions[6] has been suggested as a causal factor in the collapse or decline of civilisations (*e.g.* Baillie, 1998, 1999; Atwell, 2001; Amesbury *et al.,* 2008). However, the validity of claimed correlations between specific volcanic eruptions and the loss or deterioration of former societies has been questioned; terms such as 'collapse' and 'decline' are in any case contentious (*i.e.* our interpretation of archaeology is based on modern preconceptions) and the dates of changes in material culture are often very difficult to pinpoint in the archaeological record (*cf.* Buckland *et al.,* 1997).

Returning to the early medieval cooling event, a significant drop in temperature combined with increasingly wet conditions is likely to have impacted on farming and horticulture, particularly in upland environments such as the central Lake District. Depending on the severity of the changes and the availability of land elsewhere, this might have resulted in abandonment of 'marginal' areas (*cf.* Barber, 1981) or perhaps a change in farming practices as suggested above. Interestingly, evidence for an early medieval cold, wet period has also been found in North German (Dosenmoor) and Danish (Svanemose) peat bogs through analysis of the types and proportions of *Sphagnum* spp. (Barber *et al.,* 2004). A decline in conditions in this area has been identified as a possible reason for Anglo-Saxon migration (Barber *et al.,* 2004), though this is perhaps more likely to have inspired movement to southern England rather than to Cumbria where conditions were probably similar to those in Angeln (*e.g.* Barber, 1981; Mauquoy & Barber, 1999; Hughes *et al.,* 2000; Wimble *et al*., 2000).

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[6] Increases in sulphate ions (thought to derive from eruption debris in the air) in the GISP2 icecores often appear to correspond to climatic cooling events, identified in the icecores themselves, peat bogs and tree ring data, as explained previously. Large explosive eruptions (such as those of Krakatoa and Santorini) are thought to affect the climate as the debris and gases thrown into the atmosphere reduce penetration of UV rays from the sun (Hammer *et al.,* 1980; Baillie & Munro, 1988; Blackford & Chambers, 1991; Zielinski *et al.,* 1994; Chambers & Blackford, 2001).

### 1.2.6. Summary of the early Dark Ages

Documentary and archaeological evidence regarding Dark Age England is very limited; the body of recognised archaeological material from this period has grown steadily, but for many areas the data are sparse compared to those available for the preceding and subsequent periods. Theories about the impact of the Roman invasion and withdrawal and the later Anglo-Saxon incursions/migrations are many and varied, exemplified by the three extreme, irreconcilable examples discussed above. Developments in archaeological theory have led to a reappraisal of the evidence relating to this period with mixed results. Some sites show evidence for continuity of pre-Roman practices and land ownership, others demonstrate an abrupt change at the end of Roman occupation and a clear difference between the material culture of Romano-Britons and Saxons. The key to the mystery of early Dark Age Britain may lie in the nature of English society at this time. The fragmentation of England into tribal areas following the Roman withdrawal suggests that it was not a united nation under Roman rule, and reverted to former tribal affiliations after the occupation. In this case the Anglo-Saxon invasion would have been comparable to that of the Romans, taking on each tribal area individually; we may therefore expect a variety of responses, ranging from Dark's vision of Germanic invaders driven back by organised military units, to peaceful migration in some areas. As Davies implies, our labelling of groups as 'Celtic' or 'Saxon' is misleading; there is no reason to suppose that the tribes of Britain felt any more affinity for each other than for the Anglo-Saxons across the water, and as in the case of Verica calling on Roman allies to defeat his neighbours, some groups may have brought in Anglo-Saxons to fight alongside them in regional battles (Davies, 2000). This is compatible with Gildas' version of events wherein Saxon soldiers were employed to defeat other enemies. The prevalence of Anglo-Saxon place-names, archaeology and most importantly, language, suggests a significant influx of people to England during the post-Roman period. Despite the many fallacies and biases of historical documents, it seems unlikely that numerous scholars would write of Anglo-Saxon attacks if these did not occur. Equally, whatever skirmishes took place between the Romano-British tribes (*cf.* Dark, K., 2000) the presence of forts in coastal locations suggests significant attacks from the continent.

### 1.3. The later Dark Ages: Viking England

> 'Here terrible portents came about over the land of Northumbria, and miserably frightened the people: these were immense flashes of lightening, and fiery dragons were seen flying in the air. A great famine immediately followed these signs; and a little after that in the same year on 8 January the raiding of heathen men miserably devastated God's church in Lindisfarne Island by looting and slaughter.'[7]
>
> (*The Peterborough Manuscript, Anglo-Saxon Chronicle*, AD 793, translated by Swanton, 2000).

The passage above is perhaps the most famous extract from the *Anglo-Saxon Chronicle* and describes the Viking attack on the monastery at Lindisfarne in AD 793. Sporadic Viking raids targeting religious establishments started in the late 8th century AD, increasing in frequency in the middle of the 9th century and culminating in the establishment of Danegeld payments (comparable to a modern protection racket) and permanent settlement of the Danelaw region (Map 1.1) (Kendrick, 1930; Wilson, 1980; Hadley, 2000; Kurrild-Klitgaard & Tinggaard Svendsen, 2003; Richards, 2007). The debates surrounding the Anglo-Saxon invasion and migration are mirrored in discussions of the 'Viking Age' of the 8th/9th - 11th centuries AD. A key similarity exists in the paucity of contemporary written sources describing the attacks; there are occasional references to 'heathen' raids and it has been suggested that Offa's organisation of defence against 'pagan peoples' is indicative of further, undocumented attacks (Richards, 2007). The number of men involved in the raids, the nature and brutality of their attacks and the reasons for their actions are difficult to ascertain, as is the nature and scale of migration once settlements were established. These issues and the evidence available from the period are discussed in the following section.

Map 1.1: Map of England showing the extent of the Danelaw.

[7] Giles (1847) provides a slightly different translation of the latter part of the quotation; '..the ravaging of heathen men lamentably destroyed God's church at Lindisfarne through rapine and slaughter', while Richards (2007) supplies 'In this year dire portents appeared over Northumbria and sorely frightened the people. They consisted of immense **whirlwinds and** flashes of lightening, and fiery dragons were seen flying in the air. A great famine immediately followed these signs and a little after in the same year, on 8 **June**, the ravages of heathen men miserably destroyed God's church on Lindisfarne, with plunder and slaughter' (words highlighted in bold show significant differences). Aside from the date of the attacks, these differences are not important as regards the overall meaning of the text, but highlight the subjective element in translations of old English.

### 1.3.1. Why did the Vikings attack?

Many possible motivations have been advanced for the Viking attacks, including overcrowding problems in Scandinavia (Oxenstierna, 1957), material or financial gain (Roesdahl, 1987), the procurement of slaves (Whitton, 1988) an inherent hatred of Christianity (Foot, 1991) and as believed by the monastic victims of the attacks, 'divine retribution' in punishment for the 'evils' of Anglo-Saxon society (Oxenstierna, 1957). The latter is conveyed by the biblical imagery in the Lindisfarne excerpt (above) and the grouping together of unrelated misfortunes as though they are part of a single phenomenon; the resemblance to Gildas' account of the Saxon invasion is striking. Regardless of what people thought at the time, the decision to target monasteries is unlikely to have been related to their religious function; there is no evidence that religious materials were purposefully destroyed, and on at least one occasion a scripture was sold back to the church after a raid (Foot, 1991). This suggests that the objective was procurement of wealth rather than attacks on Christians per se. Overcrowding was probably a factor in the eventual settlement of Scandinavians in England, but contributes little to our understanding of the initial raiding phase.

The most compelling explanation of the raids concerns the nature of early medieval Scandinavian society. Norway and Denmark were at this time divided between a number of kings or 'jarls' rather than an overarching monarch, and Swedish kings were elected and obliged to follow the laws of the land[8] (Jones, 1968). Raiding demonstrated power to rival leaders and provided high status goods that could be 'gifted' to followers as a show of generosity and wealth, or traded for luxurious items (Jones, 1968; Roesdahl, 1987). In anthropology the process of ostentatious gift-giving ('gift exchange') is recognised as a means of ensuring allegiance and subordination through a sense of obligation or debt (Mauss, 1923). If Norse society operated within this system, the regular procurement of valuable goods would have been a necessity for retaining the social hierarchy. Translations of Skaldic (Scandinavian) verse reveal the importance placed upon generosity in the early medieval period, exemplified by the following extract from *Nóregs konunga tal* (the list of Norway's kings):

[8] This was an unusually advanced system for medieval Europe; although monarchs in (for example) France and England could be overthrown in battle (usually by their own relatives), they were rarely called upon to justify their actions, at least not prior to the revolutions resulting in the deaths of Louis XVI and Charles I respectively.

By their clothing, their gold armlets
You see they are the king's friends
They bear red cloaks, stained shields,
Silver-clad swords, ringed mailcoats,
Gilded sword-belts, engraved helmets,
Rings on their arms, as Harald gave them.

(unknown author, 13th century AD, reproduced in Page, 1995: 108).

'Harald' in the poem refers to Harald the Finehaired ('Fairhair'), son of Halfdan the Black and king of Norway in the late 9th-10th century AD (Page, 1995). Marcel Mauss' (1923) seminal work on the concept of gift exchange also refers to 13th century AD Nordic poetry from *Havamal*, one of the *Edda* (a collection of Scandinavian medieval poems), as a prime example of the importance of gift-giving and the theme is recurrent in the literature and mythology of the region. Returning to the question of raiding, there is convincing evidence that trade with the Carolingian Empire to the east supplied silver for ostentatious display or gifting during the early 9th century AD, evinced by hoards and burials containing large numbers of Arabic *dirhems* (Malmer, 1997). The frequency of raiding was reduced at this time and resumed with vigour when the trade network linking Russia, Scandinavia and the East collapsed in the later 9th century (Pirenne, 1927; Foot, 1991). The unavailability of silver is perhaps the most likely reason for the Viking raids; monasteries were relatively easy targets, especially when the raids were unexpected. More importantly, many religious establishments were very affluent and held a great deal of portable wealth; an attractive prospect for the raiding parties. The advanced nature of Scandinavian ship-building technology at this time was also a vital factor in facilitating the raids; keels and sails were developed in the 5th-9th centuries AD and Norse longboats were lighter and more flexible than other contemporary ships. The nature of the boats enabled them to traverse rough seas rather than hugging the coastlines (by which means the journey from Norway to northern England was significantly reduced) and travel quickly, increasing the surprise element of the attacks and the speed of withdrawal once an area had been pillaged (Oxenstierna, 1957).

### 1.3.2. Norse settlement and the Danelaw

The first wave of attacks was relatively short-lived, and of limited impact outside of the establishments targeted. In contrast, the multiple incursions of the $9^{th}$ century led to permanent settlement and establishment of the Danelaw, which incorporated much of eastern England (Kendrick, 1930; Wilson, 1980; Kurrild-Klitgaard & Tinggaard Svendsen, 2003; Richards, 2007). Viking settlements such as York (*Jorvik),* characterised by Scandinavian-style artefacts and runic inscriptions, contrast with Anglo-Saxon settlements to the south and west, but the populations were probably not entirely separate given the relatively close proximity of settlements. It is unclear how many Vikings actually settled in England; although aspects of Norse language remain, particularly in northern and central English placenames, their influence was not as great as that of the Saxons. The widespread acceptance of 'English' as a common language is perhaps supportive of the notion of integration of Saxon and Norse groups rather than of coexisting, culturally isolated populations. The period following the Viking raids was relatively calm and is thought to have been characterised by peaceful settlement and farming in most areas, although as discussed in Section 1.4, struggles between Saxons, Norse and tribes in Scotland continued in some areas for centuries.

### 1.4. The Lake District: landscape and history

> 'Sunshine is delicious, rain is refreshing, wind braces us, snow is exhilarating; there is really no such thing as bad weather, only different kinds of good weather.'
>
> (John Ruskin, 1819-1900, quoted by Lord Avebury)

The Lake District National Park is an area of outstanding natural beauty in the Northwest of England (Image 1.1., Map 1.2 overleaf). The park lies within the county of Cumbria, formed when Cumberland, Westmorland, Lancashire-North-of-the-Sands and part of the West Riding (Yorkshire) were grouped together in 1974 (Rollinson, 1978). As England's largest national park, the Lake District encompasses an area of 2292km$^2$, attracts 12 million visitors a year and is home to more than 42000 people (National Park Authority, 05/06/2006). Although it is now considered one of the most beautiful parts of England, this rugged, mountainous landscape is challenging to farmers and has not always seemed attractive to visitors; Daniel Defoe described it as 'the wildest, most barren and frightful' county in all of England and Wales, 'bounded by a chain of almost unpassable [*sic*] mountains' (Defoe, 1724-7).

Image 1.1. View of Upper Easedale, Eagle Crag and Pavey Arc (Barry Forster, 2006).

The underlying geological formations consist of a mixture of volcanic rocks, slates, carboniferous limestones and sandstones (Map 1.3). Throughout the Quaternary, successive glaciations carved out valleys between the mountains, radiating from the central Lake District (Donaldson & Rackham, 1984); these glacial valleys and hollows are now occupied by the lakes that give the area its name (Map 1.2) (Pearsall & Pennington, 1973; Knapp, 1984). There are fourteen large lakes in the national park, ranging from Rydal Water (31Ha) to Windermere (1459Ha) (National Park Authority, 2008) as well as a plethora of small lakes and tarns. Moraines and hanging valleys such as Hobgrumble Gill, Taylor Gill Force and Stanley Gill bear testimony to the glacial history of the landscape (Pearsall & Pennington, 1973).

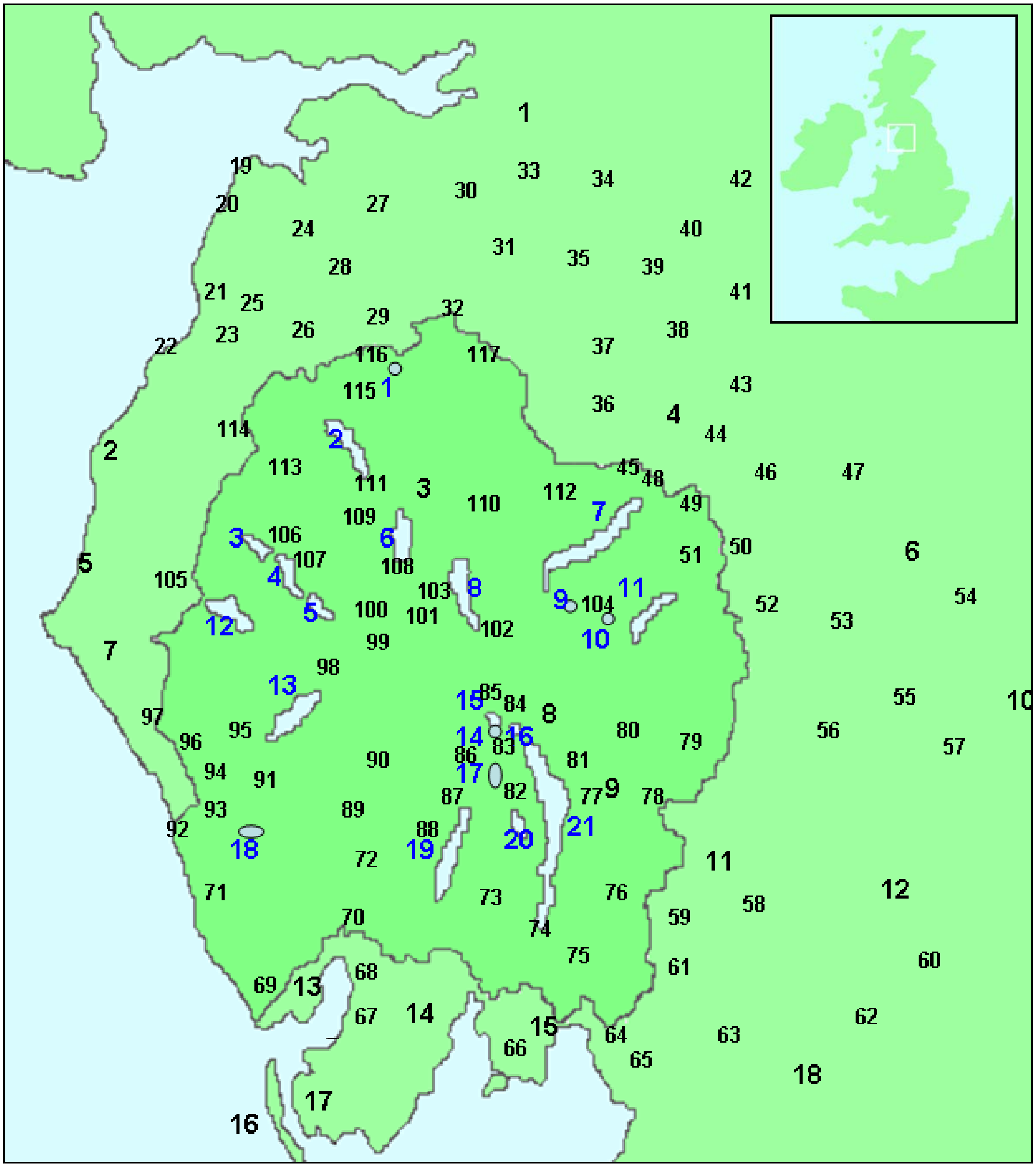
Despite the rocky terrain, much of the grassland is populated by sheep (Images 1.2 and 1.3), particularly of the characteristically hardy Herdwick breed, thought to have been introduced by Norse settlers (Ruskin museum (Coniston), 2007). Cattle are found on the flatter, higher quality pastures and there is some cereal cultivation (mostly of barley) in the valleys, but the mountainous landscape and poor weather conditions limit agricultural activity in the area. This is demonstrated by the percentage land cover of different management types within the park (Table 1.2) (DEFRA Census, 2002)).

Image 1.2: Herdwick sheep above Derwent Water (Barry Forster, 2006).

Image 1.3: Herdwick sheep at High Yewdale (Tony Richards, Visit Cumbria website, last accessed 03/07/2008)

Table 1.1: Principal uses of farmland in Cumbria in the early 21st century AD (DEFRA, 2002)

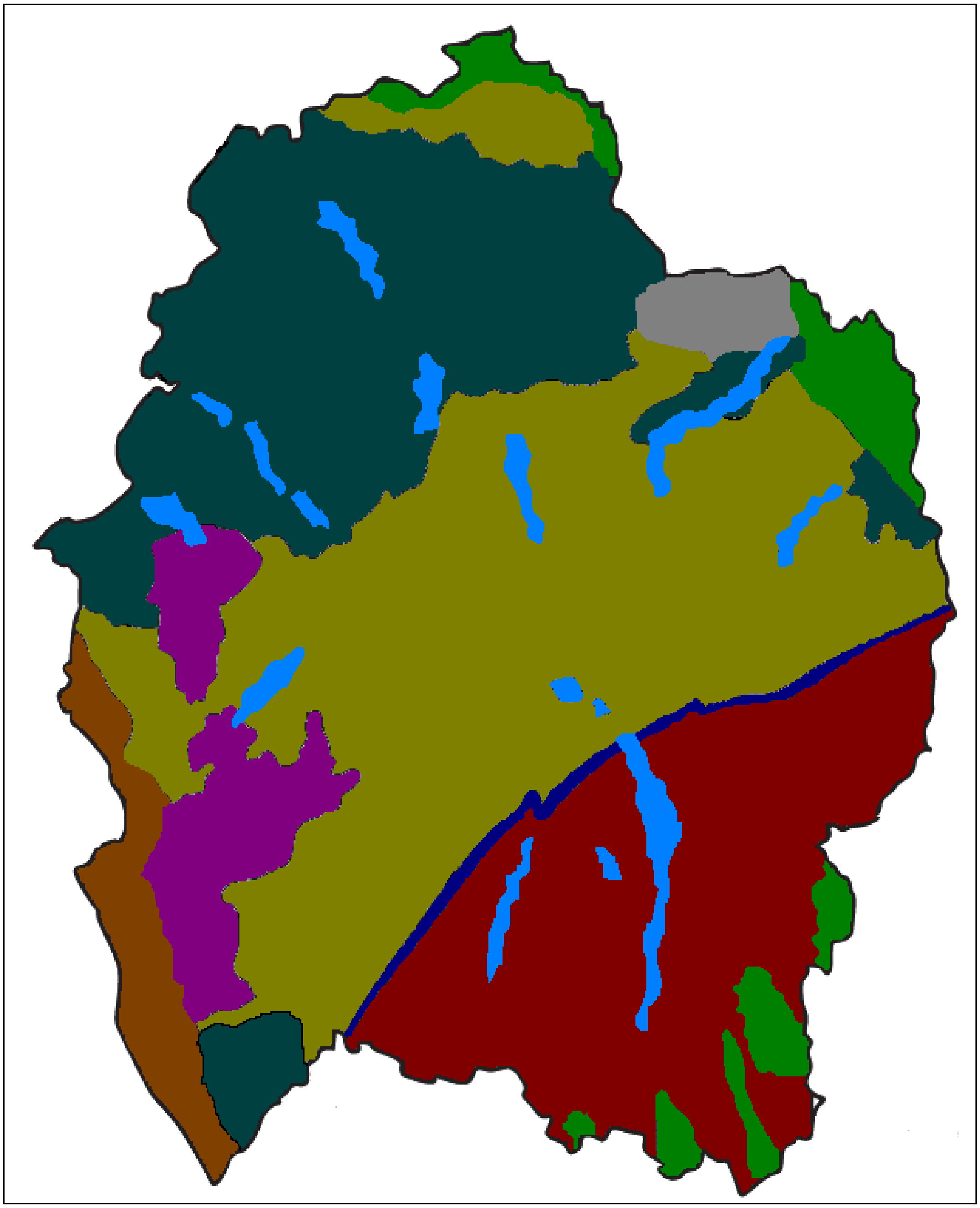
| **Description** | **Area (in hectares)** | **As % of total** |
|---|---|---|
| Permanent pasture | 243089 | 53.3% |
| Temporary pasture | 40077 | 8.8% |
| Rough grazing - sole rights | 130918 | 28.7% |
| Cereals - barley | 17152 | 3.8% |
| Cereals - other | 4462 | 1.0% |
| Other crops and bare fallow | 3877 | 0.8% |
| Woodland on agricultural holdings | 9284 | 2.0% |
| Set-aside | 3337 | 0.8% |
| Other land | 3450 | 0.8% |
| **Total** | **455646** | **100.0%** |




Map 1.2: Cumbria and the Lake District (dark grey area shows extent of Lake District National Park).

Table 1.2: Key to lakes, cities, towns and villages shown on Map 1.2.

| | | | | | |
|---|---|---|---|---|---|
| | **LAKES** | 25 | Aspatria | 72 | Ulpha |
| 1 | Overwater Tarn | 26 | Bothel | 73 | Force Forge |
| 2 | Bassenthwaite Lake | 27 | Wigton | 74 | Newby Bridge |
| 3 | Loweswater | 28 | Mealsgate | 75 | High Newton |
| 4 | Crummock Water | 29 | Ireby | 76 | Crosthwaite |
| 5 | Buttermere | 30 | West Curthwaite | 77 | Bowness-on-Windermere |
| 6 | Derwent Water | 31 | Welton | 78 | Staveley |
| 7 | Ullswater | 32 | Caldbeck | 79 | Garnett Bridge |
| 8 | Thirlmere | 33 | Buckabank | 80 | Kentmere |
| 9 | Brothers Water | 34 | Wreay | 81 | Troutbeck |
| 10 | Hayeswater | 35 | Low Braithwaite | 82 | Hawkshead |
| 11 | Haweswater | 36 | Greystoke | 83 | Little Langdale |
| 12 | Ennerdale Water | 37 | Skelton | 84 | Rydal |
| 13 | Wastwater | 38 | Plumpton | 85 | Grasmere |
| 14 | Elterwater | 39 | High Hesket | 86 | Skelworth Bridge |
| 15 | Grasmere | 40 | Armathwaite | 87 | Coniston |
| 16 | Rydal water | 41 | Lazonby | 88 | Torver |
| 17 | Tarn Howes | 42 | Newbiggin | 89 | Seathwaite |
| 18 | Devoke Water | 43 | Langwathby | 90 | Cockley Beck |
| 19 | Coniston Water | 44 | Brough | 91 | Eskdale Green |
| 20 | Esthwaite Water | 45 | Dacre | 92 | Ravenglass |
| 21 | Windermere | 46 | Cilburn | 93 | Muncaster |
| | **TOWNS & VILLAGES** | 47 | Kirkby Thore | 94 | Irton |
| 1 | Carlisle | 48 | Pooley Bridge | 95 | Wasdale |
| 2 | Workington | 49 | Askham | 96 | Gosforth |
| 3 | Keswick | 50 | Little Strickland | 97 | Calder Bridge |
| 4 | Penrith | 51 | Bampton | 98 | Wasdale Head |
| 5 | Whitehaven | 52 | Shap | 99 | Seathwaite |
| 6 | Appleby-in-Westmorland | 53 | Crosby Ravensworth | 100 | Seatoller |
| 7 | Egremont | 54 | Warcop | 101 | Rosthwaite |
| 8 | Ambleside | 55 | Great Asby | 102 | Wythburn |
| 9 | Windermere | 56 | Tebay | 103 | Watendlath |
| 10 | Kirkby Stephen | 57 | Ravenstonedale | 104 | Hartsop |
| 11 | Kendal | 58 | Old Hutton | 105 | Ennerdale Bridge |
| 12 | Sedburgh | 59 | Levens | 106 | Loweswater |
| 13 | Millom | 60 | Dent | 107 | Buttermere |
| 14 | Ulverston | 61 | Milnthorpe | 108 | Grange |
| 15 | Grange-over-sands | 62 | Barbon | 109 | Newlands |
| 16 | Walney Island | 63 | Burton-in-Kendal | 110 | St John's in the Vale |
| 17 | Barrow-in-Furness | 64 | Arnside | 111 | Thornthwaite |
| 18 | Kirkby Lonsdale | 65 | Silverdale | 112 | Matterdale |
| 19 | Silloth | 66 | Flookburgh | 113 | Lorton |
| 20 | Beckfoot | 67 | Askam-in-Furness | 114 | Cockermouth |
| 21 | Allonby | 68 | Kirkby-in-Furness | 115 | Bassenthwaite |
| 22 | Maryport | 69 | Silecroft | 116 | Uldale |
| 23 | Tallentire | 70 | Broughton-in-Furness | 117 | High Row |
| 24 | Bromfield | 71 | Bootle | | |



Map 1.3: Geological map of the Lake District

KEY TO MAP 1.3:

- Sandstone
- Carboniferous limestone
- Mell Fell conglomerate
- Silurian flags and shales
- Coniston limestone
- Borrowdale volcanic group
- Skiddaw group
- Granite
- Water (lakes)

The ‘natural’ beauty of Lakeland has been vital to the development of tourism and of policies for the protection and conservation of the area, yet the landscape we see today has been shaped and managed by people for thousands of years. This area of high, rocky ground, encompassing the town with the highest annual rainfall in England (Seathwaite (99, Map 1.2) (Manley, 1973) may seem less than ideal as a place of settlement, but in spite of this Lakeland has a rich and varied history of human activity stretching back at least seven thousand years. Although the focus of this investigation is the Lake District, some of the evidence presented here relates to the broader area of Cumbria. This is included to gain a picture of the wider landscape and to take into account the arbitrary nature of the park boundary when considering the history of this region. All sites mentioned in the following section are marked on Map 1.4 (p33)[9].

### 1.4.1. The prehistoric landscape (*c* 5000 BC - AD 69)

Image 1.4: Hafted Neolithic hand-axe found at Ehenside Tarn (held at the British Museum, London).

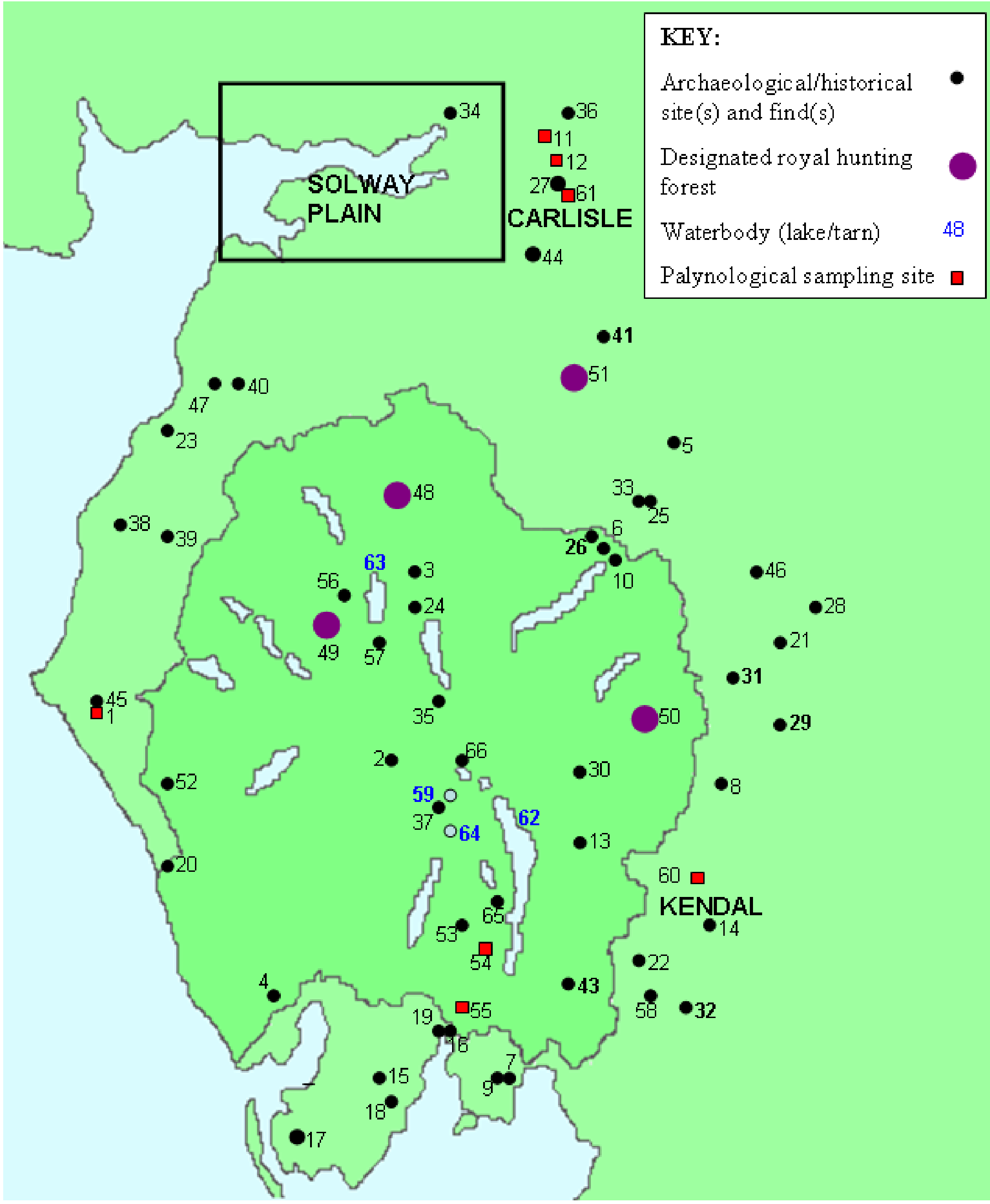
The first recorded archaeological remains in Cumbria are microliths of Mesolithic age (5000-3000 BC), coinciding with palynological evidence from Ehenside Tarn (**1**) indicative of deliberate clearance or modification of woodland by burning (Walker, 1965; Rollinson, 1978). Pollen data suggest that agriculture was underway approximately two thousand years later, at the time of Neolithic stone axe production in the Langdale Pikes (**2**) (Image 1.4). Langdale hand-axes have been found in Yorkshire, Scotland, the Isle of Man and southern England, suggesting long-distance networks of trade or exchange (Fell, 1973a; Cummins, 1974; Rollinson, 1978). Bradley’s assessment of links between vegetation change and the distribution of Neolithic artefacts and monuments suggests that areas of woodland clearance are separate from those of habitation, perhaps indicating a lifestyle of nomadic pastoralism (Bradley, 1972). Alternatively, the pattern might be a product of differential visibility and preservation resulting from current and historical land-use.

Human occupation of the Lake District continued into the Bronze Age (approx. 2300-700 BC), during which time the stone circles of Castlerigg (**3**), Swinside (**4**) and Long Meg and her daughters (**5**) were constructed (Clare, 2007). The first permanent woodland clearances are

[9] Roman military sites are not included as these are shown in Maps 1.5 and 1.6, p38.

thought to have occurred in this period, freeing up land for grazing and cultivation (Pennington, 1964; 1965; 1970). Numerous Bronze Age burial cairns, often containing characteristic ‘beaker’ ceramics, are found in areas where the pollen data suggest pastoral land-use (Bradley, 1972; Rollinson, 1978), in addition to smaller stone circles (**6**, **7** & **8**).

Iron Age (approx. 700 BC – AD 43) stone-walled settlements containing circular huts associated with ‘Celtic fields’ have been found on the eastern periphery of the Lake District and in Little Urswick (**9**) in southern Cumbria, and there is evidence for extensive settlement around the Solway Plain at this time (Fell, 1973a; Dumayne-Peaty & Barber, 1997, 1998). A small number of ‘hillforts’ have been found in Cumbria (**10**), in addition to occasional finds of Iron Age objects in graves (Fell, 1973a). Pollen diagrams from Bolton Fell Moss (**11**) and Walton Moss (**12**) show high levels of arboreal pollen (80-90% of the total land pollen) during the late Bronze/early Iron Age, followed by a large-scale clearance event in the range of 165 BC – AD 75 (calibrated). The presence of rye (*Secale cereale),* oats/wheat *(Avena-Triticum*-type) and ribwort plantain (*Plantago lanceolata*) suggests agricultural clearance, presumably by the Brigantes tribe that occupied the area (Dumayne-Peaty & Barber, 1998). Rye is thought to have been introduced to the North of England in the late Iron Age/early Romano-British period (Dark, 2005), making it useful as a date marker.




Map 1.4: Location of archaeological sites and finds referred to in Section 1.4 (with the exception of Roman forts - see Maps 1.5 and 1.6).

Table 1.3: Sites and finds shown on Map 1.4

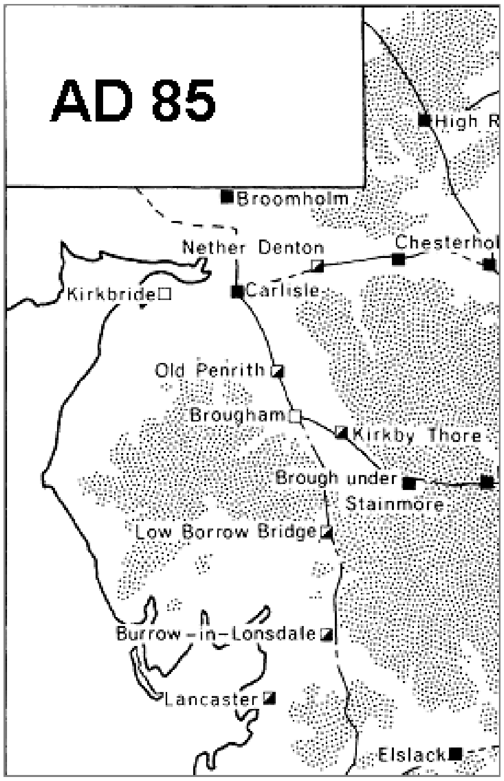
| | | | | | |
|---|---|---|---|---|---|
| 1 | Ehenside Tarn | 23 | Ewanrigg | 45 | Egremont |
| 2 | Langdale axe factory | 24 | Shoulthwaite | 46 | Newby |
| 3 | Castlerigg stone circle | 25 | Fremington | 47 | Hayton |
| 4 | Swinside stone circle | 26 | Dacre | 48 | Skiddaw |
| 5 | Long Meg & her daughters | 27 | Birdoswald | 49 | Thornthwaite |
| 6 | Moor Divock (stone circle) | 28 | Eden Valley | 50 | Sleddale |
| 7 | Birkrigg stone circle | 29 | Orton Scar | 51 | Inglewood |
| 8 | Orton (Gamelands stone circle) | 30 | Bryant's Gill | 52 | Calder Abbey |
| 9 | Stone walls settlement, Little Urswick | 31 | Shap | 53 | Grizedale Forest |
| 10 | Dunmallard Hill | 32 | Sillfield/Preston Patrick (oval enclosure) | 54 | Deer Dyke Moss |
| 11 | Bolton Fell Moss | 33 | Ninekirks (Brougham) | 55 | Huletter Moss |
| 12 | Walton Moss | 34 | Solway Moss | 56 | Newlands Valley |
| 13 | Hugill | 35 | Dunmail Raise | 57 | Borrowdale |
| 14 | Millrigg | 36 | Bewcastle cross | 58 | Sedgwick |
| 15 | Ulverston | 37 | Little Langdale: rectangular buildings and Thingmount | 59 | Elterwater |
| 16 | Grange-over-sands | 38 | West Seaton | 60 | Whinfell Tarn |
| 17 | Furness Abbey | 39 | Eaglesfield | 61 | Talkin Tarn |
| 18 | Urswick | 40 | Aspatria | 62 | Windermere |
| 19 | Cartmel | 41 | Hesket-in-forest | 63 | Derwent Water |
| 20 | Walls Castle | 42 | Ormside | 64 | Tarn Howes |
| 21 | Ewe Close/ Crosby Ravensworth | 43 | Witherslack | 65 | Beatrix Potter's House (Hilltop) |
| 22 | Sizergh Fell | 44 | Cumwhitton | 66 | Wordsworth's cottage (Dove Cottage, Grasmere) |

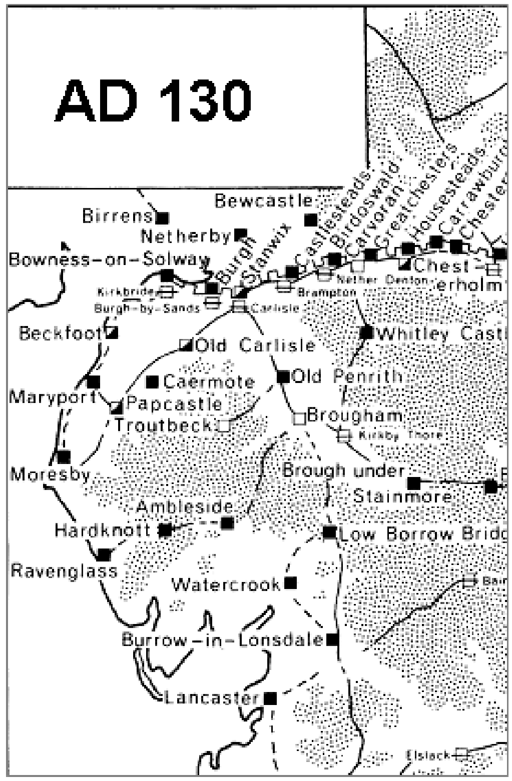
The late Bronze/early Iron Age is considered to have been a period of climatic cooling and subsequent abandonment of high altitude areas, including the central Lake District (*cf.* Barber, 1982). There is a paucity of finds belonging to Iron Age material culture from the more mountainous parts of Lakeland, perhaps supporting the concept of temporary abandonment. Another possibility is poor visibility of Iron Age structures and artefacts. This may be owing to a lack of archaeological investigation in the area, the presence of vegetation cover that obscures features such as soilmarks, cropmarks and remains of plough and furrow field systems in aerial photography (*e.g.* woodland, heather moorland (Drewett, 1999)), or poor conditions of preservation. The second hypothesis is to some extent supported by Dark's findings of increased clearance and agricultural activity at upland sites during the early Iron Age (Dark, 2006).

Whether the changes in prehistoric culture outlined above involved a spread of ideas or an actual movement of people is debatable. As mentioned previously (Section 1.2.3), traditionally it was supposed that innovation in technology or subsistence practices required input from an external source. This view has been challenged by archaeologists struck by continuity within individual groups, juxtaposed with diversification in the material culture of spatially separate groups (Clark, 1966; Adams, 1968). These issues are beyond the scope of the project to discuss in full with regard to prehistory, but are conceptually similar to problems surrounding the question of the scale and nature of the Anglo-Saxon invasions as discussed in Section 1.2.

### 1.4.2. The Romano-British period (approximately AD 69 - 410)

The Roman invasion and occupation of Britain in AD 43 spread to Northwest England from AD 69-84, and probably had a significant impact in the northerly counties. The Romans met with fierce resistance during their military campaigns to seize control of the region and numerous fortifications were built to consolidate their occupation (Faulkner, 2004). In AD 85 forts were in place at Carlisle, Old Penrith, Brougham and Low Borrow Bridge. By AD 130 more had sprung up at locations such as Ambleside (Galava), Hardknott Pass and Ravenglass, in addition to numerous military buildings associated with Hadrian's Wall (Breeze & Dobson, 1985 (Maps 1.5 and 1.6)). These large constructions would have required significant quantities of resources such as wood and stone, in addition to food, clothing and weaponry for the resident garrisons (Dumayne, 1993, 1994; Dumayne & Barber, 1994; Dark, P. 2000). A network of roads was also established at this time linking the forts with the supply port at Ravenglass (Fell, 1973b).




Map 1.5: Military sites in Northwest England AD 85 (Breeze & Dobson, 1985: 5).

Map 1.6: Military sites in Northwest England, AD 130 (Breeze & Dobson, 1985: 10).

Aside from the military sites, the archaeological evidence from Romano-British Cumbria seems indicative of little change; the building styles of pre-Roman tribes persist (*e.g.* at Hugill (**13**) near Windermere and Millrigg (**14**) in Kentmere), perhaps suggesting continuity of population and a lack of Romanisation (Fell, 1973b). This supports the contention that Roman influence was minimal at rural sites in comparison to urban centres and military bases (*cf.* Grant, 1989). This is probably the case as the residents of rural settlements are unlikely to have been replaced or swamped by Roman immigrants considering the nature of the Roman conquest.

Small numbers of Roman coins have been found at Ulverston (**15**), Grange-over-sands (**16**), Furness Abbey (**17**) and Urswick (**18**), in addition to a hoard of 600 in Cartmel (**19**). There is also a Roman bathhouse at Walls Castle (**20**) near Ravenglass; Romanisation is more likely to be seen here than in the central Lake District because of the importance of the town as a supply port. It has also been conjectured that the changing design of farm buildings at Ewe Close (**21**) could result from Roman influence (Image 1.5), but as the age of the monument is uncertain[10] this has not been confirmed. The presence of a glass bead alongside Iron Age objects in a burial cairn on Sizergh Fell (**22**) has also been noted as a possible sign that aspects of Roman culture (or at least material culture) were being adopted by indigenous populations (Fell, 1973b). Nevertheless, there is insufficient evidence from domestic contexts to be sure of the degree of Roman influence in this region. It is probable that Roman objects and produce were obtained by elite groups as status symbols rather than as items for everyday use (*cf.* Faulkner, 2004), but whether or not the Roman occupation impacted significantly on the lifestyles and practices of the majority of people is difficult to establish. Examining the evidence for vegetation change in a range of locations may help to clarify this issue in terms of changing impact on the landscape; evidence for continuity of vegetation and land-use would tend to suggest a limited Roman influence, whereas dramatic developments in the landscape across the region would accord with widespread change as the Empire enveloped this area (*e.g.* large-scale clearances, changes in farming practices or woodland regeneration (suggesting abandonment of farmland)).

Image 1.5: Earthworks at Ewe Close, Crosby Ravensworth (Visit Cumbria website, 08/05/2007)

[10] Interpretations of this site differ; Collingwood (1907-8) describes it as 'Romano-British', yet Fell (1973c) likens the layout of the buildings to Norse farmsteads, implying that it continued in use to a later date. There does not appear to be any dating evidence from this site, making it impossible to establish age without excavation. Because of these difficulties Ewe Close is also mentioned in the sections on Norse archaeology and Rheged under Dark Age Cumbria.

### 1.4.3. Dark Age/early medieval Lakeland (*c* AD 410 – 1066)

In Cumbria, as in much of Britain, the paucity of written and archaeological records from the Dark Ages makes it difficult at present to determine the impact of Roman departure on the landscape (Fell, 1973c; Pearsall & Pennington, 1973; Rollinson, 1978; Whyte, 1989). The limited archaeological and historical records reveal little about people living in the area at the time, and as of yet there has been no attempt to focus on this period in terms of the palaeoecological record. There are many reasons for this, not least the assumptions made about the history of the post-Roman and early medieval period by historians and archaeologists. It seems to have been generally accepted that this phase of history was well enough understood to warrant no further, detailed investigation. Whyte's assessment (1989: 74) of the available archaeological and palynological evidence for Dark Age Cumbria shows:

> '..how little we know about the Dark Ages in the Lake District and their effect upon the landscape. Tangible elements…are scarce in the present landscape…the lack of dating evidence compounds the problem.'

As this statement suggests, there are few, known archaeological features in the Lake District dating to the centuries following the Roman withdrawal (Fell, 1973c; Newman *et al.*, 2004); this may be owing to the biodegradable nature of materials used in construction (see Section 1.1), and perhaps a lack of visibility as much of the land is given over to pasture and protected from industrial or urban development. Archaeological sites are more likely to be identified on land that is ploughed (*e.g.* cropmarks are more visible, finds brought to the surface) or where building work necessitates survey and excavation to prevent the destruction (without record – excavation is destructive) of important sites (Drewett, 1999). With regard to excavated remains, little archaeological investigation of this period has occurred and survival of Dark Age artefacts and structures is poor (Fell, 1973c). Newman *et al.* (2004) provide an excellent synthesis of the known archaeological sites and finds dating to this period, drawing on numerous sources including CWAAS (Cumberland and Westmorland Antiquarian and Archaeological Society) publications and unpublished archaeological reports (e.g. McCarthy, 1990; Atkin, 1993; Instone, 1995; Oliver *et al.*, 1996; Heawood & Howard-Davis, 2002); although the number of recognisably early medieval sites has increased in the late 20$^{th}$ and early 21$^{st}$ centuries, there are still remarkably few examples when compared to those of earlier and later periods. Dark Age environmental archaeological remains are also scarce (Donaldson

& Rackham, 1984; Newman *et al.*, 2004), although a possible grain-drying kiln has been identified at Ewanrigg (**23**), radiocarbon-dated to approximately AD 790-900 (Huntley & Stallibrass, 1995; Newman *et al.*, 2004). Many of the known rural archaeological sites in Cumbria, particularly burials, were excavated by antiquarians or archaeologists before the advent of radiocarbon dating; as handmade early medieval ceramics can be difficult to distinguish from prehistoric pottery and diagnostic finds are rare, the age of these sites is often uncertain (*cf.* Newman *et al.*, 2004). Recent excavations of a hillfort at Shoulthwaite (**24**) produced radiocarbon dates of AD 598-657 and AD 618-644; as Newman *et al.* (2004) suggest, this raises the possibility that other hillforts in the area are of early medieval date or were reoccupied at this time (this type of site is usually consigned to the Prehistoric era). Metalwork is often difficult to date out of context and the recognised practice of recycling Romano-British materials and artefacts such as stone, pottery and glass (e.g. at Fremington (**25**) and Dacre (**26**)) could potentially make post-Roman remains difficult to distinguish from earlier material (*cf.* Newman *et al.*, 2004).

Excavations of Romano-British, northern English forts and *vici*[11] have produced sequences indicative of a gradual reduction in use rather than a sudden abandonment (Fell, 1973c); at the fort of Birdoswald (**27**) (Hadrian's Wall) there is some evidence for continuity of use into the 5$^{th}$ and perhaps 6$^{th}$ centuries AD (Wilmott, 1997; Newman *et al.*, 2004), although Faulkner suggests this is an unusual case (2004). As explained above, the removal of troops from Hadrian's Wall and other active forts in the region must have affected the local population, if only in the reduction of activity in the landscape around them (Dumayne, 1993, 1994; Dumayne & Barber, 1994; Dark, P., 2000). However, this may not be the case in central and southern Lakeland, away from the heavily fortified border. Presumably grain supplies were procured from local land if possible, to avoid the additional effort, risk and cost of transportation. If this is the case, areas where there is little evidence of Roman influence the pollen data may show minimal change throughout the Iron Age, Roman and Dark Age periods, or perhaps even increased activity in the Dark Ages as Anglo-Saxon and Norse populations arrived. Unfortunately, early medieval sites and finds are generally rare in the North of England and Cumbria is no exception (Dark, K., 2000).

Aside from Roman military sites, the limited remains from the early post-Romano-British-to-Anglo-Saxon period include two burials added to earlier barrow graves, excavated by Canon Greenwell in the 1800s, which were found to contain artefacts of 7$^{th}$ century date (Fell, 1973c).

[11] *Vici* (pl.) or *vicus* (sing.) - civilian settlements associated with, but outside of, Roman military sites, sometimes spreading roads approaching a fort (Wacher, 1996).

The burials are located in the Eden Valley (**28**), which Fell interprets as evidence for use of the area's fertile soils, presumably for agriculture. A few other 7th century ornamental artefacts have been recorded for which the origin is unclear, other than that they were probably discovered in Cumberland (Fell, 1973c; English Heritage NMR[12], last accessed 02/05/2009). Tantalisingly few remains of habitation have been identified for this period; examples include the sunken-feature *grubenhauser*-type buildings at Fremington (**25**) and rectangular structures at Orton Scar (**29**), Bryant's Gill (**30**) and Shap (**31**) (Dickinson, 1985; Newman *et al.,* 2004). Diagnostic 7th-8th century AD loomweights were found at several of the sites and at Fremington there was a rare example of a kiln with associated handmade potsherds (Oliver *et al.,* 1996; Newman *et al.,* 2004). In terms of land-use, an oval enclosure thought to be related to farming and conjectured to be of early medieval date, has been recorded in southern Cumbria (**32**) (Atkin, 1993; Newman *et al.,* 2004), but environmental archaeological and palaeoecological studies relating to this period are scarce (Hodgkinson *et al.,* 2000; Newman *et al.,* 2004. See Section 1.5).

The most prevalent early Dark Age remains are ecclesiastical and include a cemetery and probable monastic site at Dacre (**26**), burials associated with a 7th century AD silver-gilt cup at Ninekirks, near Brougham (**33**) and numerous fragments of sculpted crosses (see Section 1.4.3.2) (Pevsner, 1967; Bailey, 1977; Newman *et al.,* 2004; E.H. NMR, 2009). The pattern of sites and finds of this type indicates that settlement remains ought to be widespread, but so far this remains to be seen. A deposit containing cattle bones, seemingly deliberately placed (heads and front feet only), was found at Solway Moss and might be a pagan offering of the 7th-11th centuries AD (Hodgkinson *et al.,* 2000; Newman *et al.,* 2004).

#### 1.4.3.1. Rheged

'Owain dealt them doom
As the wolves devour sheep;
That warrior, bright of harness,
Gave stallions for the bard.
(Taliesin, *Death song for Owain ab Urien,* 6th century AD, in Jones, 1977)

[12] Hereafter cited as 'E.H. NMR, 2009'. The NMR was accessed through *Web*GIS while the author was working for English Heritage, but can also be accessed at the NMR offices in Swansea.

Historical information relating to Dark Age Cumbria is also very limited. The Kingdom of Rheged existed at this time, encompassing parts of Southwest Scotland, Cumbria, and perhaps Yorkshire[13] (Jackson, 1939; Hunter Blair, 1963; Fell, 1973c; Fisher, 1973; Wood, 1981; Dark, K., 2000). Little is known of the kingdom; Urien was its king in the 6th century AD and fought ongoing battles with neighbouring kings, until he was assassinated while holding Holy Island under siege (Jackson, 1939; Hunter Blair, 1963; Fisher, 1973; Wood, 1981). It has been suggested that Rheged and its royal line have their origins in an Iron Age chiefdom in the same location, surviving through the Romano-British period and beyond. This is difficult to substantiate as there is little to go on other than the names of the kings (Fell, 1973c). The kingdom, its famous king and its prince (Owain) feature in one of the earliest British poems, *the Gododdin of Aneirin* (6th century AD), which speaks of a bloody battle at 'Catraeth' (Catterick, North Yorkshire), and in *Death song for Owain ab Urien* (Taliesin, 6th century AD) (both reproduced in Jones, 1977). It has been suggested that Urien inhabited the aforementioned stone-walled settlement of Ewe Close at Crosby-Ravensworth (**21)** (Image 1.5). Carlisle is generally thought to have been a more likely location for the king's court (Fell, 1973c), but without clear evidence at either location this remains doubtful.

#### 1.4.3.2. Mid- to late-Anglo-Saxon and Norse Cumbria (approximately AD 700-1066)

The Norse raids and establishment of settlements (Section 1.3) do not seem to have affected Cumbria initially, but by the 10th century AD Irish Vikings and Scots are thought to have settled in parts of the Lake District, while Norwegian Vikings were spreading into the Carlisle region (Kendrick, 1930). This posed a threat to neighbouring Northumbria, which had been regained from the Vikings by Edmund (King of England excluding what remained of the Danelaw). In the mid-10th century he attacked Cumbria, deposed its last 'Welsh' (perhaps indicating continuity from Rheged) king, Domnholl ('Dunmail', as in Dunmail Raise (**35**)), and handed the area over to Malcolm of Scotland (Kendrick, 1930).

Finds of later Anglo-Saxon and Norse date are scarce; numerous stone fragments from 8th to10th century AD crosses such as the one at Bewcastle (**36**) have been found in the Lake District and Northumbrian influence is seen in occasional finds of coinage (Pevsner, 1967; Fell, 1973c; Newman *et al.,* 2004; E.H. NMR, 2009). Norse dwellings and farms are thought to have been built from wood and turf, so as with earlier Dark Age structures preservation is poor.

[13] McCarthy has suggested that the kingdom was actually centred further north (McCarthy, 2002). The general consensus seems to be that it included parts of Cumbria though (*e.g.* Fell, 1973c).

Rectangular buildings at several locations including Little Langdale (**26**) and Ewe Close (**21**, Image 1.5) have been likened to those found in Viking settlements; this has not however been confirmed through excavation (Fell, 1973c; E.H. NMR, 2009). One of the most significant monuments of this date is the 'Thingmount' in Little Langdale (**26**) (Image 1.6). The mound is flat on top with terraced sides and is very similar to the Tynwald mount on the Isle of Man, a Scandinavian-style 'law ting' or meeting place (Collingwood, 1930; Fell, 1973c; Newman *et al.*, 2004; E.H. NMR, 2009). The NMR mentions that this is one of three such sites in Cumbria, though none of these has been excavated fully and the age of the monuments has not been confirmed by absolute or artefactual dating evidence (E.H. NMR, 2009). Placenames are thought to indicate that similar monuments existed elsewhere in the region in the past, but if so these have not yet been identified (Newman *et al.*, 2004).

Norse 9th and 10th century burials have been found at West Seaton (**38**), Eaglesfield (**39**), Aspatria (**40**), Hesket-in-forest (**41**) and Ormside (**42**). Scandinavian-style hogback stones are found in some Cumbrian churchyards (Pevsner, 1967; Newman *et al.*, 2004; E.H. NMR, 2009) and rare finds of swords such as that at Witherslack (**43**) are also thought to mark Viking burials (Edwards, 1998; Newman *et al.*, 2004). Later Norse gravestones and stone crosses show a mixture of mythological Norse and Christian symbolism (Pevsner, 1967; Fell, 1973c), suggestive of a mixing and merging of cultural identities at this time. The most impressive find in recent years has been a 'Viking cemetery' at Cumwhitton (**44**) (near Carlisle), containing the bodies of four men and two women with associated grave goods (jewellery, riding equipment and weaponry). The cemetery is thought to date to the 10th century AD and is unusual on account of the presence of multiple, uncremated corpses (Pitts, 2004).

Image 1.6. The Thingmount, Little Langdale (**37**).

A small amount of archaeological material has been recorded that indicates probable early medieval metalworking; iron slag was found at Dacre (**26**) and at Bryant's Gill (**30**) and 'hoards' of later Anglo-Saxon/Norse metalwork have been noted at several locations (Newman *et al.,* 2004). Although the evidence is very limited, it has been suggested that the development of metalworking industries in areas such as Egremont (**45**), which is recorded as early as the 12$^{th}$ century AD, began in the Dark Ages (Instone, 1995, cited in Newman *et al.,* 2004).

To summarise, early medieval remains are relatively scarce in Cumbria, particularly those relating to settlement and land-use. Ecclesiastical sites and monuments are scattered across the region, indicating that settlements were far more widespread than the evidence from domestic contexts alone suggests, but problems of preservation, visibility and a lack of dating evidence hamper recognition of Dark Age sites. Excavation or re-excavation of monuments of uncertain date might yield further early medieval archaeology, but at present little is known about this period in the Lake District and Cumbria. The relative dearth of archaeological and historical data available for the region at this time provides strong incentive for palaeoecological investigation as a means of establishing human impact on the landscape (Section 1.5).

### 1.4.4. The middle and later medieval periods (AD 1066 – 1485)

The Norman invasion in 1066 did not initially impact on northern Britain. It was the 'harrying of the North' in 1069-1070 that wrought havoc, during which William I had crops, herds, equipment and food destroyed, causing 100 000 northerners to starve to death (Orderic Vitalis, 1141). This is thought to have caused a lull in farming (Chiverrell *et al.,* 2007), which Oldfield identified with (undated) regeneration of ash woodland in Cumbria (Oldfield, 1969). However, it is debatable whether William's tyranny extended into Cumbria; the area was owned by neither Scotland nor England prior to 1092 and may not have suffered to the same extent as the Northeast (Rollinson, 1978). William II (William Rufus) is recorded as visiting Carlisle in 1092 to 'restore the town and build the castle' (Anglo-Saxon chronicle, 1092 (in Giles, 1847: 468)), perhaps suggesting that the area was not under Norman control prior to this date. From the turn of the century (11$^{th}$-12$^{th}$) onwards the area remained 'English' until 1135 when it was seized briefly by Scotland, then again by England in 1157 (Rollinson, 1978).

In terms of features within the landscape, medieval strip-fields can be seen in villages such as Newby (**46**), Hayton (**47**) and Cumwhitton (**44**) (Roberts, 1988). Presumably the Commons were also demarcated at this time of tenant farmers and feudal lords. Private 'forests' (areas set aside for hunting, which were not necessarily wooded) were established at Skiddaw (**48**), Thornthwaite (**49**) and Sleddale (**50**), while Inglewood royal forest (**51**) was the largest area reserved for hunting in England, protected by law from poaching and tree-felling (Rollinson, 1978).

A key development in the Cumbrian landscape at this time was the procurement of vast tracts of land by monastic establishments such as the Abbeys of Furness (**17**), Calder (**52**) and Seaton (**38**). As an example of the extent of this, by AD 1242, Furness Abbey had acquired 14000 acres of land in Eskdale (Rollinson, 1978: 50). Both Oldfield and Pennington linked palynological evidence for extensive pastoral farming in southern Cumbria to monastic clearance (Oldfield, 1963, 1969; Pennington, 1979). The monasteries cultivated cereal crops for consumption but were also engaged in the lucrative business of sheep farming; wool was in high demand at this time and had been produced in Kendal as early as the 14$^{th}$ century AD. The wool trade continued successfully after the monastic dissolution, and in the late 16$^{th}$ century large quantities of wool and cotton from northern England (including Cumberland and Westmorland) were being exported to continental Europe (Hewart, 1900). Sheep are able to graze woodier and more diverse vegetation than cattle, and can cope with hillier topography. The hardiness of the Cumbrian Herdwick breed is particularly noteworthy, making them ideal inhabitants of the uncultivable, mountainous parts of the Lake District (Ruskin museum, 2007). The monks did not clear all of their land for grazing; they also retained large areas of mixed oak woodland (such as Grizedale Forest (**53**) in the Furness Fells), which were coppiced on a 14 year cycle to provide for their own woodland industries (Pearsall & Pennington, 1973). Timber from the coppices was used up to and after the dissolution for producing barrels (coopering), cups, bowls and charcoal. Bark was used in the leather tanning process and sheep ('hogges', hence Hogg Close Wood) were allowed to browse in woodland over winter (Pearsall & Pennington, 1973; Rollinson, 1974). The need for maintenance of sustainable woodland is a possible explanation for forest regeneration from the 11$^{th}$ to 14$^{th}$ centuries AD at Deer Dyke (**54**) and Huletter Mosses (**55**) (Coombes *et al.*, 2009). Alternatively, the increase in arboreal pollen may represent abandonment of farmland consequent upon the devastating effects of Scottish raids in the 13$^{th}$ and 14$^{th}$ centuries, in the course of which buildings and crops were destroyed and there were many deaths (Rollinson, 1978). The ravages of the Black Death (1348, 1361-2) must also have affected the population, though Coombes has argued that the resulting depopulation produced no distinctive signal in the palynological record (Coombes *et al.*, 2009).

### 1.4.5. Tudor and Stuart times (AD 1485 – 1714)

As iterated above, much of the Lakeland countryside was owned by the monasteries until the dissolution in 1536-40. Although the dissolution obviously led to a change in ownership, it is thought that farming and industry continued unabated (Rollinson, 1978). A marked decline in arboreal pollen at Deer Dyke (**54**) and Huletter Mosses (**55**) in the 16th and 17th centuries AD is thought to represent the rise of Yeoman farmers and extensive agricultural clearance to produce more food for the growing population (Coombes *et al.*, 2009). Despite these efforts, poverty was rife at this time. Life near the Scottish border was dangerous and uncertain; raiding parties known as 'reivers' (from both sides of the border) wrought havoc, stealing crops and animals and burning buildings (Durham, 1995; MacDonald Fraser, 1995). This activity is unlikely to be seen in the palaeoecological records as farming continued (the most popular time for raiding was *after* the harvest) and people remained in the area, yet it had a devastating effect on the inhabitants of villages in the region (MacDonald Fraser, 1995).

In Tudor times (1485-1603) shipbuilding became an important national industry. Exploration, piracy and war necessitated the expansion of the English navy, which in turn required vast quantities of good quality oak. In 1663 there was a national census of trees owing to concern over dwindling supplies, although depletion of woodland had already been targeted in a 1546 royal decree to regulate the use of trees by tenants (Kipling, 1974). There was also intensive gold, silver and copper mining centred around the Newlands Valley (**56**) near Keswick, for which purpose skilled German miners were imported in 1565 (Rollinson, 1978). Charcoal was required for the smelting of mined ores (Rollinson, 1978); considering the scale of activity this must have had a dramatic effect on the structure of woodland, although the timber is likely to have originated from old coppices established by the monasteries.

The discovery and subsequent commercial mining of graphite in Borrowdale (**57**) is thought to have occurred from 1555 onwards. Graphite is a useful commodity for pencil manufacture, marking sheep, glazing pottery, fixing dyes and casting cannonballs, shot and bomb shells; limited supplies of the material led to high prices, smuggling and theft until the closure of the mine in 1836 (Rollinson, 1974; The Cumberland Pencil Museum, 2007).

### 1.4.6. From the Georgian Age to the present day (AD 1714 – 2010)

The production of charcoal for smelting continued into the 20th century, and had another important use from the 18th century onwards; charcoal made from juniper ('savin') is used in the production of gunpowder, which was a thriving industry in the southern lakes at sites such as Sedgwick (**58**) and Elterwater (**59**) (Pearsall & Pennington, 1973; Rollinson, 1974). The bobbin mills were also established at this time, utilising birch and hazel to produce bobbins for the cotton mills (Pearsall & Pennington, 1973; Rollinson, 1974). The effects of these industries on woodland are not documented, but must have been significant, although as in previous centuries woodland was probably managed as coppice for continual use rather than decimated.

In the mid-to-late eighteenth and early nineteenth centuries vast areas of upland 'waste' and common ground were enclosed throughout England and Wales (Chapman & Harris, 1982; Whyte, 2003). Parliamentary enclosure reorganised not only ownership of the land, but people's perceptions of the landscape, carving up the fells with dry stone walls and altering patterns of land-use. The loss of common and waste grounds to enclosure had an adverse effect on the poorest people by restricting access to grazing land (Shoard, 1997), although it has been suggested that much of the non-marginal common ground was in effect owned privately as early as the 17th century (Clark & Clark, 2001). Although it was theoretically possible to oppose individual acts of enclosure, as Hill explains, for a peasant to do this 'all he would have to do was learn to read, hire an expensive lawyer, spend a few weeks in London and be prepared to face the wrath of the powerful men in his village' (Hill, 1967: 270). One of the reasons for enclosure was the French Revolution in 1792 and the ensuing Napoleonic Wars, which caused a crisis in grain supplies as Britain was not producing a large enough crop to be self-sufficient (Winchester, 1989). At this time surveys of the English countryside were carried out to investigate and advise on the possibility of 'improving' parts of the landscape, converting them into productive land (*e.g.* Bailey & Culley, 1805; Pringle, 1805). The reports suggest that most parts of upland Westmorland were given over to sheep-farming rather than agriculture, something which the authors sought to remedy through planting schemes designed to improve soil fertility (Pringle, 1805). In Cumberland a number of plantations were appearing around gentlemen's houses, and it was recommended that larch, beech and pine were planted on 'improvable' hillsides deemed unsuitable for agriculture (*e.g.* Bailey & Culley, 1805; Pearsall & Pennington, 1973). Most of the conifer plantations seen today were planted by the Forestry Commission in the mid-twentieth century, but there are areas of hillside where earlier, square-edged plantations were created within former enclosures (Winchester, 1989).

This phase of planting is seen as a pine rise in the palynological records at Whinfell (**60**) and Talkin Tarns (**61**) (Pennington, 1979; Langdon *et al.*, 2004).

Aside from being a target for agricultural improvement, by the eighteenth century the dramatic scenery and apparently untouched wilderness of the lakes had become a source of inspiration for writers, poets and artists, including Coleridge, Wordsworth, and Ruskin (Lindop, 1993). Tourists had visited the area as early as the 17$^{th}$ century AD, but it was not until the romantic era that the Lake District became a popular destination (Ritvo, 2007). Wealthy landowners were attracted to the area and landscaped their estates to conform to a romantic ideal, creating parks and mixed deciduous woodland on former farmland (*e.g.* Windermere (**62**), Derwent Water (**63**), Tarn Howes (**64**)) (Kipling, 1974; Winchester, 1989). The extension of the road and railway networks into this area in the nineteenth century made the Lake District much more accessible for tourists. By 1978 twenty million people were thought to have lived within 3 hours drive of the lakes (Rollinson, 1978: 87), and hordes of tourists invade the area each year to engage in outdoor activities and visit heritage sites such as Beatrix Potter's house (**65**) and Wordsworth's cottage (**66**).

### 1.4.7. Summary

Of all the time periods described above, that for which the least data are available and that is consequently the least well-understood, is the early to middle medieval period, in particular the Dark Ages. Further archaeological investigation of the area may unearth the remains of buildings and artefacts, but without building work in progress or extensive survey it is unlikely that sites will be discovered. Also, on account of the problems of survival and representativity detailed above, excavation may not always yield the information we would like. An alternative or complementary strategy is to investigate the impact of people on vegetation in the past. Revealing the past vegetation and land-use history of an area through palaeoecological proxies provides a basis for interpreting archaeological and historical data, painting a picture of the landscape in which people lived and revealing the ways in which they managed the land around them. This is an invaluable resource; as explained in Section 1.1 in most cases (*i.e.* where there are not exceptional conditions of preservation) the archaeological record is thought to retain only a small percentage of the objects and items used and consumed on a daily basis (Drewett, 1999; Renfrew & Bahn, 2000); palaeoenvironmental data can help to fill in the gaps. Furthermore, establishing the presence, absence or type of anthropogenic impact on the landscape across a region could potentially help archaeologists to identify areas worthy of further investigation; a landscape with a long history of farming, for example, is more likely to yield evidence of human settlement than an area that has been heavily forested since the early Holocene.

### 1.5. Palaeoecology: establishing the environmental context

A group's impact on the environment is influenced by its socio-cultural belief system and means of subsisting (*e.g.* agriculture, horticulture, woodland management, rearing livestock, hunting and gathering); understanding the way in which people interact with and create landscapes around themselves can therefore provide valuable insight to their way of life. The nature of past environments and human impact upon them can be established through analysis of proxy evidence retained in the palaeoecological record, improving our understanding of the history and archaeology of an area by placing it within an environmental context.

#### 1.5.1. Determining vegetation patterns through pollen analysis

Pollen preserved in lake sediment or peat bogs is a useful proxy for vegetation change. Although a number of factors affect the representativity of pollen records (*i.e.* the degree to which the composition of a pollen assemblage reflects the actual composition of species), significant changes in the types and relative numbers of pollen grains accumulated at a site are normally indicative of changes in the surrounding landscape. It is therefore possible to determine land-use within the catchment area of a lake or bog through examination of the pollen record, particularly in conjunction with evidence for soil erosion and changes in nutrient status (lakes) established through analysis of sediment accumulation, geochemistry or diatoms. Broad changes in vegetation such as that from colonising pine/birch forest to mixed deciduous woodland, succession from carr woodland to poor fen, or large-scale forest clearances are often readily identifiable within the palynological records, but subtler developments such as the introduction of cereal crops or the clearance of small areas for grazing and cultivation are more difficult to detect (Brown, 1997). It is important that large and small scale changes are identified wherever possible if historical land-use is to be elucidated; for this to be achieved it is necessary to recognise the complex nature of the relationship between a pollen assemblage and the surrounding vegetation.

#### 1.5.1.1. Pollen recruitment, source area and representativity

A fundamental assumption of pollen analysis is that the nature of the pollen assemblage accumulating at a site is determined by the vegetation abundance in the surrounding area (*cf*.. von Post, 1916, summarised in Manten, 1967). However, it has long been recognised that plants are represented to varying degrees in the record, depending on the average number of grains produced by the plant, the weight and morphology of the grains and the robustness of the pollen exine (and hence its survival rate). The nature of the deposition site also impacts on species representation owing to the differential 'sensing' properties of lakes and bogs of varying sizes (Tauber, 1967; Bradshaw & Webb, 1985; Prentice, 1985, 1986; Bonny, 1976; Sugita, 1993, 1994, 2007a; Broström *et al.*, 2004). This is because the size of the catchment area for pollen, dependant on a number of interacting factors, strongly influences the quantities of various pollen types reaching a site. A bias towards lighter grains such as those of pine (*Pinus* spp.) and against heavier, larger grains like those produced by wheat (*Triticum* spp.) exists in all assemblages (Andersen, 1967; Tauber, 1967; Prentice, 1988), but is amplified as the basin size increases. Big basins have larger pollen source areas than small basins (Figure 1.2), as a larger surface area is exposed to airborne pollen and (with the exception of plants growing on the bog surface or within the lake itself) the distance that locally produced grains must travel to reach the centre of the site is greater (Tauber, 1965; Webb *et al.*, 1978; Prentice, 1985, 1988; Bradshaw & Webb, 1985; Sugita, 1993, 1994). Consequently, for a large lake or bog, light, well-dispersed pollen grains originating far from the site make a greater contribution to the pollen assemblage than heavy grains from local sources (Tauber, 1967; Prentice, 1985, 1986, 1988; Sugita, 1993). This results in a complicated situation whereby the pollen source area varies *for each taxon,* meaning that the pollen spectrum records vegetation abundance over a range of distances from the lake or bog (Janssen, 1966, 1973; Prentice, 1985; Prentice *et al.*, 1987; Faegri & Iversen, 1989). Determining the approximate extent of the relevant source area for pollen (RSAP), defined by Sugita as the radius from the sampling point beyond which the correlation between vegetation abundance and pollen ceases to improve[14] (Sugita, 1994, 2007a & b; Broström *et al.*, 2004), together with the degree to which plants at different distances from the sampling point contribute to the assemblage, is therefore vital for the interpretation of

[14] This definition applies to modern and past datasets, but can only be tested fully where modern vegetation and surface pollen samples are compared or where closely dated pollen samples correspond to thoroughly mapped historical landscapes (e.g. Nielsen & Sugita, 2005).

pollen data (Prentice, 1985; 1988). The RSAP for any given site is influenced by the size and nature of the sampling basin, the contribution of overland flows and incoming streams to the assemblage (Bonny, 1976, 1978, 1980) and most problematically, the species composition, abundance and distribution of local and regional vegetation (Sugita, 1994; Calcote, 1995; Koff *et al.,* 2001; Bunting *et al.,* 2004; Nielsen & Sugita, 2005; Sugita, 2007a). Numerous modelling, calibration and simulation techniques have been developed to address these issues and improve the accuracy with which past vegetation is reconstructed from pollen data (*e.g*. Davis, 1963; Tauber, 1967; Janssen, 1966; Prentice & Parsons, 1983; Prentice 1985, 1986; Overpeck *et al.,* 1985; Sugita, 1993, 1994, 2007a & b; Jackson *et al.,* 1995; Eklöf *et al.,* 2004; Middleton & Bunting, 2004; Nielsen, 2004; Bunting & Middleton, 2005, 2009; Sugita *et al.,* 2006; Gaillard *et al.,* 2008; Bunting *et al.,* 2008); although modelling approaches cannot provide definitive answers, they are an invaluable aid to interpretation of the pollen record and are being used increasingly within the palynological community. The background to modelling and simulation techniques is explained briefly below as an introduction to the simulation software employed in this project.

#### 1.5.1.2. Pollen modelling and simulation: R-values and underlying assumptions

> 'All models are wrong, but some are useful'
>
> (Shinya Sugita)

The above-mentioned variations in the pollen production and dispersal properties of plants make it difficult to establish a quantitative relationship between fossil pollen assemblages and past vegetation. Margaret Davis' seminal work on the application of R-values was one of the first attempts to achieve this, with the R-value itself being simply the ratio between the abundance of pollen from a plant-type and the percentage cover of the same plant in the landscape (Davis, 1963). Past vegetation cover is generally unknown prior to analysis, so R-values are obtained by a combination of surface pollen studies and modern vegetation survey, a process of calibration that remains central to the methodology of pollen modelling and simulation approaches today (*cf.* Prentice, 1986, 1988; Bunting *et al.*, 2008). Furthermore, the assumptions of uniformitarianism required to justify this calibration process are common to the R-value approach and all subsequent models; for values derived from a modern landscape to be applicable to the fossil pollen record, the pollen production and dispersal properties of species must be assumed to be constant (or at least to vary in proportion to one another) through time and space. It must also be assumed that modern landscapes can provide reasonable analogues for past landscapes (Prentice, 1986, 1988; Bunting *et al.*, 2008). The validity of these assumptions has been questioned; dispersal properties are based on the morphology of pollen grains and must be assumed to be relatively unchanging for pollen identification to be possible, but productivity is known to vary significantly depending on the prevailing environmental conditions (*e.g.* Bonny, 1980; Broström *et al.*, 2004; Nielsen, 2004). If the pollen productivities of taxa *covary* this does not present a problem for pollen percentage values (though impacting significantly upon absolute pollen counts), but the assumption of covariance is also doubtful (Bonny, 1980; Calcote, 1995). This has serious implications for all pollen analysis and not just that involving mathematical modelling. Equally, the comparability of modern and past landscapes is doubtful, particularly in the case of 'cultural landscapes' wherein modern farming or management techniques favour or exclude certain taxa (Brun *et al.*, 2007), or impact on the pollen productivity of species (Nielsen & Odgaard, 2004). These difficulties are discussed in greater detail in Chapter 6 (Section 6.4), in terms of the advantages and limitations of the modelling software employed in this project.

#### 1.5.1.3. Extended R-values, Pollen Productivity Estimates (PPEs) and fall speeds

Although the R-value approach compensates for differences in the quantity of pollen produced and deposited by taxa, in practice its application is problematic (Parsons & Prentice, 1981; Prentice & Parsons, 1983; Prentice, 1986). R-values have been found to vary significantly between sites and regions and the model fails to differentiate 'local'/'extralocal' from 'background' pollen inputs as the catchment areas for local/regional vegetation are not defined. In addition, the simple, linear equation used in this model attributes equal weighting to all plants of the same type within the surveyed area in terms of their contribution to the pollen assemblage, regardless of the distance between the plant and the sampling point. Although the relationship between absolute pollen and plant abundance values may be linear, when these values are transformed into percentages the relationship becomes non-linear ('the Fagerlind effect') (Prentice, 1988; Sugita, 1994); consequently it is not possible to apply a simple linear equation to convert pollen percentages to vegetation abundances (Prentice, 1986, 1988). The correlation between pollen at the sampling point and vegetation abundance has been shown to improve leptokurtically (as in Figure 1.1) at increasing distance from the site

(Prentice, 1985, 1988); initially, as the distance from the sampling point is increased the relationship shows dramatic improvement, but beyond a certain point (in this case approximately 2800 m), there is little change. The point at which the correlation ceases to improve is the extent of the RSAP as defined by Sugita and pollen reaching the site from beyond this point is classed as 'background' pollen within the LRA framework (Sugita, 1994, 2007a & b; Broström *et al.*, 2004). Establishing the composition of the 'background' pollen component and thus the difference between local and regional vegetation can only be achieved by comparing the pollen data from a network of sites (Prentice *et al.*, 1987; Sugita *et al.*, 1999; Sugita, 2007a & b).

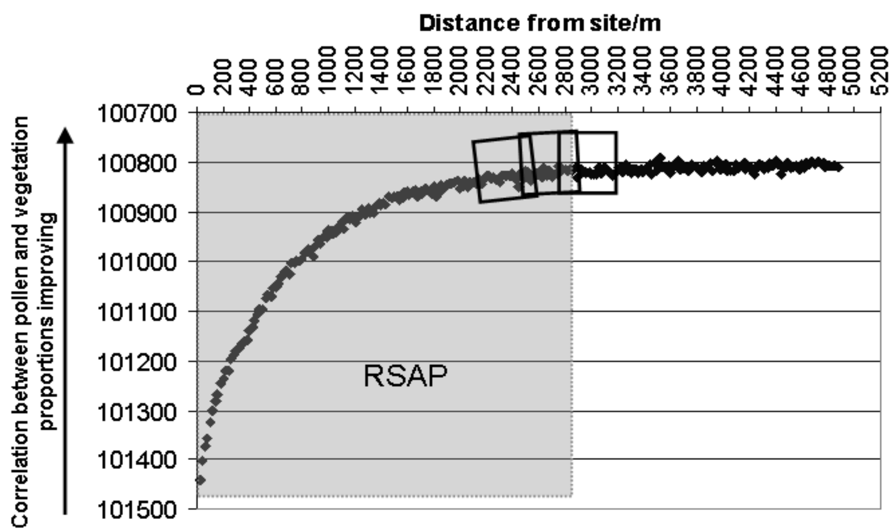


Figure 1.1. Graph showing the leptokurtic relationship between pollen percentages and vegetation abundance; lowering of 'likelihood function score' indicates improved correlation between pollen and plant abundances. Squares demonstrate the 'moving window' method of identifying the levelling off of the curve (Broström, pers. comm.).

The need to separate local and regional/long-distance elements within pollen assemblages and counteract the Fagerlind effect for percentage data led to development of the Extended R-Value (ERV) models of Parsons and Prentice (1981) and Prentice and Parsons (1983), which were later incorporated to the Prentice and Prentice-Sugita modelling approaches (Prentice, 1985, 1986, 1988; Prentice *et al.*, 1987; Sugita, 1994, 2007a & b). ERV models 1 and 2 use pollen proportions to estimate pollen productivity and background pollen, the latter being defined as pollen reaching the site from beyond the RSAP (Prentice & Parsons, 1981; Parsons & Prentice, 1983; Sugita, 1993, 1994). Sugita suggested a further modification, ERV model 3, which calculates distance weighted plant abundance (dwpa) using pollen proportions (Sugita, 1994). This sub-model also estimates pollen productivity and background pollen loading, but unlike ERV 1 and 2 does not assume that background pollen constitutes an unchanging proportion of the assemblage (Sugita, 1994). This flexible approach allows for the fact that both the area from which pollen in the assemblage is derived and the percentage attributable to ‘local’ and ‘regional’ vegetation may vary through time, depending on the composition and distribution of vegetation communities (*cf.* Jacobson & Bradshaw; Bradshaw & Webb, 1985; Sugita 1994; Calcote, 1995; Jackson & Kearsley, 1998; Parshall & Calcote, 2001; Bunting, 2003; Bunting *et al.*, 2004; Nielsen & Sugita, 2005). ERV 3 uses a taxon-specific PPE[15] (pollen productivity estimate) and grain ‘fall speed’ to distance-weight taxa individually, a method which has been shown to provide the most accurate simulations of distance-weighted vegetation to date (Broström *et al.*, 2004; Nielsen & Sugita, 2005).

Sugita (1993) suggested another modification of Prentice’s original algorithm, the ‘Prentice-Sugita model’, which is designed to model for pollen accumulation in lake sediment rather than on peat bogs or moss polsters. The Prentice model assumes that pollen landing on the peat/moss surface is incorporated to the pollen assemblage at that specific location, while the Prentice-Sugita model works on the assumption that pollen landing at any point on a lake surface (*i.e.* not only that immediately above the sampling point) will be mixed together prior to deposition (Sugita, 1993). Both models are oversimplifications, but the Prentice-Sugita algorithm is thought to model the real-world situation for waterbodies more accurately than the Prentice model (Sugita, 1993, 1994), so this version of the model was employed here (Chapter 5).

As indicated above, R-values have now largely been replaced with PPEs, which are values based on the average productivity of a taxon relative to a reference type (usually Poaceae), and fall speeds, representing the differential dispersal properties of pollen grains (Bunting & Middleton, 2005; Sugita, 2007a). PPEs can be obtained by direct measurement if the pollen output of a plant is recorded in controlled conditions, but as pollen production and release for an individual plant may vary daily, seasonally and annually (Bonny, 1980), a vast quantity of measurements would be required to produce a reliable PPE. The alternative method is to use pollen data from a surface sample in an area for which the vegetation has been surveyed up to at least the radius of the estimated RSAP; as a pollen sample often represents several years of deposition this is more suitable for providing an *average* PPE (if fall speed has been determined and accounted for) throughout that time period (Broström *et al.*, 2004; Sugita *et al.*,

[15] Jane Bunting recently suggested that this should be changed to Relative Pollen Productivity Estimates (RPPEs) (PPE workshop, University of Hull, May 2010), but PPE is used here as this is the term found in all of the literature cited and the change to RPPE has not (yet) been embraced by the modelling/simulation community.

2006). Fall speed is determined either by dropping grains within a cylinder of air and recording the time taken for them to fall (Sugita, pers. comm.) or through the application of Stokes' Law, by which the terminal velocity of a particle (*i.e*. a pollen grain) in a fluid (air) can be approximated using grain size measurements (Broström *et al.,* 2004).

#### 1.5.1.4. HUMPOL v3, the Landscape Reconstruction Algorithm (LRA) and the Multiple Scenario Approach (MSA)

The Prentice and Prentice-Sugita algorithms incorporating ERV models are utilised in various software suites (*e.g.* Sugita, 1993, 1994, 2007a & b; Eklöf *et al.,* 2004; Middleton & Bunting, 2004; Bunting & Middleton, 2005, 2009; Sugita *et al.,* 2006; Gaillard *et al.,* 2008; Bunting *et al.,* 2008). Two applications were considered for use in this project, namely HUMPOL v.3 (Bunting & Middleton, 2005) and the Landscape Reconstruction Algorithm (LRA) (Sugita, 2007a & b). Both programs incorporate the same calculations and are reliant on PPEs and fall speeds acquired from studies of modern vegetation and surface pollen assemblages; the key difference between them is that the LRA uses pollen data to simulate vegetation abundances while HUMPOL does the reverse.

The LRA is composed of two complementary models, REVEALS (Regional Estimation of Vegetation Abundance from Large Sites), which uses pollen data from large sites to simulate regional vegetation cover, and LOVE (LOcal Vegetation Estimate), which aims to establish the nature of vegetation communities at a smaller scale using data from small lakes or bogs (Sugita 2007a & b). By combining the models it is possible to estimate both the regional and local vegetation patterns within an area. Tested on modern and historical assemblages (where corresponding vegetation maps are available), the LRA has been shown to produce more accurate reconstructions than pollen proportion data alone and seem to work well irrespective of the vegetation type and cover (Nielsen *et al.,* 2005; Sugita, 2007b). When the incorporation of modelling to this study was first considered, it was hoped that the LRA could be utilised; ultimately, for reasons explained in Chapter 5, HUMPOL was used instead.

HUMPOL v.3 is a simulation suite consisting of several programs (Mosaic v.3, Polflow v.3, PolLog v.3 {Richard Middleton, 2004} and Polsim v.3 {Shinya Sugita, 2002}), which produces estimates of pollen assemblages based on vegetation communities distributed within a landscape designed by the user (Bunting & Middleton, 2005). The software produces expected pollen proportions (pollen loading) for selected taxa at predefined intervals (*e.g.* 20 m) from a simulated sampling point, using the Prentice-Sugita algorithm (Sugita 1994) and PPEs and fall speeds for each pollen type. Producing simulations for multiple landscape designs allows the user to ‘test’ a variety of scenarios, by varying the composition, extent and distribution of different vegetation communities. In addition to varying the vegetation cover it is possible to alter the simulated wind conditions, the sampling basin size and the extent of the area modelled; several projects have been carried out specifically to explore the impact of varying certain aspects of a modelled landscape (*e.g.* Bunting *et al.*, 2004; Bunting *et al.*, 2008; Hellman *et al.*, 2009a & b). Simulated pollen outputs can be compared to *real* pollen data; theoretically, the landscape scenario(s) most similar to that from which the pollen assemblage derives should provide the best match for the data. However, as HUMPOL cannot distinguish between ecologically likely and improbable landscapes, caution is required when interpreting the results. Caseldine *et al.* (2007) found that the least likely landscape simulation provided the closest match for their data, demonstrating the importance of understanding both the pollen data and the limitations of the models.

The most sophisticated model to date is the Multiple Scenario Approach (MSA), which consists of a suite of programs incorporating GIS, soils data and digital elevation models (Bunting *et al.*, 2008; Bunting & Middleton, 2009). The MSA is still being developed and is not yet available for general use, so it could not be employed in the current study; it is included here as it has developed out of HUMPOL and seems likely to be adopted more widely in the future. The MSA formulates numerous, *ecologically possible* landscape reconstructions based on the pollen data (Bunting *et al.*, 2008; Bunting & Middleton, 2009). One of the key objectives of the MSA and earlier modelling programs is to address the issue of equifinality; the fact that there are almost always multiple plausible interpretations of a given pollen assemblage (Bunting & Middleton, 2009). It is impractical to run a large number of HUMPOL simulations because of the time required to create the necessary files and to run the various programs, but in the MSA suite thousands of possible landscape scenarios can be tested (Bunting *et al.*, 2008; Bunting & Middleton, 2009).

Although the equations and computer programs employed for vegetation reconstruction based on palynological data have become increasingly sophisticated, they remain simple considering the complexity of the real world (Prentice, 1985; Sugita, pers. comm.) and are best considered an aid to interpretation rather than a solution to all the difficulties inherent in understanding pollen data. Jackson and Lyford (1999) highlight the problems associated with modelling in terms of the numerous factors that are ‘unknown’ and therefore unaccounted for in the process (*e.g.* past atmospheric conditions). However, these factors are also unaccounted for in traditional, qualitative interpretations of pollen data. Stalwarts of the pollen modelling community are very open about the limitations of numerical modelling and the simplified nature of the modelled landscape (*e.g.* Jane Bunting, Marie-José Gaillard, Shinya Sugita), yet the programs appear to produce useful data and have been successful in reconstructing modern landscapes based on pollen data (Nielsen & Sugita, 2005; Sugita 2007a & b; Bunting, 2008; Bunting *et al.*, 2008; Gaillard *et al.*, 2008; Hellman *et al.*, 2009a).

**1.5.1.5. Differences between sampling basins**

As the size and nature of the sampling site has a significant impact on the source area from which pollen is derived it is important to choose sites appropriate to the research questions being asked (*cf.* Bradshaw & Webb, 1985). The study sites utilised in this project are discussed in detail in Chapter 3 and were selected for their ability to yield a local/extralocal pollen record (*sensu* Jacobson & Bradshaw, 1981). Lakes were chosen in preference to peat bogs because of the complications arising from vegetation growing on the bog itself (Bunting *et al.*, 1998; Bunting, 2002) and the fact that many bogs in the UK, including Blelham Bog and Bolton Fell Moss within the study area (Oldfield, 1970; Barber, 1981) have been damaged by peat-cutting or drainage, sometimes to the extent that a continuous pollen record cannot be obtained from the site (*e.g.* Lower Lancarrow and Carn Galver in Cornwall (Forster & Robinson, forthcoming)). Sediments within lakes and tarns are less prone to human disturbance and often provide a relatively continuous record provided the site has not been dredged or otherwise modified by people (Oldfield *et al.*, 1983). Small tarns without inflowing streams were used where possible as the pollen assemblage accumulating in sites of this type should be derived from a relatively small catchment area (Sugita 1994, 2007a & b)[16]. Figure 1.2 shows three lake-based landscape scenarios and the approximate proportions of pollen input that would be expected to arise from various sources in each case. The optimal sampling location for obtaining an assemblage representative of regional vegetation is a large lake within an open landscape (Figure 1.2(a)), while for a local pollen record a small lake or tarn within an enclosed basin is ideal (Figure 1.2(c)) (Pennington, 1964, 1965; Sugita, 2007a & b). Inflowing streams tend to carry pollen from outside of the site's catchment area for airborne pollen, thus increasing the source area represented (Figures 1.3 & 1.4) (Jacobson & Bradshaw, 1981;

[16] For example, Sugita (1994) suggests an RSAP radius of approximately 600-800 m for a lake with a radius of 250 m.

Davies & Tipping, 2004; Brown *et al.*, 2007). In addition, vegetation growing beside the stream (*e.g.* alder (*Alnus* spp.) and willow (*Salix* spp.)) is likely to be overrepresented as pollen from these plants may fall directly into the water (Pennington, 1964, 1965, 1979). This is demonstrated by Bonny's work at Blelham Tarn, which shows that where inflows are present a high proportion of pollen reaching the sediment is streamborne rather than airborne, skewing the dataset (Bonny, 1976, 1978, 1980). Pollen models do not currently account for pollen reaching the deposition site in this manner, which is problematic when simulations are carried out for tarns or lakes with substantial inflowing streams (discussed further in Chapter 6).

**1.5.1.6. Differential preservation**

In addition to the sources of bias outlined above, pollen assemblages are often affected by differential preservation. A 20-year experiment testing the survival rates of 19 pollen and spore types in various sedimentary conditions revealed notable differences between pollen from various species and between the environments tested (Havinga, 1984). Robust grains produced by taxa such as dandelion (*Taraxacum officinale*) and alder (*Alnus glutinosa*) were shown to survive in far greater numbers than fragile grains (*e.g.* yew (*Taxus baccata*)) in all of the test conditions, but the relative order of preservation was not consistent for all species in all conditions. For example, pollen of ash (*Fraxinus excelsior*) was found to be slightly better preserved than that of birch (*Betula* spp.) in *Carex* peat, while in *Sphagnum* peat the relationship was reversed, with a much more significant difference in survival rates of the two pollen types (Havinga, 1984). Podzols were found to be the most destructive environment for all pollen types, leading to heavy losses of even the very robust grains. In addition to outright destruction of pollen, 'thinning' and 'cavitation' processes may obscure or damage features of the grain, making identification difficult. This skews the countable pollen assemblage further, as the robust types are often those with pronounced areas of thickening in the exine (Images 1.7 & 1.8), facilitating identification even when grains are damaged severely.

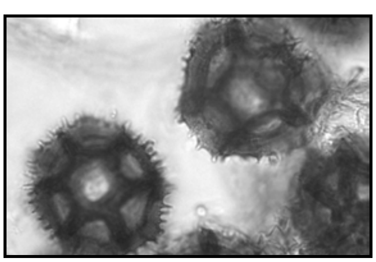


Image 1.7: Dandelion (*Taraxacum officinale*) pollen grains (x1000 magnification)

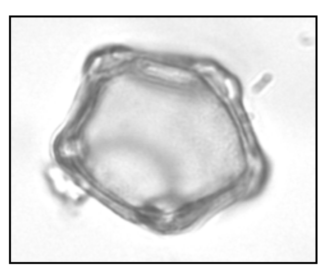


Image 1.8: Alder (*Alnus glutinosa*) pollen grain (x1000 magnification)

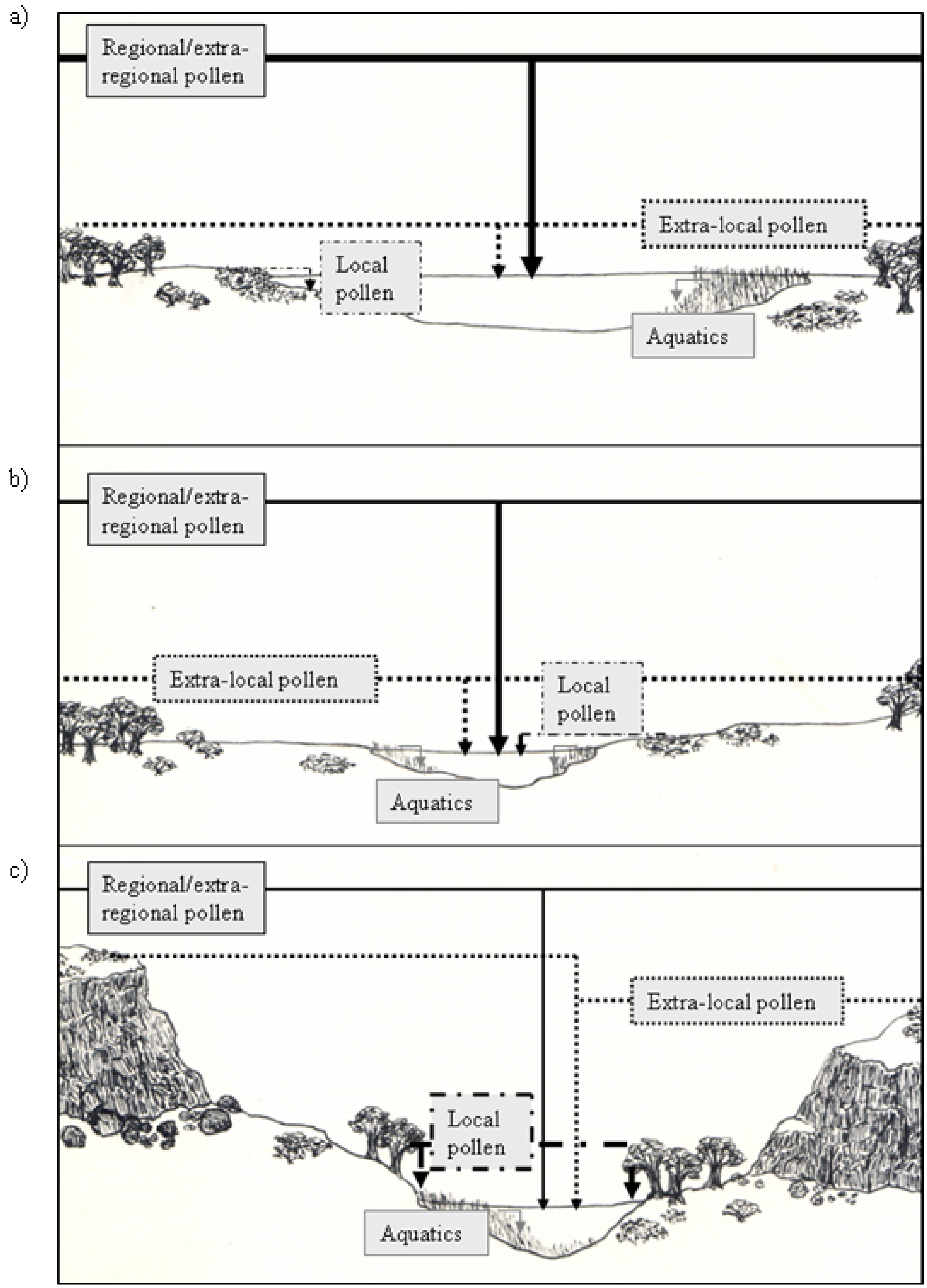
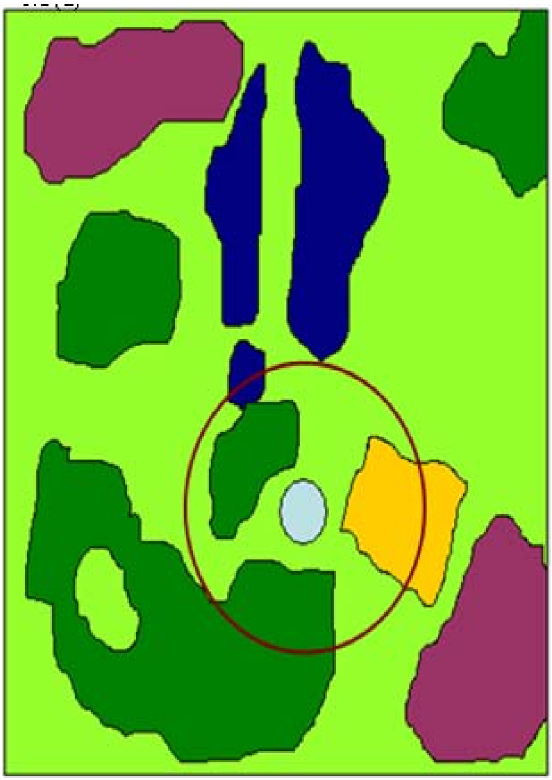
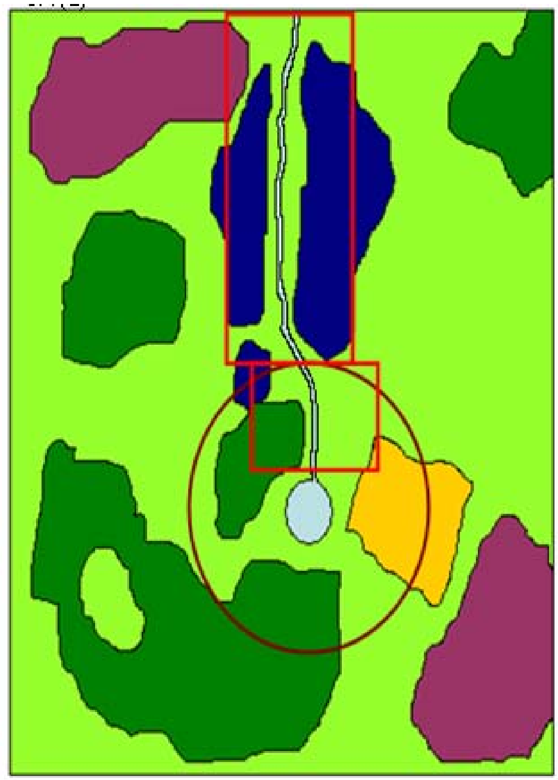
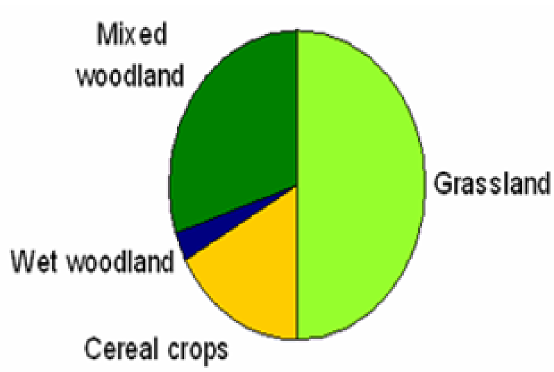


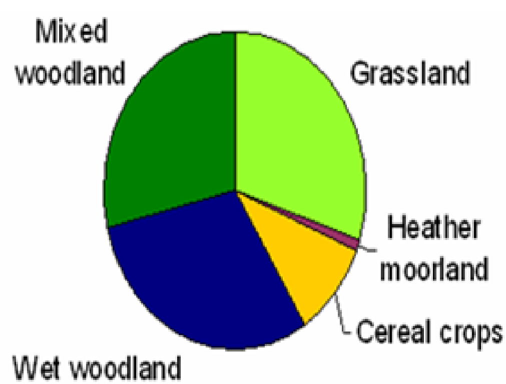

Figure 1.2: Approximate pollen inputs to lake sediment in three scenarios: (a) large lake in an open landscape, (b) small lake in an open landscape and (c) small lake in an enclosed landscape. The thickness of the arrows indicates the proportion of pollen coming from a given source (fine arrows indicate a small input while thick ones denote a significant proportion of accumulated pollen).





1.3(a) 1.4(a)




1.3(b) 1.4(b)

Figures 1.3 and 1.4: Illustrating the impact of streamborne pollen on the RSAP in a simplified landscape. 1.3 (a) Lake without inflows: dark red circle indicates RSAP and (b) estimated percentages of pollen accumulated from each vegetation type.
1.4 (a) Lake with one inflow: dark red circle indicates original RSAP, bright red rectangle indicates extension of RSAP with addition of streamborne pollen and (b) estimated percentages of pollen accumulated from each vegetation type.

Where the sedimentary conditions are known it might be possible to allow for preferential destruction of certain taxa, but when a species' pollen has been lost entirely from the record this information cannot be regained. In extreme cases taphonomic processes may transform the assemblage entirely from that at the time of deposition, rendering it practically useless as a tool for identifying past vegetation (Havinga, 1984).

Owing to the problems outlined above it is important to attempt to establish the state of pollen preservation for any given sample. Recording the number of damaged, degraded and unidentifiable grains in an assemblage is useful, as spikes in these are likely to indicate poor conditions of preservation. Addition of an exotic marker (*e.g. Lycopodium* spores) in order to calculate absolute pollen concentrations is worthwhile as overall concentrations should fall significantly where preservation is poor. Low levels of diversity are also likely to indicate differential preservation, particularly where robust pollen types are prevalent.

### 1.5.2. Detecting agriculture and grazing within the pollen record

People have been keeping livestock and cultivating crops for millennia for the purpose of food production. The extent to which communities or individuals adapt the landscape around them provides insight to their way of life and may give an approximation of population density; presumably, if agriculture is the principal provider of food, the more people there are to feed, the greater the area that needs to be cleared and cultivated. Unfortunately, detecting agriculture and livestock grazing within the pollen record is notoriously difficult. Cereal pollen grains are often few and far between and can be difficult to identify (Section 1.5.2.1) and many of the 'weed' species associated with arable and pastoral land are also found in open, unfarmed landscapes (*e.g.* plantains (*Plantago* spp.)) or produce pollen that is unidentifiable beyond a 'type' incorporating taxa from diverse habitats (*e.g.* fat hen, which falls within Chenopodiaceae). Evidence for loss of woodland is inconclusive as this may occur for a number of reasons, both natural and anthropogenic (*cf.* Limbrey, 1975; Brown, 1997) (Section 1.5.2.2). Despite these problems, the importance of farming practices to our comprehension of past societies necessitates the use of all available lines of evidence to detect landscape management within the palaeoecological record.

#### 1.5.2.1. Cereal pollen

The clearest indicator of landscape management is the presence of pollen from cereal crops. Unfortunately, cereals are difficult to distinguish from other grasses; despite numerous attempts to improve the separation of cultivated types and wild grasses the method remains imperfect (*e.g.* Beug, 1961; Andersen & Bertelsen, 1972; Andersen, 1979; Köhler & Lange, 1979; Dickson, 1988; Edwards & McIntosh, 1988; Küster, 1988; Tweddle *et al.*, 2005; Forster, 2005). Table 1.4 shows Andersen's (1979) criteria for separating cereals and wild grasses by grain-size measurements and surface texture. Previous work by the author demonstrates that not all grains fall within these types and some pollen may be placed in conflicting groups according to (for example) mean pollen size and annulus diameter (Forster, 2005). Furthermore, surface texture is often hard to establish with confidence and crumpled or obscured pollen is practically impossible to measure accurately. The most difficult grains to identify positively are those of barley (*Hordeum vulgare*) and einkorn (*Triticum monococcum*), which are both classed as *Hordeum*-type. This group includes nine wild grasses (Andersen, 1979), the habitats of which are shown in Table 1.5. Those shaded grey are unlikely to occur in the study period or area as they are types that have either been introduced to Britain relatively recently or that inhabit maritime environments. These taxa can reasonably be eliminated as possible identities of the *Hordeum*-type grains found in the course of the current research, but as the table shows there are four wild taxa within the group that cannot be dismissed. A brief appraisal of criteria for cereal identification is included in the methods section.

Problems of identification are compounded by the pollen dispersal mechanisms of cereal plants. Wheat (*Triticum* spp.) and barley (*Hordeum vulgare*) are self-pollinating and produce small numbers of large, heavy grains that are unlikely to travel far from the source; consequently they are rarely incorporated to sediments that are not in close proximity to farmed land (Edwards *et al.*, 1986; Edwards & McIntosh, 1988). Rye (*Secale cereale*) is wind-pollinated, so produces and disperses far more pollen, meaning its grains are more likely to be found within sediments, but will be overrepresented relative to the other cereal types (Hicks, 1972).

#### 1.5.2.2. Indicator species for anthropogenic activity

Owing to the problems outlined above it is not possible to depend entirely upon the presence of cereal pollen when seeking evidence for agricultural activity in the palynological record.

Plants that grow in close association with crops or on disturbed ground also provide information about past human activity (Oldfield, 1963, 1969; Turner, 1964; Dimbleby, 1978; Behre, 1981, 1988; Berglund *et al.*, 1986; Vorren, 1986). In her study comparing the pollen assemblage from a predominantly agricultural area in East Anglia with that from a grazed landscape in Wales (Tregaron Bog), Turner (1964) established that the ratio between plantains (*Plantago* spp.) and the combined total of certain 'arable indicators'[17] was markedly different in the two landscapes. She found that plantains were far more prevalent in pastoral landscapes, equating increases in grass (Poaceae), bracken (*Pteridium aquilinum*) and plantain with rough grazing environments. Turner's (1964) arable indicator species were demonstrably more important in pollen assemblages from cultivated land. The 'arable/pastoral index' approach does not appear to have been widely adopted, perhaps because the myriad species incorporated to the group of agricultural indicators inhabit a broad range of habitats. Unfortunately, there are very few specifically 'arable weeds' that are confined to crop-fields and a given plant or pollen type might be considered 'arable' by one researcher and 'pastoral' by another (Buckland & Edwards, 1984). Pastoral types are also found in many habitats; sorrel (*Rumex* spp.) and bracken (*Pteridium aquilinum*) are commonly noted as indicators of grazing, but also respond well to fire and colonise areas cleared by burning, which may occur naturally, accidentally, or through a deliberate anthropogenic act to produce clearings (Stevenson & Rhodes, 2000). Similarly, stinging nettles (*Urtica dioica*), are a common plant in pasture as they are encouraged by high nitrate levels within soils (Olsen, 1921), which may be derived from urine. However, nitrophilous plants could also be indicative of human habitation (*i.e.* middens or latrines associated with settlements), the addition of nitrate-based fertilisers to crop-fields or, particularly in the case of sporadic finds, the presence of wild animals. Grasses are even more problematic as indicators of open ground because of the large number of genera in the Poaceae family; with the exception of cereals, identifying Poaceae to genus or species level is rarely, if ever, attempted and the 'grass' curve in a pollen diagram may represent taxa from a wide range of habitats. For example, reeds (*Phragmites communis*) produce Poaceae-type pollen, so an apparent expansion of grassland in an assemblage from lake sediment might actually reflect the development of reed swamp at the lake margins, rather than changes in the wider landscape (Barber, 1988).

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[17] Compositae (a broad family incorporating sunflowers, ragweeds, marigolds and fleabane), Cerealia (cereals), Chenopodiaceae (fat hen and goosefoot), *Artemisia*-type (mugwort/wormwood) and Cruciferae (almost 2000 species, including turnip, swede, cabbage, mustard, cress and rocket) (Turner, 1964; Clapham *et al.*, 1962; Stace, 1997).

Despite the problems of equifinality outlined above, there have been numerous attempts to define ‘arable’ and ‘pastoral’ taxa and certain pollen types occur repeatedly in lists of anthropogenic indicators (Table 1.6) (*e.g.* Oldfield, 1963, 1969; Turner, 1964; Dimbleby, 1978; Behre, 1981, 1988; Berglund *et al.,* 1986; Vorren, 1986). Interpreting occurrences of these types is nonetheless problematic; many of the non-cultivated herbaceous taxa found in crop-fields or grazed habitats are also associated with ruderal environments (see Table 1.6), meaning that without additional supporting evidence their presence is inconclusive. Plants that expand into areas cleared of woodland for farming purposes also flourish in natural clearings created by wind-throw, lightning or the spread of disease (*cf.* Limbrey, 1975; Buckland & Edwards, 1984; Brown, 1997; Behre, 2007). Most of these species are native plants of open ground; mugwort, for example is often prevalent in Lateglacial contexts, but would not usually be interpreted as relating to human activity at such an early date, whereas a small amount of this plant’s pollen in a Neolithic or later context could be considered significant (Behre, 2007). This is problematic; if the age of the sample influences the interpretation according to what is expected for that period the interpretative process becomes circular. Dramatic declines in arboreal pollen may provide a clear indication of anthropogenic activity in the form of woodland clearance, particularly when associated with an expansion of grasses, plantains (and herbaceous taxa in general), bracken and hazel (*Corylus avellana*-type) (Iversen, 1949; Turner, 1964; Dimbleby, 1978; Behre, 1981, 1988; Berglund *et al.,* 1986; Edwards, 1993). However, small patches of farmland within forests are less likely to be detected in the pollen record and would be difficult to distinguish from natural clearings, particularly in the absence of cereals and arable weeds (Göransson, 1988; Brown, 1997).

Further links between pollen signals and specific management practices have been identified by various authors. Buckland and Edwards (1984) note the destructive impact of grazing and browsing by livestock or wild herbivores as a means of sustaining or even increasing the size of woodland clearings. Similarly, experimental work in Scotland suggests that increases in heather (*Calluna vulgaris*), crowberry (*Empetrum nigrum*) and bilberry (*Vaccinium myrtillus* (‘*Vaccinium*-type’ pollen)) could signal a reduction in grazing pressure on moorland (*cf.* Pakeman *et al.,* 2003). Nielsen and Odgaard (2004) identify peaks in hazel pollen with coppicing, which encourages flowering, while Oldfield dates the loss of mugwort in Northwest England to the early 19$^{th}$ century introduction of deep ploughing (Oldfield, 1963, 1969). The latter raises another issue affecting the interpretation of fossil pollen assemblages; the reduction of biodiversity resulting from intensive farming techniques makes modern agricultural fields poor analogues for historical or prehistoric crop-fields (Brun *et al.*, 2007). This can be alleviated to some extent by examining the flora of fields cultivated ‘organically’ (*i.e.* without pesticides or synthetic fertilisers) (Buckland & Edwards, 1984) or by experimental simulation work, wherein the estimated pollen output of ‘no analogue’ vegetation communities and landscape scenarios can be tested. The Multiple Scenario Approach promises to be very useful in this respect as all *ecologically possible* landscape designs can be tested in the model (Bunting & Middleton, 2009).

Table 1.6 shows indicator species associated with agriculture, grazing and disturbance (*e.g.* ploughing, clearance or trampling by animals) that were used in the interpretation of pollen data for this project. The groups displayed here were used in the organisation of some of the pollen diagrams; categorising species in this manner is helpful in identifying episodes of agriculture and pastoralism and is a useful way of organising taxa within the diagrams to make them more readily interpretable (*e.g.* Lomas-Clarke & Barber, 2004, 2007). Table 1A (Appendix 1) shows basic habitat information and ecological groupings for all taxa identified during pollen analysis for this study.

Where several of the taxa in Table 1.6 are found together it is probable that farming was in progress, although as explained above, it may not be possible to establish whether this was predominantly pastoral or agricultural in nature. Owing to the large range of habitats occupied by some of the indicator species and the resulting problems of equifinality, it is important that the pollen assemblage is considered as a whole rather than in terms of individual taxa. This interpretative difficulty may be addressed by the application of correspondence analysis (Hill, 1974; Hill & Gauch, 1980) or through the pollen modelling/landscape simulation approaches described in Section 1.5.1 (*e.g.* Prentice, 1985, 1986, 1988; Sugita, 1993, 1994, 2007a & b; Bunting & Middleton, 2005, 2009; Gaillard *et al.*, 2008). Another way to reduce the likelihood of spurious interpretation is to use additional proxy environmental data to support the pollen evidence (for example diatoms or geochemical analysis) as well as documentary and archaeological evidence of land-use where these are available (*e.g.* Coombes *et al.*, 2009). As explained in the following sections, rates of sediment accumulation and the diatom flora within lakes are sensitive to land-use patterns in the catchment area (*e.g.* Battarbee, 1986; Dearing & Foster, 1986; Bennion *et al.*, 2000; Hatfield & Maher, 2009). Sediment description and characterisation have been used together with diatom analysis in the current project to complement the palynological data.

Table 1.4: Criteria for separation of pollen of cereals and wild grasses, after Andersen (1979). (terminology after Tweddle *et al.*, 2005, as some of the species names have changed)

| **Group classification** | **Mean pollen size/µm (average of length&width)** | **Mean annulus diameter/ µm** | **Surface sculpturing** | **Pollen index (longest length/ length at 90** | **Cultigens within group** | **Wild taxa included in group** |
|---|---|---|---|---|---|---|
| Wild grasses | Less than 37 | Less than 8 | Scabrate/ Verrucate | - | - | Most wild spp. |
| *Hordeum* type | 32-45 | 8-10 | Scabrate | - | *Hordeum vulgare* (barley), *Triticum monococcum* (Einkorn) | *Ammophila arenaria*, *Bromopsis inermis*, *Elytrigias juncea*, *E. repens*, *Glyceria fluitans*, *G. notata*, *Elymus arenarius*, *Hordeum jubatum*, *H. murinum* (see Table 1.5 for common names) |
| *Avena-Triticum* type | More than 40 | More than 10 | Verrucate | - | *Avena nuda* , *A.sativa* (cultivated oat),*Triticum aestivum* (common wheat), *T.aestivum* sub-species *compactum* (club wheat), *T. dicoccon* (emmer wheat), *T. durum* (durum wheat), *T. polonicum* (polish wheat), *T. spelta* (spelt) | *Avena fatua* (wild oat) |
| *Secale cereale* | (none given) | 8-10 | Scabrate | More than 1.26 | *Secale cereale* (rye) | N/A |

Table 1.5: Habitat data for wild species in the *Hordeum* group (reproduced from Forster, 2005, habitat data from Stace, 1997). Shaded taxa are thought unlikely to occur within the study area.

| **Species** | **Common name** | **Native/introduced?** | **Known habitat information** |
|---|---|---|---|
| *Ammophila arenaria* | Marram | Native | Mobile sand-dunes, common on coasts, rare inland |
| *Bromopsis inermis* | Hungarian brome | Introduced | Rough, grassy places, waysides & field margins |
| *Elytrigias juncea* | Sand couch | Native | Maritime sand-dunes, coast |
| *Elytrigia repens* | Common couch | Native | Cultivated, waste and rough ground |
| *Glyceria fluitans* | Floating sweet grass | Native | On mud or shallow water by rivers & ponds, marshes, ditches & wet meadows |
| *Glyceria notata* | Plicate sweet grass | Native | |
| *Elymus arenarius* | Lyme-grass | Native | Mobile sand-dunes, rarely inland |
| *Hordeum jubatum* | Foxtail barley | Introduced | Waste places - alien from wool, bird-seed & grass-seed |
| *Hordeum murinum* | Wall barley | Native | Weed of waste and rough ground, barish patches in rough grassland |

Table 1.6: Indicator species found in arable fields and on grazed or otherwise disturbed land (habitat information from Clapham *et al.*: 1962; Turner, 1964; Dimbleby, 1978; Behre, 1981, 1988 & 2007; Berglund *et al.,* 1986; Vorren, 1986 & Stace, 1997). Caveats in square brackets.

| **Species** | **Common name** | **Grouping** |
|---|---|---|
| *Centaurea cyanus* | Cornflower, bluebottle | Arable weeds |
| *Polygonum* | Knotgrass, bistort, red shank, willow weed, persicaria, water pepper, bindweed | |
| Chenopodiaceae | Goosefoot, fat hen [may also be grown for eating] | Arable/disturbed ground |
| *Plantago major/media* | Great/hoary plantain [*P.major* is an arable indicator, *P.media* merely indicates grassland] | |
| *Artemisia*-type | Mugworts, wormwood | Pastoral taxa and ruderals/plants of disturbed ground and wasteland |
| *Campanula*-type | Bellflower, bats-in-the-belfry, harebell, bluebell, Venus's looking-glass | |
| Caryophyllaceae | Many spp. Including campions, catchflys, pinks, sweet Williams, chickweed, stitchwort, pearlwort & sandwort | |
| *Centaurea nigra* | Lesser knapweed, hardheads | |
| *Cichorium intybus*-type | Chicory, nipplewort, cat's ear, hawkbit, ox-tongue, lettuce, dandelion, hawkweed, hawks-beard, thistles | |

| Species | Common name | Grouping |
|---|---|---|
| Asteraceae (Compositae) | Many species including daisies, mugworts, knapweeds, chicory, dandelions and thistles | Pastoral taxa and ruderals/plants of disturbed ground and wasteland |
| *Plantago lanceolata* | Ribwort plantain | |
| Ranunculaceae | Many species [though some aquatic] including buttercups, crowfoots, spearworts, meadow rues | |
| *Rumex acetosa, R..acetosella* | Sorrel, sheep's sorrel | |
| *Trifolium*-type | Trefoil, clover | |
| *Urtica urens*, *U. dioica* | Small nettle, stinging nettle | |
| Poaceae (formerly Gramineae) | Grasses [includes reeds/aquatics (*e.g. Phragmites*)] | Cleared ground |
| *Corylus avellana*-type | Hazel [type also includes *Myrica gale* (bog myrtle)] | |
| *Pteridium aquilinum* | Bracken | |

### 1.5.3. Changes in sediment accumulation and composition

In addition to changes in vegetation that may be recognisable in the pollen record, anthropogenic activity in the landscape can affect erosion and run-off in the catchment area. Lake sediments may reflect these impacts in terms of changes in the rate of sediment accumulation and/or the composition of lake sediment (Dearing & Foster, 1986). Changes in the nature of sediment within a core may reveal episodes of past erosion and subsequent inwash to a lake/tarn. Minerogenic inputs are likely to originate from catchment soils, and where rapid accumulation occurs, can be indicative of disturbance within the area. The most obvious cause of this is deforestation; dramatic examples of its effects can be seen around the world (*e.g.* the Amazon, the Ganges) (Bradshaw *et al.,* 2007), but the impact is similar though less pronounced on a local scale. Tree roots stabilise the surrounding soil and their leaves intercept and slow the passage of rainwater to the ground, lessening the impact of rainfall and reducing surface run-off and rates of soil erosion. In addition, as trees take up many litres of water through their roots the saturation levels of the soil are reduced, allowing precipitation to soak in rather than pooling on the surface or flowing over land. Other causes of increased erosion include ploughing, which breaks up soil structures and destroys the root packs of grasses and other herbs that normally stabilise the soil (Limbrey, 1975), and grazing/trampling by animals (more pronounced where herds/flocks are confined to a specific area, as is the case with most domesticated animals). These scenarios are all likely to result from anthropogenic activity in the catchment area. Extreme weather events, landslides or colluvial slumps may produce the same sedimentary signal, but these are unlikely to produce supporting trends in the pollen and diatom data indicative of human impact on the landscape.

### 1.5.4. Diatom analysis in relation to land-use

As outlined above, land-use patterns can impact upon the run-off and erosion rates within a lake's catchment, leading to changes in the quantity and occasionally type of material deposited on the lake-bed. Alterations in the chemical composition of sediment and overland flow reaching the site sometimes affect the properties of lake water (*e.g.* increasing acidity owing to peat erosion, inwash of phosphorous from fertilised fields) and thus the diatom flora present. Analysing changes in the diatom assemblage from a lake, particularly in conjunction with analysis of pollen or other proxy environmental indicators, therefore provides an insight to land-use history in the lake's catchment area.

Diatoms are single-celled, microscopic algae consisting of two valves with silica walls (Dincauze, 2000; EPA Biocriteria website, accessed 10/12/2008). Because of their siliceous composition they survive well in most lake sediments with many of their characteristic features preserved (Battarbee, 1986), facilitating identification to species level in most cases. Diatom species are habitat-specific, providing proxy evidence for chemical and physical properties of the water in which they live, such as salinity, nutritional status, acidity, water depth and possibly temperature. The ecological niche inhabited by different diatoms is determined through observation of modern types and the conditions in which they are found (*e.g.* Denys, 1991-2a & b). As diatoms live within the sampling environment (*i.e.* the tarn/lake) there are fewer problems associated with representativity of species than there are in pollen analysis. Elizabeth Haworth's work correlating live (at the time of collection) diatom populations with fossil diatoms from the same period produced positive results, with good agreement between the two datasets (Haworth, 1976, 1980). Although taphonomic factors may result in the destruction of fragile frustules, fossil diatom assemblages appear to provide a good indication of former species abundance without the need for mathematical transformation or modelling. One significant problem encountered by diatomists concerns nomenclature; there are numerous authorities and diatom identification guides and a single diatom species may have several names, and in some cases might even be classified as more than one genus. Many types have been renamed in recent years and there have been workshops to clarify the typologies (*e.g.* Munro *et al.*, 1990), but it is frequently necessary to check the named authority and cross-reference this with the coded list of freshwater algae for the British Isles (Whitton *et al.*, 2003), wherein the current and former names of diatoms and the relevant authorities are recorded. For example, Thwaites {1848} called *Cyclotella krammeri, C. meneghiniana, C. ocellata* and *C. rossii* by the now disused name of '*Cyclotella kuetzingiana*' and a large number of species previously referred to as types of *Navicula* have been redistributed among other genuses (*e.g. Brachysira*, *Fallacia* and *Sellaphora*).

### 1.5.4.1. Disentangling diatom ecology

Certain diatoms are good indicators of specific, ecological conditions (for example, *Cyclostephanos dubius* is found in eutrophic environments) (Battarbee, 1986), but it can be difficult to assess the implications of a large and varied floral assemblage; typical counts of 4-500 diatoms might incorporate more than a hundred different species depending on the degree of biodiversity at a given site. As diatoms respond to numerous environmental factors, establishing the prevailing conditions involves looking at the flora in detail to identify the most likely habitat represented by the assemblage overall. This can be achieved using a technical guide to diatom ecology such as Denys (1991-2a & b), in which diatoms are given scores relating to their preferred habitats, considering each aspect of the habitat (*e.g.* trophic status, acidity and salinity) separately for each diatom. Alternatively, transfer functions can be used as a means of viewing changes within an assemblage as a whole. Modern analogues ('training sets') are studied to establish the prevalence of different species in various conditions, in order that these data can be used to estimate past conditions based on the fossil diatom flora (*e.g.* Birks *et al.*, 1990). Transfer functions look at a single aspect of the aquatic environment (*e.g.* total phosphorous (TP) levels) and estimate the nature of this based on the species present (*e.g.* Bennion, 1994; Bennion *et al.*, 1996; Bennion *et al.*, 2000; Rosén *et al.*, 2000). There are some problems with this approach; Sayer has shown that inferred phosphorous levels from transfer functions may disagree with those suggested by long-term records of aquatic plants (Sayer, 2001) and Bennion *et al.* (2005) found that TP estimates were less accurate when benthic (living on or near bottom sediments, as opposed to 'planktonic', living on or near the surface) taxa predominated, as these are insufficiently sensitive to changing nutrient status. The ecological conditions affecting the assemblage of diatoms within a lake are numerous and difficult to disentangle, and identifying the overriding factor in determining species distribution is not always possible. Similar to pollen modelling, diatom transfer functions are potentially a useful interpretive tool when faced with large, diverse assemblages, provided that the limitations of the method are recognised and the ecology of individual species is considered.

In terms of vegetation change and human impact, the most useful information to be gained from the diatom flora pertains to the nutrient status of waterbodies; eutrophication owing to increased levels of phosphorous is likely to indicate the input of organic matter from the catchment area (Bennion *et al.*, 2000). Organic matter might originate from a number of sources, such as manure or fertiliser on fields, fish-farming or a sewage outlet, all of which result from human activity in the catchment (*e.g.* Pennington, 1943; Round, 1961; Evans, 1970). Although eutrophication could occur naturally, where it can be shown to have occurred concomitantly with vegetation changes indicative of anthropogenic impact, we can be fairly confident that some form of landscape management was underway.

## 1.6. Previous palaeoecological work in Cumbria

The decision to focus this study on vegetation and land-use changes of the early historic period was based not only on the relative dearth of archaeological and documentary evidence relating to that time (Section 1.4.3), but also on the limited attention this period has so far received in terms of palaeoecological work. Although a substantial body of palynological and diatom-based research has been undertaken in the study area, the Dark Age record is rarely investigated or discussed in detail. A summary of the literature relating to pollen analysis in the Lake District and Cumbria follows. Diatom studies are covered subsequently in Section 1.6.2.

### 1.6.1. Palynological work in Cumbria: summary of previous studies

> '..most of the recorded ecological history [of the south-east Lake District]…from the Elm Decline onwards can be explained largely in terms of man's exploitation of the local environment.'
>
> (Oldfield, 1963: 39)

A large corpus of palynological data exists for Cumbria and the Lake District, charting vegetation change in a variety of locations from the Lateglacial period onwards (e.g. Pearsall & Pennington, 1947; Pennington, 1947, 1965, 1970, 1981, 1991; Walker, 1955, 1965; Smith, 1958, 1959; Oldfield, 1960, 1963, 1965, 1969, 1970; Franks & Pennington, 1961; Oldfield & Statham, 1963; Dickinson, 1973, 1975; Barber, 1981; Mackay & Tallis, 1994; Dumayne &

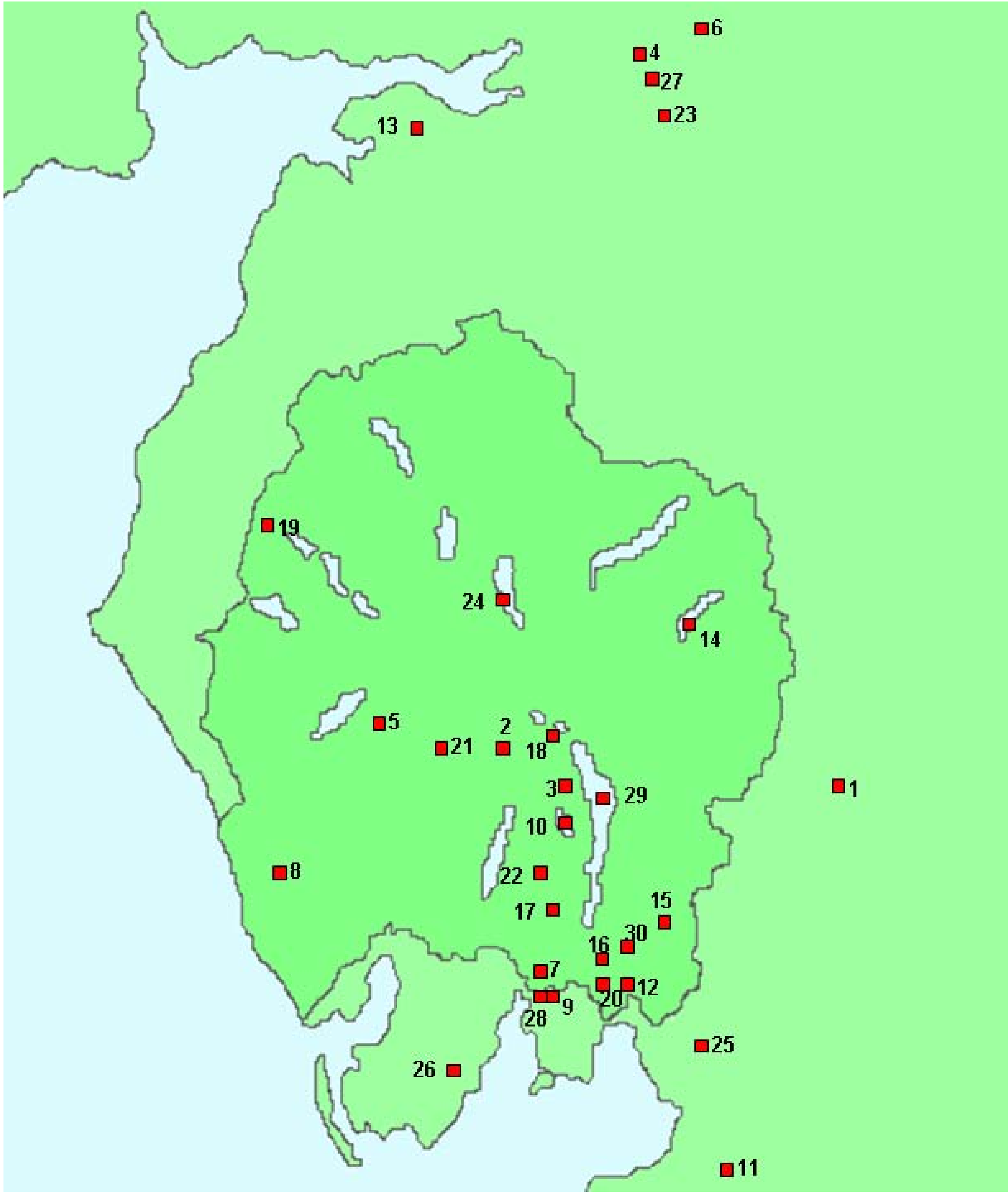
Barber, 1998; Dark, 1999; Wimble *et al.*, 2000; Cox *et al.*, 2001; Langdon *et al.*, 2004; Clark *et al.*, 2007; Chiverrell *et al.*, 2007, 2008; Yeloff *et al.*, 2007; Coombes *et al.*, 2009; Hatfield & Maher, 2009). Key developments such as the succession from open tundra through colonising birch woodland to mixed woodland (Figures 1.5a and b), are supposed to have been driven by natural succession or climatic changes, being discernible in most pollen assemblages representing the late Pleistocene and early to mid-Holocene. There are differences in the behaviour of individual species depending on terrain and underlying geology (such as variation in pine percentages at the time of the pine maximum (Oldfield, 1965)), but the general sequence of change at most sites enables them to be fitted to Godwin's zonation scheme (*e.g.* Godwin, 1934a & b,1956). For many early pollen diagrams Godwin's zones provide the only chronology, and in the study area the majority of profiles pre-dating 1970 lack radiocarbon dating evidence. Map 1.7 shows all sites referred to in this section.

Most early studies of the region did not attempt to describe changes beyond the elm decline and contain only low resolution pollen data for the last 2-3000 years. The local variability of records resulting from anthropogenic activity was considered a hindrance in the identification of broad, regional changes (*cf.* Walker, 1955). Although human interference makes interpretation of pollen data more difficult, the combination of historical, archaeological and palynological evidence is a powerful tool for interpretation. Frank Oldfield's seminal works in the south-east Lake District highlighted the potential for establishing links between historical events and palynological evidence for human impact, an important breakthrough in the interpretation of palaeoecological data (Oldfield, 1963, 1969). Following on from Winifred Pennington's tentative correlation of significant clearance phases with the Romano-British and Norse periods (Pearsall & Pennington, 1947), Oldfield pinpointed clear changes in the pollen records and identified the most likely events or periods to which these changes related (Table 1.7, Oldfield, 1963, 1969). When this approach was developed dating evidence in palynological studies was sparse (as seen in Table 1.9) and establishing approximate dates for the historical period was an important step forward. Radiocarbon dating was relatively uncommon and where available was rarely applied to the upper sections of cores. Where age measurements were obtained these were radiometric, limiting the precision of the technique on account of the need to sample over a large depth-range in order to obtain sufficient material for analysis; Barber (1981) recounts submitting wet samples of 130-200 g of peat for radiometric dating, and NERC guidelines state that the minimum required for this is 1g of carbon, while for AMS dating it is just 1mg (NERC radiocarbon laboratory website, accessed 07/05/2009).

Table 1.7. Correlation of vegetation change and historical events or periods in Northwest England (summarised from Oldfield, 1963: p37-8 & 1969: Table 1, p302).

| **Vegetation history** | **Historical event/phase** |
|---|---|
| Forest regeneration and little agricultural activity | Post-Roman period – retrogressive and unsettled (C5th -6th AD) |
| Subdued farming activity with probably some lowland clearance | Anglo-Saxon settlement (C6th-8th AD) – slight importance, settlement of a few lowland areas only |
| Oak wood clearance, probably on uplands and mainly for pasture | Norse colonisation (C9th-10th AD), much upland settlement, important locally |
| Brief forest regeneration phase with ash | Norman invasion and Domesday survey poorly recorded (C11th AD), harrying of the North laid the area waste? |
| Resumption of mainly pastoral farming at a rather subdued level | Establishment of Furness Abbey 1127, clearance and enclosure, mainly for pasture |
| Period of extensive pastoral farming | C14th -15th AD monastic sheep farming peak (Furness) |
| Extension of cleared land for both arable and pasture | *c* 1500 AD onwards, enclosure impinging on Abbey lands. Dissolution of Abbey 1537 – temporary setback in local farming followed by rise of yeoman farmers, clearance and enclosure. Division of Abbey lands, clearance of woodland, enclosure of commons (mixed farming). |
| Greatly increased cereal cultivation in an almost completely cleared and drained landscape, 19th century. Loss of mugwort (*Artemisia*) (caused by the advent of deep ploughing) | Gradual adoption of improved farming methods, crop rotation, deep ploughing, etc. Partial reclamation and drainage of mosses and marshes, extension of arable and pasture lands. Increase in oat cultivation. Artificial parklands and plantations, pine, etc. |

Although Oldfield's technique made a valuable contribution to palynology, fitting vegetation changes to a pre-determined framework simply reinforces preconceptions about different historical groups and periods (*cf*. Bradley, 1972). When applied in this manner, there is a danger that palynology will provide a 'landscape backdrop' that complies with assumptions about the past rather than acting as a tool for exploring and understanding history in its own right. There is also a risk that these interpretations become 'facts' without any independent dating evidence (discussed in the following section). Fortunately, AMS radiocarbon dates are now a common feature of pollen diagrams, enabling more period-specific questions to be asked of vegetation data and allowing us to query long-held assumptions about historical vegetation change.



Map 1.7: Pollen sampling sites in Cumbria and surrounding areas mentioned in Section 1.6.1.

Table 1.8: Pollen sampling sites shown on Map 1.7.

| | | | | | |
|---|---|---|---|---|---|
| 1 | Archer Moss | 11 | Fairsnape Fell | 21 | Red Tarn |
| 2 | Blea Tarn | 12 | Foulshaw Moss | 22 | Rusland Moss |
| 3 | Blelham Tarn | 13 | Glasson Moss | 23 | Talkin Tarn |
| 4 | Bolton Fell Moss | 14 | Hawes Water | 24 | Thirlmere |
| 5 | Burnmoor Tarn | 15 | Helsington Moss | 25 | Thrang Moss |
| 6 | Butterburn Flow | 16 | Helton Tarn | 26 | Urswick Tarn |
| 7 | Deer Dyke Moss | 17 | Huletter Moss | 27 | Walton Moss |
| 8 | Devoke Water | 18 | Loughrigg Tarn | 28 | White Moss |
| 9 | Ellerside Moss | 19 | Mockerkin Tarn | 29 | Windermere |
| 10 | Esthwaite Basin | 20 | Nichols Moss | 30 | Witherslack Hall |

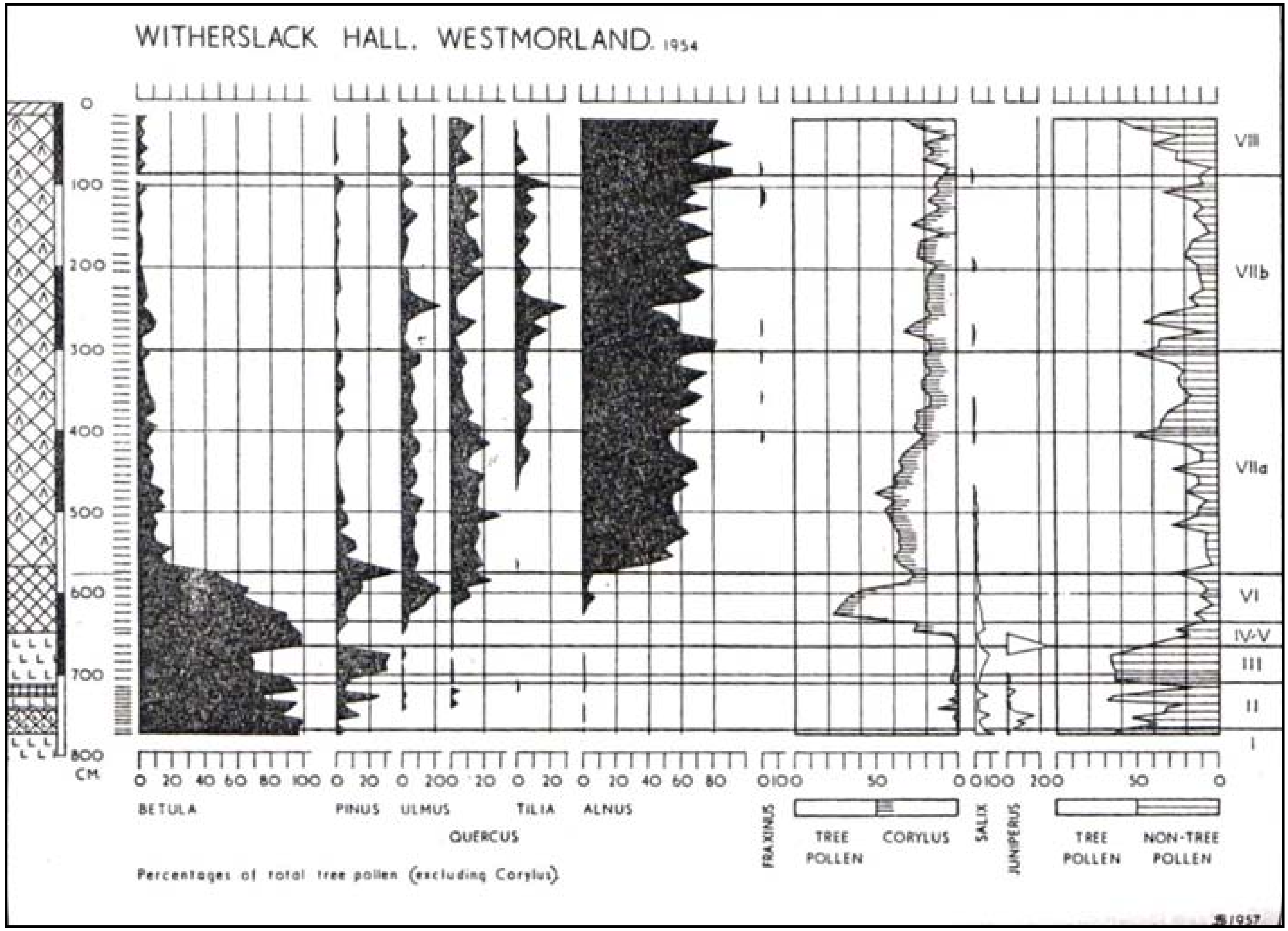



Figure 1.5(a) Witherslack Hall pollen percentage diagram showing arboreal taxa (Smith, 1958: 370).

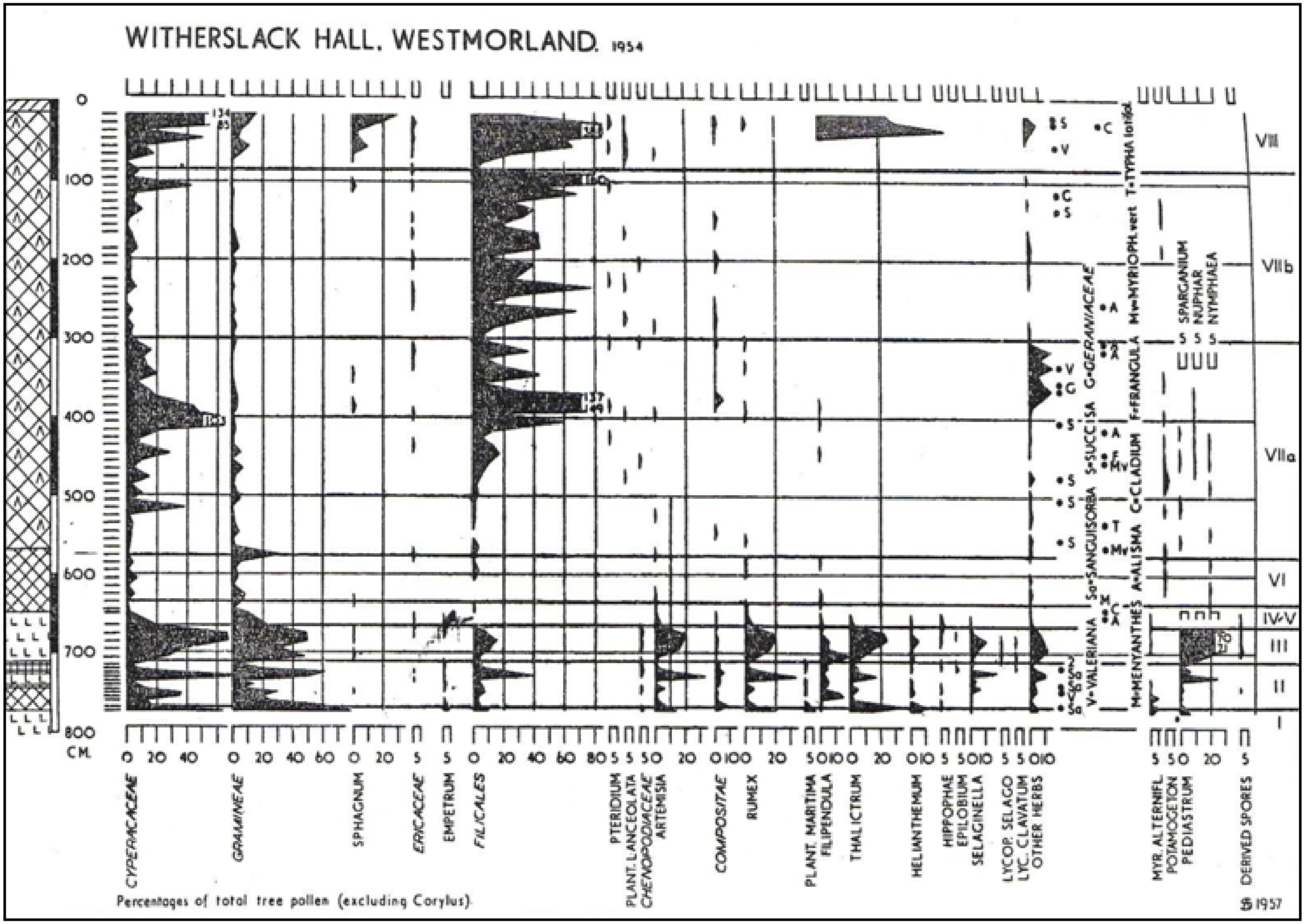



Figure 1.5(b) Witherslack Hall pollen percentage diagram showing non-arboreal taxa and spores (Smith, 1958: 371).

#### 1.6.1.1. Prehistoric and Romano-British human impact in Cumbria and the Lake District

The first significant clearances in the Lake District were originally thought to have occurred during the late Neolithic or early Bronze Age (*e.g.* Walker, 1955; Smith, 1959; Pennington, 1964, 1965), but radiocarbon dates on pollen profiles suggest a late Bronze to early Iron Age date in most areas (*cf.* Dark, 1999). Dickinson describes a 'significant' Bronze Age reduction in woodland at Rusland Moss (1973, 1975), while data from most sites indicate small-scale, short-term clearings with low levels of agri-pastoral indicators (*e.g.* Dumayne-Peaty & Barber, 1998; Wimble *et al.,* 2000; Langdon *et al.,* 2004; Yeloff *et al.,* 2007; Chiverrell, *et al.,* 2008). Larger scale deforestation is seen in the late Iron Age to early Romano-British period, accompanied by evidence for mixed farming in most places (where records are available). Although there is a general acceptance of large-scale Romano-British clearance for farming in this area, of the studies known to the author (Table 1.9) many that claim to show this event were published without radiocarbon dates. As explained in Section 1.1, traditionally the Romano-British period has been viewed as a time of expansion and progress in England, so in early studies of the region it was naturally assumed that the first large-scale woodland clearances would be of Roman date (*e.g.* Pearsall & Pennington, 1947; Smith, 1959). From the available data it seems that the decline in woodland associated with arable and pastoral farming began earlier, in the Iron Age, continuing through the Romano-British period in some areas, but not necessarily with increased intensity. Notable exceptions are seen at Butterburn Flow and Deer Dyke Moss, where a reduction or abandonment of agriculture occurs in the late Iron Age-to-early Romano-British period (Yeloff *et al.,* 2007 and Coombes *et al.*, 2009 respectively), perhaps reflecting disruption caused by the Roman invasion. During the mid- to late-Romano-British period there is a decline in agriculture at some sites, while others show renewed clearance. The impression gained is of localised differences and inconsistencies, suggesting that broad descriptions of change across the region are not possible once human interference becomes a significant determinant of vegetation development. This premise was noted by Pennington (1964), who highlighted the variability in palynological records and sedimentation rates in tarns, accrediting this to human activity in the catchment areas of the sites. The lack of consistency in pollen records across the study area continues throughout the early medieval and later periods, indicating that small-scale vegetation studies, based on pollen from small lakes or bogs (see Section 1.5.1.1), are likely to be more informative than regional analyses in this area.

Table 1.9. Summary of work addressing 1st Millennium AD vegetation change in the Lake District and surrounding areas. Grey rows are those where there are no radiocarbon dates.

| **Period** | **Author(s) & date** | **Location/site(s)** | **Radiocarbon dates (most relevant)** | **Summary (sections in bold indicate problems with dating/interpretation)** |
|---|---|---|---|---|
| **Late Iron Age/early Romano-British** | Pennington, 1965 & 1981 | Blelham Tarn | 120 BC<br>AD 542<br>(date ranges not stated) | Temporary clearance, late Iron Age (interpreted as Neolithic/Bronze Age in Pennington, 1965) followed by woodland regeneration |
| | Barber, 1981 | Bolton Fell Moss | AD 90+/-60<br>AD 780+/-50<br>AD 765+/-60 | Significant clearance phase, pastoral indicators. Late-Roman woodland regeneration |
| | Dumayne-Peaty & Barber, 1998 | Walton Moss | 165 BC-AD 75<br>88 BC-AD 208 | Rapid woodland clearance – agriculture |
| | Wimble *et al.*, 2000 | Lyth Valley: Foulshaw Moss | 351BC- AD 60<br>170 BC-AD 127<br>AD 184-539<br>AD 241-539<br>(separate core)<br>393-5BC<br>AD 29-381<br>AD 34-391 | Extensive clearance, few arable indicators and cereals. Ends early to mid-Romano-British period with woodland regeneration |
| | Wimble *et al.*, 2000 | Lyth Valley: Helsington Moss | 158 BC-AD 228<br>AD 27-338 | Extensive clearance, few arable indicators and cereals. Ends early to mid-Romano-British period with woodland regeneration |
| | Wimble *et al.*, 2000 | Duddon Estuary: White Moss | (south)<br>167 BC-AD 130<br>AD 361-640<br>(north)<br>core 1:<br>360 BC-AD 46<br>AD 27-338<br>AD 90-420<br>core 2:<br>45 BC-AD 69<br>AD 260-597 | Extensive clearance, few arable indicators and cereals. Ends late Iron Age/ early Romano-British period with woodland regeneration |
| | Chiverrell *et al.*, 2008 | Howgill Fells: Archer Moss | AD 412+/-25 | Substantial clearances<br>**Low resolution pollen data** |

| Period | Author(s) & date | Location/site(s) | Radiocarbon dates (most relevant) | Summary |
|---|---|---|---|---|
| **Roman invasion?** | Dumayne-Peaty & Barber, 1998 | Walton Moss | 165 BC-AD 75<br>88 BC-AD 208 | Brief hiatus in agriculture |
| **Romano-British ('Brigantian')** | Pearsall & Pennington, 1947 | Lake District (general),Windermere | NONE | Clearance event<br>**No dating evidence** |
| | Smith, 1959 | Lonsdale Mosses: Foulshaw Moss, Nichols Moss, Helsington Moss | NONE | Agricultural clearance<br>**No dating evidence** |
| **Romano-British ('Brigantian')** | Pennington, 1965, 1970 | Lake District (general): Mockerkin Tarn, Blea Tarn, Red Tarn, Burnmoor Tarn | NONE for most sites, Burnmoor Tarn:<br>AD 390+/- 130 | First major clearances: upland oak clearance<br>**Date based on distribution of clearance relative to UNDATED archaeological remains** |
| | Pennington, 1970 | Devoke Water | AD 200+/-130 to<br>AD 580+/- 190 | Permanent clearance, agriculture, cereal pollen<br>**Dates – could run into post-Roman/early Anglo-Saxon period** |
| | Dumayne-Peaty & Barber, 1998 | Bolton Fell Moss | AD 4-332<br>AD 690-980 | Small gradual clearance |
| | Yeloff *et al.*., 2007 | Butterburn Flow | AD 55-125<br>AD 200-270<br>AD 635-725 | Abandonment of agriculture |
| | Coombes *et al.*, 2009 | Deer Dyke Moss | AD 135-430<br>AD 545-650 | Decline in agriculture |
| **Late Romano-British/post-Roman** | Dickinson, 1975 | Rusland Moss | 13+/-50 BC<br>AD 589+/-55 | Clearance and cereal cultivation |
| | Mackay & Tallis, 1994 | Fairsnape Fell (Forest of Bowland) | 94 BC- AD 22<br>AD 233-382<br>AD 409-536 | Arable and grazing indicators. Renewed clearance late Romano-British and into post-Roman period? |

| Period | Author(s) & date | Location/site(s) | Radiocarbon dates (most relevant) | Summary (sections in bold indicate problems with dating/interpretation) |
|---|---|---|---|---|
| Post-Roman | Oldfield, 1963, 1969 | Hawes Water, Thrang Moss, Urswick Tarn, Ellerside Moss, Helton Tarn, Witherslack Hall, Helsington Moss, Nichols Moss and Foulshaw Moss | NONE EXCEPT AD 436+/-100 at Helsington Moss | Forest regeneration, little agriculture **No relevant dates for most profiles, quite low resolution** |
| | Yeloff *et al.*, 2007 | Butterburn Flow | AD 200-270 AD 635-725 | Agriculture – low levels, but cereals present |
| | Chiverrell *et al.*, 2008 | Howgill Fells: Archer Moss | AD 412+/-25 | Woodland regeneration **Low resolution pollen data** |
| | Coombes *et al.*, 2009 | Deer Dyke Moss | AD 545-650 | Continued decline in agriculture - brief pastoral clearance *c*AD 500 |
| | Coombes *et al.*, 2009 | Huletter Moss | AD 560-670 AD 655-860 | Heavily wooded – alder (carr on bog?), hazel, oak, birch, elm. Low level pastoral clearances |
| Early Dark Ages | Pearsall & Pennington, 1947 | Lake District (general),Windermere | NONE | Woodland regeneration **No dating evidence** |
| | Dickinson, 1975 | Rusland Moss | AD 589+/-55 | Woodland regeneration |
| Dark Ages (post Roman/Anglo-Saxon/Norse) | Barber, 1981 | Bolton Fell Moss | AD 90+/-60 AD 780+/-50 AD 765+/-60 AD 1030+/-70 | Gradual post-Roman woodland regeneration, subdued agricultural activity until approx. AD 1000 when cereal curves become continuous and grass and plantain increase |
| | Dumayne-Peaty & Barber, 1998 | Walton Moss | 165 BC-AD 75 AD 1659-1955 | Woodland regeneration, subdued agriculture, some cannabis **Substantial gap in radiocarbon dates – problematic if rates of accumulation changed** |
| | Wimble *et al.*, 2000 | Lyth Valley: Foulshaw Moss | AD 184-539 AD 241-539 AD 432-690 (separate core) AD 34-391 | Clearance event **Date undefined - no dates beyond the 5-7th centuries AD** |

| Period | Author(s) & date | Location/site(s) | Radiocarbon dates (most relevant) | Summary (sections in bold indicate problems with dating/interpretation) |
|---|---|---|---|---|
| **Dark Ages (post Roman/Anglo -Saxon/Norse)** | Wimble *et al.*, 2000 | Duddon Estuary (White Moss) | south)<br>AD 361-640<br>AD 693-1018<br>(north)<br>core 1:<br>AD 90-420<br>AD 1212-1393<br>core 2:<br>AD 260-597<br>AD 1034-1289 | Pastoral clearances - lack of agricultural indicators<br>**Unclear whether Anglian or Gaelic-Norse from dates available. Interpretation is Norse, but is based on Pennington and Dickinson's undated diagrams (1965, 1970 &1975)** |
| | Cox *et al.*, 2001 | Glasson Moss, Solway Estuary | AD 1050-1290 | Hemp retting on site<br>**Low resolution pollen data, not many dates. Period interpretation based on Dumayne, 1992** |
| | Langdon *et al.*, 2004 | Talkin Tarn | AD 340-600<br>AD 260-530 | Agri-pastoral indicators – mixed farming until approx. AD 1000 |
| **Dark Ages – Anglo-Saxon** | Oldfield, 1963, 1969 | Hawes Water, Thrang Moss, Urswick Tarn, Ellerside Moss, Helton Tarn, Witherslack Hall, Helsington Moss, Nichols Moss and Foulshaw Moss | NONE EXCEPT AD 436+/-100 at Helsington Moss | Subdued farming activity, limited lowland clearance<br><br>**No relevant dates for most profiles, low resolution pollen data** |
| | Mackay & Tallis, 1994 | Fairsnape Fell (Forest of Bowland) | AD 409-536<br>AD 1164-1261 | Woodland regeneration, decline in agriculture, but still happening – cereals present |
| | Yeloff *et al.*, 2007 | Butterburn Flow | AD 635-725<br>Problematic beyond this – series of reversals | Increase in agriculture/clearance of oak and hazel later C8th AD |
| | Coombes *et al.*, 2009 | Huletter Moss | AD 655-860<br>AD 775-995 | Marked clearance – agricultural and pastoral, cannabis and cereals. Alder and oak clearance |
| **Dark Ages – early Norse** | Coombes *et al.*, 2009 | Deer Dyke Moss | AD 710-1015<br>AD 890-1120 | Marked clearance – agricultural and pastoral |

| Period | Author(s) & date | Location/site(s) | Radiocarbon dates (most relevant) | Summary |
|---|---|---|---|---|
| **Dark Ages - Norse** | Pearsall & Pennington, 1947 | Lake District (general),Windermere | NONE | Valley alder clearances<br><br>**No dating evidence** |
| | Franks & Pennington, 1961 | Esthwaite Basin | NONE | Substantial clearance phase<br><br>**No dating evidence** |
| | Oldfield, 1963, 1969 | Hawes Water, Thrang Moss, Urswick Tarn, Ellerside Moss, Helton Tarn, Witherslack Hall, Helsington Moss, Nichols Moss and Foulshaw Moss | NONE | Upland oak woodland clearance, pastoral farming<br><br>**No dating evidence relevant to period, low resolution pollen data** |
| | Pennington, 1965, 1970 | Lake District (general): Loughrigg Tarn, [Blelham Tarn] Thirlmere | NONE | Valley alder clearances, pastoralism – sheep farming<br><br>**Date based on Scandinavian place-name evidence** |
| | Pennington, 1965 & 1981 | Blelham Tarn | 120 BC<br>AD 542<br>AD 1039<br>(date ranges not stated) | Large-scale pastoral clearance by 'Norse settlers' c 11th century AD |
| | Dickinson, 1975 | Rusland Moss | AD 589+/-55<br>AD 1145+/-50 | Agri-pastoral clearance? (interpreted as pastoral, but cereals present throughout)<br>**Not dated firmly** |
| | Mackay & Tallis, 1994 | Fairsnape Fell (Forest of Bowland) | AD 409-536<br>AD 1164-1261 | Clearance, but not many cultural indicators (small-scale farming?)<br><br>**Not clear in diagram – possibly based on others' work** (e.g. Oldfield & Statham, 1963; Oldfield, 1969) |
| | Yeloff *et al*., 2007 | Butterburn Flow | AD 635-725<br>Problematic beyond this – series of reversals | Abandonment of agriculture, woodland regeneration<br><br>**Dating reversals** |
| | Coombes *et al*., 2009 | Huletter Moss | AD 1030-1225<br>AD 890-1025<br>AD 1020-1160<br>AD 985-1155<br>AD 1035-1220 | Woodland regeneration then renewed clearance and mixed farming<br>**Date reversals**<br>Inwash causing 'old' dates? |

| Period | Author(s) & date | Location/site(s) | Radiocarbon dates (most relevant) | Summary (sections in bold indicate problems with dating/interpretation) |
|---|---|---|---|---|
| **Late Dark Ages (late Norse)** | Barber, 1981 | Bolton Fell Moss | AD 690-980<br>AD 980-1260 (2nd core)<br>AD 542-667<br>AD 1159-1280 | Clearance of birch and hazel – open ground indicators increase<br><br>**Perhaps too late to be Norse considering possible date range** |
| **Late Dark Ages - (Norse) to middle medieval period** | Chiverrell *et al.,* 2008 | Howgill Fells: Archer Moss | AD 1193+/- 24 | Major clearance<br><br>**Low resolution pollen data** |

#### 1.6.1.2. The Dark Age Cumbrian landscape

In the past, historical and archaeological interpretations led to the assumption that a decline in farming followed the Roman withdrawal; examination of the available evidence suggests that this was not always the case. Descriptions of vegetation change and land-use in Cumbria from the 5th-11th centuries AD are many and varied. Sources of evidence range from place-names to undated pollen diagrams, to the ‘preferred’ or habitual farming methods of certain groups. Oldfield suggests that there was forest regeneration following the Roman withdrawal, with limited clearance during the 5th-6th centuries AD and Anglo-Saxon farming on a small-scale. This was followed by clearance of oak in the uplands during the Norse period (Oldfield, 1963, 1969). Conversely, Pennington places the clearance of upland oak in the Romano-British period and valley alder clearances in the Viking age (Pennington, 1965, 1970). As shown in Table 1.9, at the time of publication there was little or no independent dating evidence to support either theory. It is generally assumed that Anglo-Saxon groups colonised fertile, lowland areas that met the requirements for agriculture, while Norse settlers cleared swathes of poorer quality land (particularly upland areas) for grazing (Pennington, 1970; Fell, 1973c), but the justification for this distinction is somewhat dubious. A third theory, presented in McCord and Thompson’s (1998) history of the Northern Counties, states that the uplands were cleared for pasture by Anglo-Saxons because of population increases during the 5th and 6th centuries AD; no palynological evidence is provided in support of this statement and it seems to be based on the ‘rational’ response to population growth (*i.e.* increasing the land available for livestock).

As outlined above, the long-established ideas about post-Roman vegetation change in Lakeland are often based on tenuous evidence. The assignation of extensive clearances to the Norse period is based largely on place-names, in addition to the assumption that Norse groups would require land for pasture because grazing was a significant element of their economy in Scandinavia (Pennington, 1965, 1970; Fell, 1973c). Many place-names in the Lake District contain the suffix 'thwaite' meaning 'clearing' (*e.g.* Seathwaite, Crosthwaite, Tilberthwaite) and Grizedale Forest is thought to have been utilised for pannage as *griss* means pig in Old Norse (Pearsall & Pennington, 1973). Although place-names are useful for identifying former land-use or ownership they can be misleading; Scandinavian elements remain in the Cumbrian dialect even now[18], and names that appear to be of Norse origin might have been assigned centuries after the Viking period (Fell, 1973c). Equally, the meaning of words may change or vary, as in the use of 'forest' to describe medieval hunting grounds as opposed to thick woodland.

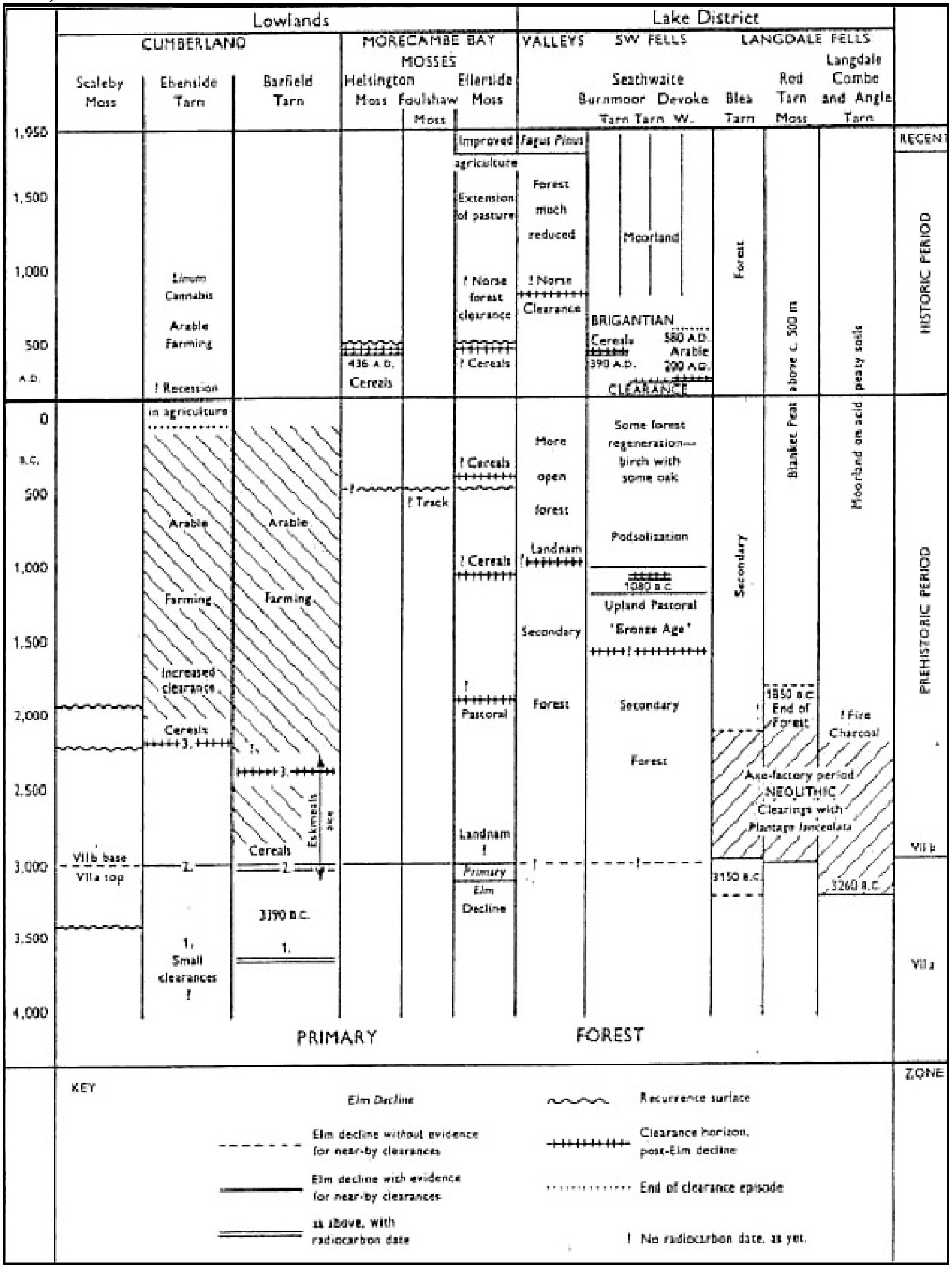
Figure 1.6 overleaf shows Pennington's summary of vegetation changes for the Lake District and neighbouring lowlands based on palynological evidence, limited radiocarbon dating and a degree of speculation. A glance at the figure confirms the limited nature of information available for the historical period; at the time (1970) the 'Brigantian' (Romano-British) phase was the only 'event' for which radiocarbon dates were available in the last 2000 years. Dated pollen cores from Cumbria are now more numerous, but coverage of the historical period remains sparse. As shown in Table 1.9, radiocarbon dating evidence is often limited and periods of interest are rarely bracketed securely. In addition, the resolution of pollen data is often too low to detect short-term changes in vegetation and land-use, particularly where the focus of the investigation is prehistoric vegetation development. However, several recent, more securely dated studies have focused on the last two millennia in detail, and these demonstrate a variety of post-Roman changes across the region (Table 1.9). Near Hadrian's Wall there is some evidence to support continuity of land-use (Langdon *et al.,* 2004; Yeloff *et al.,* 2007), but also abandonment of farming near military sites (Dumayne-Peaty & Barber, 1998; Dumayne, 1999), and in South Cumbria there is evidence for regeneration at some sites and clearance at others in the early medieval period, with deforestation occurring in the post-Roman, Anglo-Saxon and Norse Dark Ages at different locations (Wimble *et al.,* 2000; Coombes *et al.,* 2009). This variability across the county shows the unconformity of historical land-use within the region and highlights the need for localised pollen studies.

[18] In some parts of Cumbria sheep are still counted using the traditional Scandinavian system, wherein 1, 2, 3, 4, 5 is Yan, tan, tether, mether, pip.

Although the available information has certainly increased on account of recent investigations of the Romano-British and medieval periods (*e.g.* Dumayne-Peaty & Barber, 1998 and Coombes *et al.*, 2009 respectively), the Dark Ages remain neglected in terms of palynological work in the study area. This is particularly noticeable in the central Lake District, where to the author's knowledge, Pennington's invaluable works, which are largely undated and focus on prehistory, provide the only pollen data for this period (see Map 1.7 & Table 1.9).

In light of the limited data available and the seemingly variable nature of early historical land-use in Cumbria, pollen records from small lakes or tarns, which should 'sense' the vegetation within a relatively small area (Section 1.5.1), were thought to be most appropriate for establishing the nature of Dark Age land-use in this region. As explained in Section 1.5.4, pollen data are not the only indicators of vegetation change; the diatom flora of a lake may also reflect land-use patterns in the surrounding area. Diatom studies from the Lake District are discussed in the following section; although a large body of work exists, surprisingly this appears to provide no information relating specifically to the early medieval period.

Figure 1.6. Vegetation changes within the Lake District and neighbouring lowlands (after Pennington, 1970)



### 1.6.2. Diatom analysis in the Lake District

Numerous studies of diatoms in lakes and tarns have been carried out in this region (*e.g.* Pennington, 1943; Round, 1961; Evans, 1964, 1970; Haworth, 1969, 1976, 1980; Reynolds *et al.,* 1985; Bennion *et al.,* 2000; Tipping *et al.,* 2000; Clare *et al.,* 2001; Bennion *et al.,* 2005), but excluding investigations of twentieth century changes there is a dearth of work focusing on the last 2000 years. Many early works on diatoms in the Lake District are similar to palynological studies of the same era, charting broad changes from the Lateglacial period onwards. For the majority of these papers there is little or no independent dating evidence (Godwin's pollen zones were used in most cases (1934a & b)) and diatom counts are of too low a resolution to highlight subtle changes in the flora (*e.g.* Pennington, 1943; Round, 1961; Evans, 1970; Haworth, 1969). At several sites increases in *Asterionella* spp. evince eutrophication, which is thought to have occurred from the nineteenth century onwards as the result of inputs of sewage and fertiliser from nearby settlements (*e.g.* Windermere (Pennington, 1943), Esthwaite Water (Round, 1961) and Blelham Tarn (Evans, 1970)).

In addition to studies of long-term change there are several papers focusing on specific questions, such as the distribution of species (Evans, 1964), recent changes in water quality (Bennion *et al.,* 2000; Tipping *et al.,* 2000), rates of growth in living phytoplankton (Reynolds *et al.,* 1985) and the degree to which past populations are represented in the fossil record (Haworth, 1976, 1980). To the author's knowledge, analyses of diatom flora have not yet played a major role in identification of anthropogenic impact from the Romano-British to post medieval periods in Northwest England. An example of this type of study for the prehistoric period is Clare *et al.'s* (2001) investigation of the Mesolithic/Neolithic transition period, which combines archaeological, palynological, radiocarbon, sedimentary and diatom data to establish the nature of the landscape and environment at Barfield Tarn and Eskmeals. The type and degree of fragmentation of diatoms was used as a means of sourcing sediment; Barfield Tarn is not far inland and the presence of marine/brackish diatoms could indicate marine transgression. Although some of the above-mentioned studies almost certainly include diatom data pertaining to the early medieval period, the lack of a secure chronology or closely spaced sampling for this period leaves a large gap in knowledge. Diatom analysis was therefore employed to complement the palynological work in this project, in order to investigate vegetation and land-use in early medieval Lakeland.

### 1.6.3. Summary and project aims

As demonstrated above there are problems of equifinality in the interpretation of most palaeoecological proxies for human impact. This does not invalidate the analysis of any given proxy, but highlights the need for using multiple environmental indicators to obtain as accurate as possible an interpretation of the former landscape. Where the pollen, diatom and sediment data all point to human interference it is highly likely that people have been active in the area at that time. Although it may not be possible to determine the nature of this activity through the use of one proxy alone, where data from several are combined for the same time period it might be possible to limit the range of plausible interpretations. The application of modelling and simulation programs is also useful in this respect, enabling us to envisage and test a large number of possible scenarios and helping to mitigate the biases caused by differential representation of species in the palaeoecological record.

Archaeological and environmental data relating to the post-Romano-British period in the Lake District and surrounding areas are sparse. Many of the existing theories about the nature of the early medieval landscape are based on scant evidence and somewhat outdated preconceptions about the peoples inhabiting the area at the time. In recognition of changing archaeological and historical opinion concerning the Dark Ages it is necessary to reassess the interpretation of pollen data for the early historical period, re-evaluating post-Roman landscape development and environmental change in relation to the lives of the people that inhabited the area. Analysis of pollen and diatom data from six sites in the study area has been carried out in an attempt to improve understanding of this period, with the aim of answering the question of whether the Dark Ages really were 'dark', meaning retrogressive in this context. If the Roman withdrawal from Britain led to the collapse of trade and authority, followed by the arrival of barbaric invaders and a deadly plague as envisaged by writers such as Gildas (*c* AD 540) and Bede (AD 731), the resulting chaos and depopulation should be reflected in the palaeoecological record, in the form of abandonment and deterioration of farmland (*i.e.* woodland regeneration and loss of anthropogenic indicators). If not, the validity of traditional assertions regarding the post-Roman decline must be questioned and the possibility of a less catastrophic course of events should be considered (*e.g.* Wood, 1981; Hodges, 1982; Pryor, 2005).

In summary, the aims and objectives of this project are:

- To establish the sequence of vegetation change in the central and southern Lake District during the early historical period, using pollen and diatom data from sediment cores collected from small lakes (tarns)

- To use simulation software (HUMPOL v3 (Bunting & Middleton, 2005)) to understand better the patterns of past vegetation that produced the pollen records, testing the validity of traditional palynological interpretations against simulated vegetation patterns

- To link changes in vegetation and the trophic status of tarns with historical periods and/or events

- To determine the extent to which anthropogenic activity contributed to the above-mentioned changes in vegetation and trophic status

- To determine the nature and extent of land management within the Lake District/Cumbria following the collapse of Roman control

Field and laboratory methodology are described in the following chapter. The parameters and settings used in the pollen simulation approaches employed are explained in Chapter 5 as the models are an interpretative tool rather than a method for empirical data collection.

# CHAPTER 2: METHODOLOGY

## 2.1. Site selection, preparation and field methods

Owing to time and financial constraints it was not always possible to visit sites in advance of coring. Careful preparation was therefore required to establish the suitability of study sites and minimize the risk of a wasted trip. As explained in the previous chapter, local differences in vegetation are thought to be best reflected in pollen assemblages from small, enclosed lakes and tarns without inflows; sites fitting this description were therefore targeted, particularly those in close proximity to archaeological remains (Chapter 3). It was also important to check the antiquity of sites and the history of activity in the area. Some tarns that looked promising on Ordnance Survey (OS) maps were absent from older records, while others were found to be artificial (e.g. Middlerigg Tarn (Nuttall & Nuttall, 1996) and Ponsonby Tarn (Oldfield *et al.*, 1999)). A range of sources was examined for each site, including modern and historical maps, aerial photographs, academic papers, websites, walking guides and Haworth *et al.*'s (2003) *Tarns of the Central Lake District.* Dr. Elizabeth Haworth was also consulted about the suitability of sites; she has worked in the area for many years and lives locally, possessing a great deal of knowledge relating to the region's lakes and tarns. In addition, Dr. Haworth kindly offered to visit some of the tarns in person prior to coring trips.

Tarns known or suspected to have been dredged or altered through damming or fish-farming were avoided, as were those known to dry out or become very shallow in summer, because of the increased risk of turbulence affecting the sediments in windy conditions (*cf.* Jacobson & Bradshaw, 1981; Reynolds *et al.*, 1994). Unnamed tarns for which no information could be found were also excluded as it could not be guaranteed that these were old enough to yield a 2000-year pollen record. Another difficulty with many of the sites considered was the lack of bathymetric information; it was not possible to determine a depth profile without travelling to the sites and in some cases it was unclear whether the water bodies were 'tarns' as opposed to bog pools or marshy areas[1].

Lakes were required to be reasonably accessible by car because the weight of the boat and coring apparatus meant it would have been impractical (and in some cases unsafe) to carry the equipment any great distance (*i.e.* in excess of 0.5 km). When study sites had been chosen, permission was sought from the relevant authorities (Natural England

[1] Considering improvements in the quality and quantity of maps and aerial photographs available online the initial search for sites could probably be carried out much more quickly now (2009) than at the start of the project (2005-6).

(formerly English Nature), the National Park Authority, the National Trust and private land owners).

### 2.1.1. Fieldwork methods

All available information about the morphology and bathymetry of the sites was consulted prior to coring. These data were used in conjunction with a fish-finder (an echo-sounder attached to the boat) to find the deepest point in the tarns, which is usually the point of greatest sediment accumulation on account of sediment focusing processes (Lehman, 1975; Blais & Kalff, 1995). The faster the rate of sediment accumulation, the better the time-depth resolution achievable through sampling the core. Where bathymetric information was not available, water depths were determined by carrying out transects and recording the depth (on the fish-finder) at regular intervals. At several of the study sites the deepest point was in excess of the maximum that could be cored using the available equipment; in this eventuality the deepest manageable point (up to 7.5 m) was cored.

Although tarns without inflows were sought, it proved difficult to find enough suitable sites within the study area and some tarns with small inflows were necessarily included (see Chapter 3). In this case coring was carried out as far from the inflows as possible within the central/deepest part of the lake. Sediment cores were collected using a modified Livingstone corer (Wright, 1967) from the anchored boat. The corer consists of a Livingstone piston system with a modified, carbon-stable plastic tube attached in place of the metal chamber. The tubes are detached from the corer immediately after coring and sealed. This facilitates easy transport and storage of intact cores and prevents cross-contamination of sediments when multiple cores are collected. Care was taken to preserve the sediment/water interface by pipetting off excess water and sealing the coring tube close to the sediment surface. Cores were kept as close to upright as was possible considering the available transport, and were left standing in cold storage (at less than 4˚C) to settle for at least a week prior to splitting them lengthways.

A peat monolith was taken from the bog adjoining BYT for comparison to the corresponding lake core. A monolith tin was hammered into the ground, dug out and transferred to a carbon-stable plastic container made for the purpose, then wrapped and sealed within airtight (carbon-stable) plastic bags.

### 2.2. Laboratory methods

The lake sediment cores were split in half along their length, so that one half of the core could be wrapped and put into cold storage immediately to conserve it for radiocarbon dating. The split cores and peat monolith were enveloped in carbon-stable plastic bags and sealed tightly to prevent air reaching the sediment and reduce the loss of moisture. They were then placed in the dark in cold storage (at less than 4°C) to inhibit growth of algae and mould. The cores were described using a simplified version of Troels-Smith's (1955) sediment classification system and sampled for loss on ignition (LOI), SCP (spheroidal carbonaceous particles), pollen and diatom analysis. The exposed surface of the core was cleaned and samples were taken from the centre, avoiding the sediment interface with the coring tube as this may be smeared or otherwise disturbed as the corer is forced through the sediment.

#### 2.2.1. Sediment description

Each core/monolith was cleaned back using a scalpel and the newly exposed sediment surface was examined for significant changes in appearance and physical characteristics of the sediment. According to the Troels-Smith system (1955) of description, where numbers are used to define particular characteristics, a score of zero means a quality is absent (*e.g.* zero elasticity equals total plasticity, zero dryness means the sediment is extremely wet/saturated) and four signals the maximum presence of the quality or component (*e.g.* fully elastic or completely desiccated, to use the previous examples). Scores of this nature were recorded for attributes one to five, eight and nine, listed below. Attributes recorded for sediment description (after Troels-Smith, 1955 and Birks, 1968):

1) Darkness (*nigror*)
2) Degree of stratification (*stratificatio*)
3) Elasticity (*elasticitas*)
4) Degree of dryness (*siccitas*)
5) Calcareousness
6) Colour (defined using a Munsell soil chart)
7) Structure (*structura*) (*e.g.* homogeneous, fibrous, blocky, granular)
8) Sharpness of the lower boundary between sediment types/layers (*limes*)
9) Humicity (*humositas*)
10) Composition

For *limes* (8) the scores relate to specific depths over which the transition from one sediment unit to another occurs, as follows:

lim. 0 – - – boundary zone 10 mm or more

lim. 1 – diffusas – boundary zone 2 - 10 mm

lim. 2 – conspicuus – boundary zone 1 - 2 mm

lim. 3 – manifestus – boundary zone 0.5 - 1 mm

lim. 4 – acutus – boundary zone less than 0.5 mm

Samples of each identifiable sediment unit/layer were taken to test elasticity, colour and structure and small samples were added to hydrochloric acid to determine whether or not sediments were calcareous. Humicity was not recorded for lake sediments, but was estimated for samples from the BYB monolith by examination of the peat and through observation on addition to 10% potassium hydroxide (KOH).

The numbers assigned to many of the attributes above are clearly subjective, so could not easily be compared with those produced by other authors. Although basic sediment descriptions were carried out prior to sampling for SCPs, LOI, pollen and diatoms, full descriptions were not completed until all of the sediment cores had been collected; this allowed for comparison between sites and should ensure consistency in the classification of highly subjective attributes.

Composition was estimated based on the texture and visible components of the sediment samples. In the Troels-Smith classification the most important components of the sediment/peat are given numbers ranging from one to four; one indicates that a component constitutes a quarter of the sediment (approximately) and four means that the whole of the sample, excluding rare components, is composed of that material. Rare components (*i.e.* constituting significantly less than a quarter of the sample) are denoted by a + to denote presence or ++ where they are more prevalent.[2] The types of material identified in cores collected for this project are shown in Table 2.1.

[2] For example, the description $Ld^4$2 As2 Dg++ Ag+ indicates a composition of approximately 50% lake mud and 50% clay, with a small proportion of silt particles and notably more (though still very few)small herbaceous/woody fragments.

Table 2.1 Sediment components (after Troels-Smith, 1955)

| Code | Component type | Definition |
|---|---|---|
| As | *Argilla steatoides* | Clay – minerogenic particles measuring less than 0.002 mm |
| Ag | *Argilla granosa* | Silt – minerogenic particles measuring 0.002-0.06 mm |
| Ga | *Grana arenosa* | Sand – minerogenic particles measuring 0.06-0.6 mm |
| Dg | *Detritus granosus* | Small woody and herbaceous fragments together with unidentifiable fossils or fragments of these, measuring greater than 0.1 mm and less than 2 mm in length |
| Dh | *Detritus herbosus* | Herbaceous plant fragments greater than 2 mm in length |
| Dl | *Detritus lignosus* | Woody fragments greater than 2 mm in length |
| Ld[4] (Lh) | *Limus humosus* | Similar to Sh, but refers to lake mud rather than humified peat. Homogeneous deposit, humous substance, fragments less than 0.1 mm in length. Mud/marl, fragments of plants, animals and decomposed organics. |
| Sh | *Substantia humosa* | Humous substance – completely disintegrated or decomposed organic substances/humic acids. Black and structureless (*i.e*. fully humified peat) |
| Tb | *Turfa bryophytica* | Peat composed of moss, with macroscopic structure (not fully humified, may be fresh/unhumified) |
| Th | *Turfa herbacea* | Peat composed of roots, rhizomes and stems of herbaceous plants |
| Tl | *Turfa lignosa* | Peat composed of/containing woody roots, stumps, branches, etc., of trees, shrubs and ericaceous taxa. |

### 2.2.2. Loss on ignition (LOI)

The cores were sub-sampled at 4 cm intervals[3] for LOI. Where sufficient sediment was available (excluding material intended for pollen or diatom analysis) a minimum of 4 g of wet sediment was used. The wet samples were placed in clean crucibles of known mass, weighed to determine the wet sediment mass, dried at 105°C overnight in an oven (for approximately 16 hours), and weighed again. They were then placed in a furnace at 550°C for 3 hours, reweighed after cooling in a desiccator, and heated for 2 hours at 950°C before weighing a final time. The masses, times and temperatures used here follow the protocol

[3] Loughrigg Tarn was sampled at 2 cm resolution (this was the first site cored) but this was found to add little to the results and used too much of the available sediment.

advocated by Heiri *et al.* (2001), who demonstrated that these are optimal for providing repeatable results. Experimental work has shown that there is a negligible change in mass when these burn-times are exceeded (Heiri *et al.*, 2001). Loss on ignition at each temperature was calculated as a percentage of the dry mass.

It is generally accepted that the material lost at 550°C is chiefly organic carbon, while sediment destroyed in the higher temperature burn consists of carbonates. However, Santisteban *et al.* (2004) showed this distinction to be too simplistic; they concluded that although LOI is a good *qualitative* indicator of overall carbon content, it is not an accurate means of determining the quantities of organic carbon or carbonates within sediments.

### 2.2.3. Spheroidal Carbonaceous Particle (SCP) extraction and counting

Wet samples with a minimum mass of 1 g were taken at regular intervals throughout the cores and processed by the method proposed by Rose (1990, 1994). The uppermost sections of the profiles were sampled at 4 cm resolution initially; subsequent samples were placed at 1-2 cm intervals where this was required to define the curves in more detail (to facilitate correlation with typical SCP profiles from elsewhere). The sediment was dried in clean ceramic crucibles at 105°C overnight and treated with nitric acid, hydrofluoric acid and hydrochloric acid as detailed in Rose (1994).

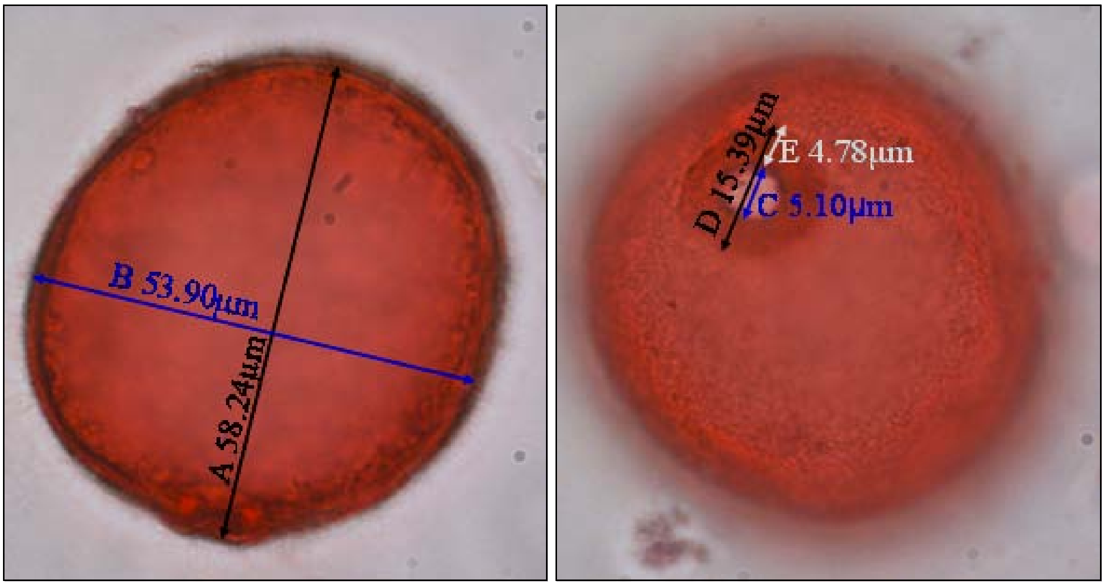
For the first few sediment samples from LGT all of the material produced was placed on a coverslip and scanned for SCPs at x400 magnification, as suggested by Rose (1994). This was found to be very time-consuming (one slide took almost two days to count and contained 862 SCPs) and when compared to the result obtained from counting a small amount of the material in the vial (weighing the vial before and after making up a slide to determine the percentage of material scanned), it was found that the improvement in accuracy achieved by counting the entire sample did not justify the extra time required. The quicker method was therefore adopted for all subsequent samples.

### 2.2.4. Pollen extraction and counting

Cores were sampled at regular intervals for pollen analysis to produce a skeleton diagram and subsequently at 2 cm resolution for the most promising cores. Samples were processed by standard procedures of potassium hydroxide digestion, microsieving (180 μm and 10 μm meshes to remove the coarse and fine fractions respectively), treatment with hydrofluoric acid, acetolysis and washing in ethanol (Faegri & Iversen, 1989; Moore *et al.*, 1991). Samples were stained using safranin, dehydrated using tetrabutyl-alcohol and mounted in silicone fluid (viscosity MS 200/2000cs). *Lycopodium* marker spores (batch 483216, average of 18583 per tablet) were added to the samples prior to treatment to facilitate calculation of absolute pollen concentrations (Stockmarr, 1971).

Pollen was counted at x400 magnification on Nikon Eclipse E200 microscope. Grains that could not be identified easily at this magnification were examined at x1000 with oil immersion. A total of 300-400 land pollen was counted for each depth; this was decided upon following a discussion of initial results from LGT, which indicated that larger counts added little information owing to the lack of diversity in assemblages. In consideration of the potential importance of rare herbs and cereals as indicators of human impact, it was agreed that in the time available, more would be gained from scanning slides (at x200 magnification) for rare types than by increasing the pollen sum (*cf.* Edwards *et al.*, 1986). In order to quantify the types found during scanning, *Lycopodium* spores were counted; scanning continued until half of the number of *Lycopodium* found in the initial count for the sample was reached. Cereals, grazing indicators and ruderals were recorded during this process, as were any types not previously encountered in the sample. In addition, the number of new land pollen grains found in every 50 grains counted was recorded to establish the diversity of the assemblages; where more than two new types were encountered within what was intended to be the final 50 grains counted for a level, a further 50 were counted.

Poaceae grains measuring in excess of 30 μm in any dimension were examined at x1000 magnification and measured using a graticule, in order to determine whether they were likely to fall into the cereal types. The measurements taken were the longest length (A), the width (perpendicular to the longest axis) (B), the diameter of the pore opening (C), the diameter of the annulus (thickening around the pore) (D) and the thickness of the annulus (E) (Images 2.1 and 2.2). This approach to identification is based on Andersen (1979) and the author’s previous work on cereals in the Peak District, in which the existing methods of classifying cereals of different types (see Chapter 1) were scrutinised and evaluated (Forster, 2005).




Images 2.1 (left) and 2.2 (right): *Triticum* sp. (x1000 magnification) showing measurements recorded for cereals/large grasses in equatorial and polar views (A: largest grain diameter; B: diameter perpendicular to A; C: pore diameter; D: annulus diameter; E: annulus thickness).

Pollen was identified using the key in Moore *et al.* (1991) and the pollen reference collection in the University of Southampton Palaeoecology Laboratory (PLUS). Nomenclature follows Bennett (1994). Additional help with difficult identifications was provided by members of the PLUS research group.

### 2.2.5. Diatom extraction and counting

Diatoms were analysed at regular intervals throughout the cores from BFT, BLT, LGT and LLT. The diatoms were extracted by a simplified version of the standard method (Battarbee, 1986), developed by Professor Anthony Long (Rob Scaife, pers. comm.). Samples of 0.5 ml volume (determined by displacement) were placed in 12 ml polypropylene tubes with a 3-4 ml of Hydrogen peroxide. The samples were left in the fume cupboard for up to a week, during which time they were inverted daily to mix the material. When the liquid had changed to an off-white colour a small quantity was placed on a circular coverslip, diluted with a little distilled water and left in an undisturbed environment to settle for as long as necessary (usually one or two days depending on the temperature). When dry, the coverslip was mounted on a slide with toluene-based naphrax, which was evaporated on a hotplate in the fume cupboard.

There are several advantages to the method described compared with standard procedures that involve heating the samples to aid digestion. Firstly, smaller quantities of hydrogen peroxide and sediment can be used in this process; large samples were not required as diatoms were found to be abundant in all of the lake sediments analysed. As washing is not carried out, it is unnecessary to centrifuge the samples, which can cause longer diatoms to break up (making identification more difficult) and is likely to lead to disproportionate loss of lighter diatoms when the supernatant is poured away. Also, leaving the wet samples to dry naturally rather than heating them on a hotplate allows more of the diatoms to settle parallel to the slide. If samples are dried quickly, diatoms have a tendency to settle perpendicular to the slide and to clump together, making identification very difficult (UCL diatom preparation procedure (available online) last accessed 01/09/2008).

Approximately 400 diatoms were counted at each level, enabling a wide range of species to be encountered while being feasible with regard to time constraints. As with the pollen counts, the number of new types found every 50 diatoms was recorded and shown to level off substantially as the number counted increased. When a view was started it was always completed to avoid selective counting or over/under-representation of certain types, meaning that in densely packed slides the counts may be closer to 500 than 400 diatoms. Diatoms were counted in phase contrast, at x1000 magnification with oil immersion, on a Nikon Eclipse E200 microscope.

Identifications were based on photographic, illustrative and descriptive material received as part of a course undertaken at UCL, Barber and Haworth (1981), Hartley (1996), Krammer and Lange-Bertalot (1986-1991) and the EDDI (European Diatom Database) webpages (last accessed 15/07/2010). Additional help with difficult identifications was provided by Dr. Katherine Selby and Michelle Robinson.

### 2.2.6. Radiocarbon sampling

Owing to the paucity of identifiable plant material in the lake sediment cores (Chapter 4), small samples of organic sediment were sent for standard AMS (accelerator mass spectrometry) dating. The monolith from Burney bog yielded woody ericaceous material, which was cleaned with distilled water and checked for extraneous rootlets and fungal hyphae under a light microscope. Two AMS dates were obtained from Beta Analytic (for LGT), but the majority of the radiocarbon dates were provided by the Natural Environment Research Council (NERC) laboratory at East Kilbride, Scotland. Care was taken to avoid any contamination of the samples by contact with skin (nitrile gloves were worn at all times), paper or plastic. All items used for cleaning the sediment surface, sampling and storing the material (metal spatulas and small glass vials) were cleaned thoroughly with distilled water before use.

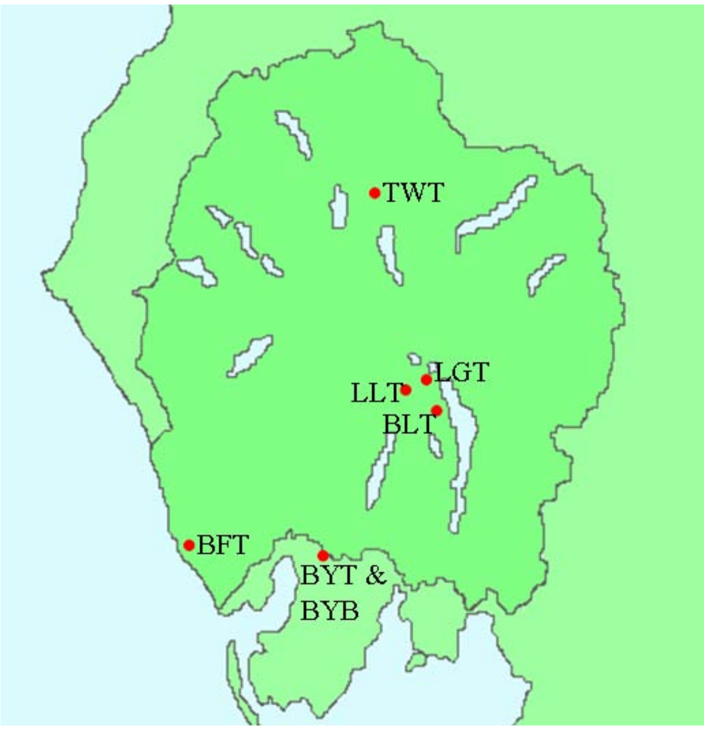
AMS dating samples were taken from the base of each core and at points where there were clear changes in the pollen/diatom assemblages (Table 2A, Appendix 2). It was hoped that further radiocarbon dates would be obtained to refine the chronology of the profiles, but because of problems with the first set of age measurements this has not been possible within the timescale of the project.

# CHAPTER 3: STUDY SITES

### 3.1. Selection of study sites

Selection of study sites was governed by accessibility, the proximity of archaeological features in the landscape and most importantly, their ability to produce pollen records representing the vegetation within a small radius of the site. As Table 3A (Appendix 3) shows, after an extensive search it was discovered that sites fitting all of the criteria were rare; most tarns have inflows and outflows and many are situated in locations that were inaccessible with the coring equipment. As a compromise, sites with small inflows have been included; the resulting increase in regional pollen input was considered preferable to difficulty of finding material suitable for radiocarbon dating in carbonate lakes, or the risk of coring sites of unknown antiquity that lacked background information.

The sites investigated for this study were Barfield Tarn (BFT), Blelham Tarn (BLT), Burney Tarn and Bog (BYT & BYB respectively), Little Langdale Tarn (LLT), Loughrigg Tarn (LGT) and Tewet Tarn (TWT) (Map 3.1). The first three sites to be cored (LGT, LLT and BLT) are clustered just south of the central Lake District, chosen with the aim of investigating differences within a relatively small area and re-examining the conclusions of Pennington's work. The remaining sites were selected in order to explore the contrast between the central area and the north (TWT) and south (BFT, BYT, BYB) of the region. In addition, tarns at varying altitude within contrasting landscapes were sought; these factors are likely to have been important in influencing the human history of the area, as reflected in both the archaeological and palaeoenvironmental remains.



Map 3.1: Location of study sites.

Soil maps are not freely available for the Lake District/Cumbria and conducting a soil survey of the area was beyond the remit of this project. Geological maps were used to determine the nature of the underlying rock (Map 1.3, Chapter 1), chiefly to confirm that the sites were not situated on carboniferous limestone because of the likely problems this would cause with radiocarbon dating. Previous studies have been carried out at several of the tarns, sometimes including work on pollen and diatoms in the sediments. As these studies have tended to concentrate on modern, very recent or prehistoric changes, they lack the resolution, time-depth or dating evidence required to answer the questions asked in the current project. These works are summarised below as they provide useful background information to the study sites. Smyly's (1958) survey of extant crustacean populations in the area included BFT, LGT, LLT and TWT, but did not reveal anything relevant to the current study and is not discussed further here.

Most of the study sites are situated in areas rich with archaeological remains (Tables 3.1-3.6); known archaeological sites, finds and monuments within 2 and 5 km radii of each tarn were sought and identified using English Heritage's GIS software (*WebGIS,* last accessed 10/12/2009*),* through which the NMR database can be queried. The program also provides access to records of 'ancient woodland' (as designated by English Heritage) and nineteenth and early twentieth century maps, which were useful for establishing the nature of post-industrial landscape changes. Although early medieval finds are rare, the profusion of archaeological sites from the prehistoric, Romano-British, medieval and later periods suggests that the region has been populated throughout human history. It is possible that the Lake District was depopulated to some extent in the post-Roman era, but as explained in Chapter 1, the absence of clearly identifiable early medieval sites in a region is not unusual and does not in itself prove that people had abandoned the location. Identifying the vegetation changes (or a lack thereof) occurring during this elusive period of history should aid an understanding of the degree to which people were exploiting the landscape and the nature of that exploitation, providing an insight to their lives that is otherwise absent.

### 3.2. Barfield Tarn (BFT)

Situated in gently undulating farmland to the south of Bootle (Images 3.1 and 3.2, overleaf), BFT is approximately 36000 $m^2$ in area and reaches a maximum depth of 7.8 m. Transects using a depth sounder revealed that the northern end of the tarn is shallow with an average depth of 0.7 m (Figure 3.1).

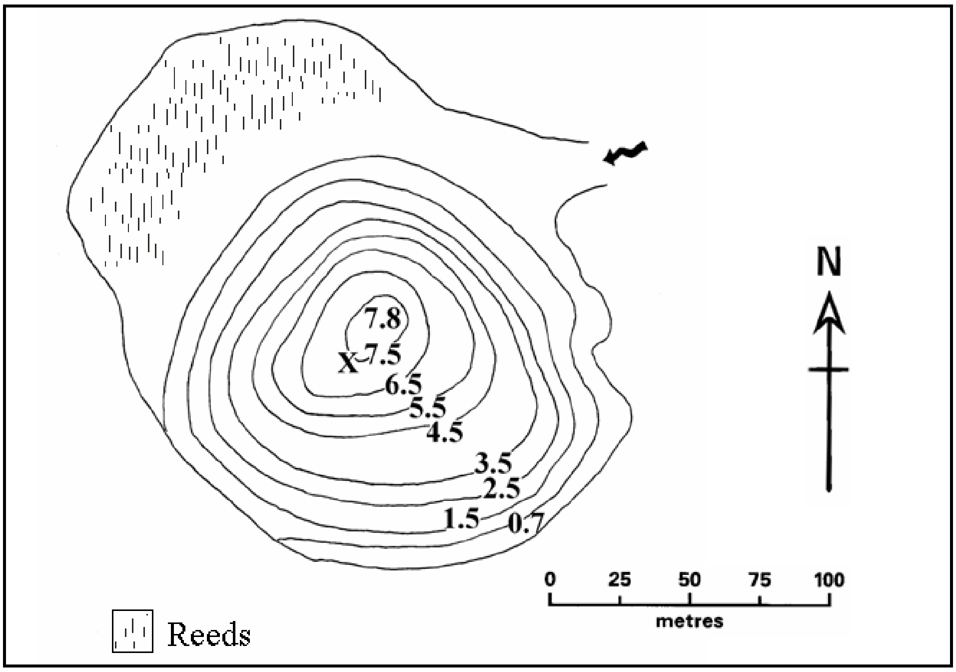


Figure 3.1: BFT bathymetry. All depths are in metres, X indicates the coring location.

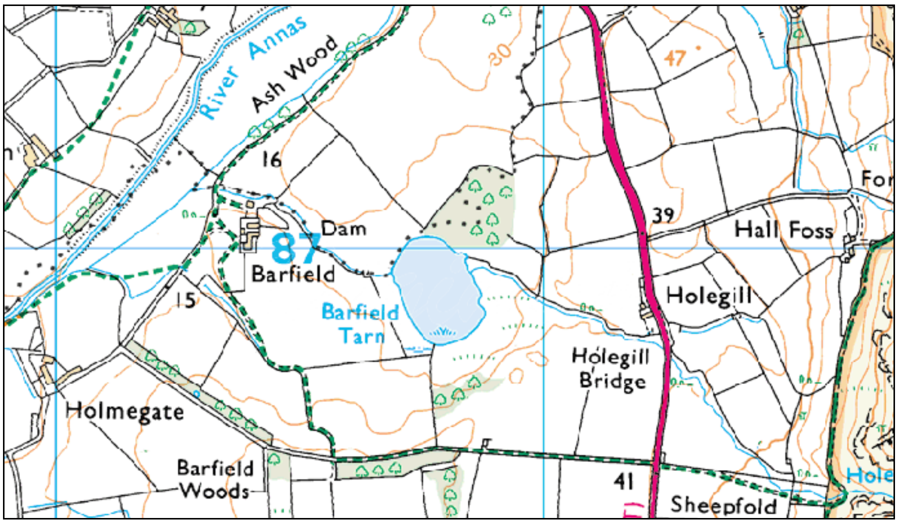
Image 3.1: BFT from the south

Image 3.2: Landscape to the west of BFT, Barfield Farm left of centre (photograph taken from the south of the tarn)

The main body of the tarn lies to the south and cores were taken here at a depth of 7.5 m (Figure 3.1). BFT lies at an altitude of 24 m OD and is only 2 km from the coast, contrasting with the higher altitude, inland study sites. The surrounding landscape consists of a patchwork of agricultural fields and pasture grazed by cattle and sheep, interspersed with small areas of woodland (Images 3.1, 3.2 & 3.3). Holegill Beck originates in the Furness Fells and flows into the eastern side of the tarn, running out to the west past Barfield Farm, to which the tarn belongs. Comparison of aerial photographs (Image 3.3), modern OS maps (Map 3.2) and nineteenth century maps (Map 3.3) reveals how little the landscape has changed in the past 150 years; field boundaries and the location of farm buildings, roads and woodland appear largely unaltered, perhaps indicating continuity of land-use.

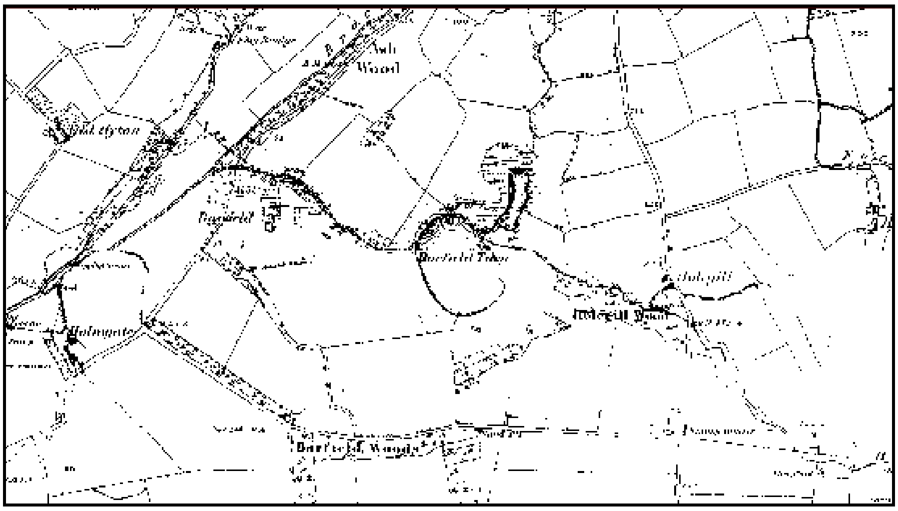
Previous palaeoecological work in the area has concentrated on the prehistoric period, principally the Mesolithic/Neolithic transition. Pennington's pollen diagram from BFT indicates a substantial woodland clearance at around 3000 BC, followed by a large-scale, long-term clearance event with associated cereal pollen dating to approximately 2200 BC; this date appears to have been derived through interpolation, assuming a constant rate of sedimentation between the radiocarbon date at 3390 +/-120 BC (Pennington, 1970). Concomitant with the clearance event there is an influx of clay to the tarn sediments, which suggests an increase in erosion within the catchment area owing to removal of the tree cover or disturbance through ploughing or trampling (Pennington, 1970; Pennington, 1981). There appear to be no published pollen counts above a depth of 300 cm, leaving a substantial gap in the vegetation history of the site. Clare *et al.* (2001) presented previously unpublished diatom data from depths of 40, 232 and 347 cm, but these are of limited value considering the wide spacing of the samples and the absence of any clear trends in species composition.

The area immediately around BFT is rich in archaeological remains (Table 3.1). Most finds and features date to the Bronze Age or earlier and with the exception of a Roman statuette found in Bootle, there are no recognisable, dated Romano-British or early medieval artefacts or monuments within 2 km of the site. However, there is substantial evidence for medieval and post-medieval occupation of the area and it seems likely that the settlement at Bootle was established some time before it was recorded in the Domesday Book (1086). Barfield Farm itself overlies earlier buildings and it is unknown how long the site has been occupied. The gentle, lowland terrain around the tarn is likely to have been attractive to farming communities in the past, particularly when compared with the mountainous land to the north. There is no evidence for ancient woodland in the surrounding area and the landscape is thought to have remained open following Neolithic clearances (Pennington, 1970).




Map 3.2: BFT, 2007 (each grid square = 1 km) (OS map produced in Digimap carto, 08/10/2007)

Image 3.3: Aerial photograph of BFT (from Getmappingplc, 08/10/2007)



Map 3.3: Excerpt from 1867 map of Cumberland,showing BFT (from old-maps.co.uk, 08/10/2007)

Table 3.1: Sites and finds within 2 km of BFT, as contained in the National Monuments Record (NMR), English Heritage (accessed via *Web*GIS, 15/03/2009)

| **NMR number** | **Period** | **Site/find description** |
|---|---|---|
| SD 08 NE6 | Prehistoric | Annaside Banks – flint scatter |
| SD 08 NE1 | Neolithic | Stone axe or hammer found at Sikebeck |
| SD 08 NE2 | Bronze Age | Annaside Stone Circle (destroyed) |
| SD 18 NW11 | Bronze Age | Stone circle |
| SD 18 NW12 | Bronze Age | Stone axe hammer |
| SD 18 NW5 | Bronze Age | Stone hammer |
| SD 18 NW6 | Bronze Age | Standing stones |
| SD 18 NW8 | Bronze Age | Large complex of earthworks, cairnfields, hut circles and field systems on Bootle Fell |
| SD 18 NW13 | Later prehistoric | Little Grassoms - field system, cairnfields and funerary cairns (Bootle Fell) |
| SD 18 NW7 | Later prehistoric [medieval] | Great Grassoms (Bootle Fell) - field system and funerary cairns |
| SD 18 NW14 | Romano-British | Votive Roman statuette |
| SD 18 NW1 | Medieval | Seaton/Seton Priory. Benedictine nunnery (remains) *c.*1190-1540. C16$^{th}$ house at same site. |
| SD 18 NW3 | Medieval | St Michael's Church – parts of the building date to the C12$^{th}$ |
| SD 18 NW7 | Medieval<br><br><br>[later prehistoric] | Great Grassoms (Bootle Fell) – remains of two dispersed settlements (stone farmhouses) and field systems. Enclosures suggest agriculture, but area is more suitable for pastoralism – mixed farming? |
| SD 18 NW18 | Medieval (or earlier) | Bootle – the town is listed in the Domesday survey of 1086 |
| SD 08 NE1 | Medieval/post-med | Ridge and furrow (including narrow ridge and furrow) |
| SD 18 NW10 | Medieval/post-med | Fishponds – Monk Foss |
| SD 18 NW20 | Medieval/post-med | Rectilinear enclosures, ditches and hollow way (aerial photographs) |
| SD 18 NW19 | ?Post-medieval | Possible remains of a water mill next to Barfield Farm on the beck running out from the tarn. Aerial photographs suggest a larger complex (now under the farm). There is a further ruined building at the site and mounds thought to represent a former orchard. |
| SD 18 NW23 | C18$^{th}$ | Bootle Chapel (1780+) – Countess of Huntingdon's chapel |
| LINEAR1349 | C19$^{th}$ | Whitehaven and Furness Junction railway, completed in 1850 |
| SD 18 NW23 | C19$^{th}$ | Bootle Union Workhouse (1856+) |
| SD 08 NE14 | C20$^{th}$ | Probable WW2 pillbox (aerial photograph) |
| SD 18 NW22 | C20$^{th}$ | WW2 pillbox |
| SD 08 NE15 | Unknown | Ditch and bank visible on aerial photograph |
| SD 08 NE3 | Unknown | U-shaped enclosure cropmarks |

### 3.3. Blelham Tarn (BLT)

BLT lies less than a kilometre to the west of Windermere, surrounded by gently sloping pastoral farmland and small patches of woodland (Image 3.4). Situated within a National Nature Reserve, the site is a SSSI (Site of Special Scientific Interest) and is flanked to the north by Blelham Bog. BLT is one of the lower altitude sites studied, lying at 50 m OD, and is also by far the largest of the tarns/lakes (approximately 160000 $m^2$). The surrounding ground is boggier and perhaps less amenable to farming than that around BFT and there are small hills to the south of the site. There are a few farms to the west and disused quarries to the north of the tarn (Brathay Quarries), in addition to substantial areas of coppice and woodland that are considered to be 'ancient' (Map 3.4). The pattern of land-use around the site appears to have altered little since AD 1850 (Image 3.5, Maps 3.5 & 3.6). However, in the *earlier* 1800s significant changes were underway in the surrounding landscape and at the site itself; in his study of Blelham Bog, Frank Oldfield notes that a plantation to the north of the bog ('Randy Pike', Map 3.4) is not shown on a map of 1818, but can be seen on OS maps by 1847, indicating that it was planted in the intervening period (Oldfield, 1970). Some of the fields in the area are thought to date to the 1830s and the level of the tarn was lowered around this time by artificial straightening of an outflow that feeds into Windermere (Oldfield, 1970). Increased grazing pressure within the catchment area during the 20$^{th}$ century is thought to have caused a rapid increase in soil erosion (Image 3.5), demonstrated by a dramatic acceleration of sediment accumulation within the tarn (Van der Post *et al.,* 1997).

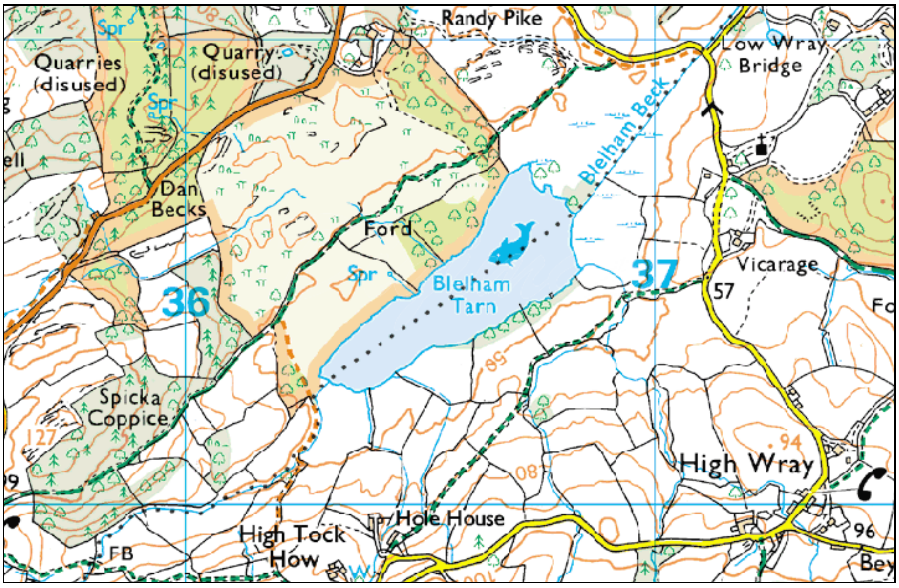
Image 3.4: BLT from the south (www.english-lakes.com, 09/10/2009)


Map 3.4: Ancient woodland in the vicinity of BLT, 1:25000 (created in English Heritage *Web*GIS, 05/07/2009). BLT is in the centre.

There are few archaeological remains close to the tarn (Table 3.2) and none confirmed as pre-dating the medieval period within a 2 km radius. There are, however, several towns and villages in the area known to date to at least medieval times (*e.g.* Hawkshead, Ambleside, Windermere) and the Roman sites at Hardknott Pass and Galava (Waterhead) demonstrate an earlier presence in the area (Shotter, 1989; Whyte, 1989). Hawkshead is thought to have Norse origins as the name is Scandinavian (*Hawkr's* shieling). The town was owned by Furness Abbey until the 12$^{th}$ century AD (Fell, 1973c).

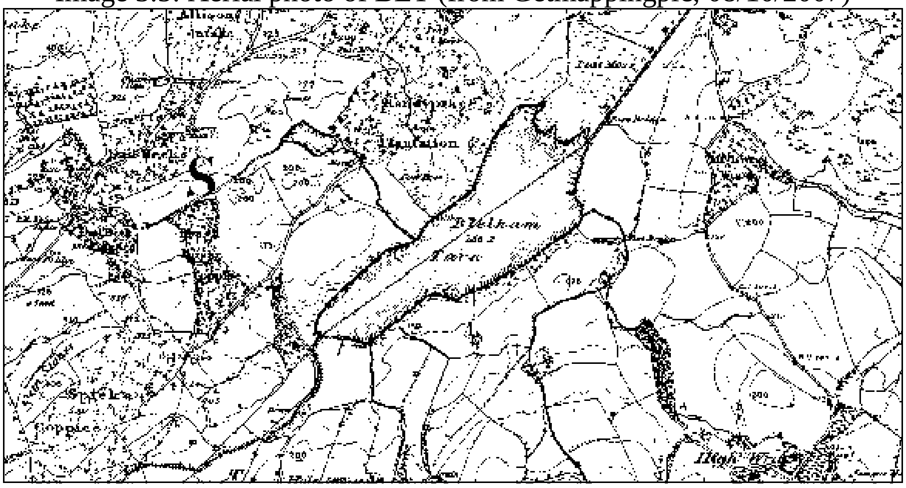
Table 3.2: Sites and finds within 2 km of BLT, as contained in the National Monuments Record (NMR), English Heritage (accessed via *Web*GIS, 15/03/2009)

| **NMR number** | **Period** | **Site/find description** |
|---|---|---|
| NY 30 SE26 | ?Medieval | Earthworks at Pull Beck, Skelwith – possibly remains of water mill |
| NY 30 SE23 | Post-med | Copper mine |
| SD 39 NE31 | Post-med | Pinstones Wood. Woodland contains remnants of bark peeler's hut and charcoal burning platforms. |
| NY 30 SE2 | Early to mid-C17$^{th}$ | Bloomery |
| SD 39 NE39 | C18$^{th}$ | Belmount – 'classical villa' overlooking Esthwaite Water (to the south) built by vicar of Hawkeshead, 1774. Bought by Beatrix Potter, 1937. |
| NY 30 SE49 | C19$^{th}$ | Wray Castle – house in the style of a castle (Gothic Revival), 1840 (additional information from Visit Cumbria website, 17/03/2009) |
| NY 30 SE19 | Unknown | Intermittent ditch of uncertain date – possibly old slate workings, but cuts off a promontory so may be defensive |
| NY 30 SE24 | Unknown | Well |
| NY 30 SE27 | Unknown | Platform – former building or charcoal burning platform? |
| SD 39 NE1 | Unknown | Quernstones |



Map 3.5: Excerpt from OS map showing BLT (each grid square = 1 km)
(OS map produced in Digimap carto, 08/10/2007)

Image 3.5: Aerial photo of BLT (from Getmappingplc, 08/10/2007)


Map 3.6: Excerpt from Lancashire and Furness map, 1850,
showing BLT (old-maps.co.uk, 08/10/2007)

In contrast to the other sites presented here, a great deal of research has been carried out on the sediments of Blelham Tarn, including analysis of pollen and diatoms, $^{14}C$, $^{137}Cs$ and $^{210}Pb$ dating and experimental work to investigate the carbon uptake of phytoplankton (Pennington, 1965, 1970, 1979, 1981; Pennington *et al.*, 1976; Bonny, 1976, 1978, 1980; Lund, 1979; Haworth, 1980; Reynolds *et al.,* 1985). Winifred Pennington's (1965) pollen data from BLT shows a distinctive episode of clearance at a depth of approximately 2 m in the lake sediments, originally thought to correspond to the Neolithic/Bronze Age, but seemingly reassigned to the late Iron Age in light of radiocarbon dating evidence (*e.g.* Pennington, 1981, Figure 6). Pennington found that this temporary clearance was followed by regeneration of oak and birch woodland, after which the next notable event was the conjectured 'Norse' pastoral clearance of approximately the 11$^{th}$ century AD, which she described as 'Viking landtakes' (Pennington, 1965). Scandinavian place-names are common in the vicinity of the tarn (*e.g.* Tock How and Low Wray); these might have been assigned in recent centuries (Fell, 1973c and see Section 1.5.2.2), but considering the relative proximity to the Thingmount at Little Langdale (*c* 7 km from BLT) (see Section 3.4) they are likely to reflect a Norse presence in the area (Pennington, 1965, 1981). Tree and shrub species are present in consistently high percentages throughout the profile, dominated by birch, oak, hazel and alder. Pennington concluded that the latter was a product of inwash, carried to the tarn by inflowing streams and therefore overrepresented in the sediment (Pennington, 1965, 1979). This is borne out by Anne Bonny's experiments at BLT, in which she investigated the sources of pollen deposited in the lake sediments (1976, 1978, 1980), concluding that in some cases up to 89% of the assemblage was derived from streamborne pollen (Bonny, 1976). Cereals, flax (*Linum* spp.) and hemp (*Cannabis sativa*) were found to occur from approximately the 15$^{th}$ century AD onwards, after which erosion rates increased substantially owing to disturbance of the catchment soils (*e.g.* ploughing) (Pennington, 1981).

The palynological and plant macrofossil work on Blelham Bog concentrated on the Lateglacial period and seems to conform to the typical vegetation succession for the area, so is not discussed further here (Pennington, 1970, 1977). Oldfield's work on the recent (*c* AD 1800 onwards) history of the bog incorporated pollen and plant macrofossil analysis, together with an assessment of maps and documentary records, in order to establish factors affecting development of the bog and its vegetation over the last two centuries (Oldfield, 1970). This research led to the conclusion that the reason for creating the nature reserve, which was the notion that the area represented a unique example of willow-woodland developing into *Sphagnum* bog, should be rejected on the basis of the evidence available (Oldfield, 1970).

One of the main reasons for selecting BLT for study was to determine whether closer sampling intervals and AMS radiocarbon dating (which requires less material than radiometric dating and is therefore more precise), could improve our understanding of the site's history over the last two millennia, particularly in relation to the phase of undifferentiated 'woodland regeneration' spanning the Romano-British and early medieval periods.  Considering the relatively large size of the tarn and the substantial input of streamborne pollen to the site (Bonny, 1976, 1978, 1980; Brown *et al.*, 2007), it was expected that the pollen assemblage from BLT would reflect larger-scale vegetation changes than, for example, LGT, providing an insight to wider vegetation patterns (*i.e.* acting as a 'regional' site as defined by Sugita, 2007a).

Elizabeth Haworth's study of the recent diatoms at BLT compares the fossil assemblage accumulated over 35 years with Lund's records of the live flora over this period (Lund, 1979; Haworth, 1980).  This work demonstrates that diatoms are well-represented in the fossil record.  In addition, experiments were carried out at the site to determine the uptake of carbon by phytoplankton (Reynolds *et al.*, 1985).  This involved the use of large enclosures (Lund tubes), within which were suspended bottles containing phytoplankton and carbon-14 ($^{14}C$).  Although the results of this study are irrelevant to the current project, the addition of $^{14}C$ to the site, albeit in sealed bottles, is potentially problematic in terms of radiocarbon dating.  This was unknown to the author when the site was selected for study[1] and if known would perhaps have led to its exclusion on account of the risk of $^{14}C$ contamination.

BLT reaches a maximum depth of 15 m; deeper than could be reached with the available coring equipment, for which reason cores were taken towards the northern, shallower end of the tarn at a depth of 6.5 m (Figure 3.2).  Email correspondence with Elizabeth Haworth suggests that the Lund tube experiments (Reynolds *et al.,* 1985) were not located at or near the coring site.  There are several small inflows to the tarn (Figure 3.2), which were avoided when selecting the coring site because of the high probability of increased disturbance and redeposition where these flow into the tarn.

[1] Blelham Tarn was not named in the title of Reynolds *et al.'s* paper, which consequently did not appear in internet searches, and Elizabeth Haworth did not initially mention this work when asked about the suitability of the site.  General searches for work on lakes in the area also failed to identify the paper as neither the Lake District nor Cumbria was mentioned in the title.

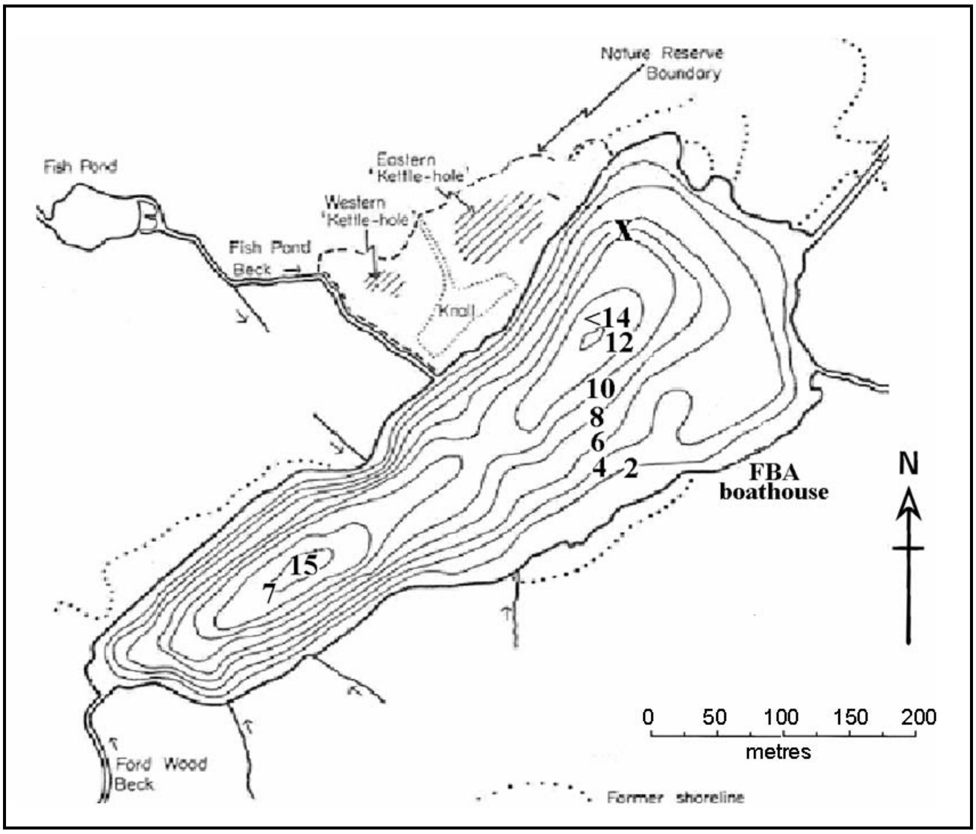



Figure 3.2: BLT bathymetry. All depths are in metres, X indicates the coring location (modified from Evans, 1970).

### 3.4. Burney Tarn (BYT)

BYT lies at an altitude of 150 m OD and appears to be in transition to a reed swamp/bog. Comparison of old maps and aerial photographs shows the tarn to have shrunk significantly over the last two centuries (Maps 3.7 & 3.8, Image 3.6), with its current size being approximately 10800 $m^2$. The tarn and neighbouring bog are situated close to the main road across Kirkby Moor and are surrounded by sheep pasture (Image 3.7). The area around the site is rich with archaeological remains (Table 3.3) including numerous Bronze Age monuments, a medieval dispersed settlement and areas of common ground that are likely to have been grazed in the past. There are also patches of woodland marked as 'ancient' (Map 3.9) that might have been utilised and managed historically, and the remains of quarries on the moors. The variety of features of different ages in the landscape and under the earth suggest long-term occupation of this area, in which case there should be significant evidence for human impact on the environment within the palaeoecological records.

The deepest part of the tarn was inaccessible with the equipment available, for which reason the 'lake' core was collected in a shallow part of the tarn that is hydrologically connected to the main body of water (Figure 3.3, Image 3.8). In addition, a monolith was taken from the adjoining peat bog (an SSSI); as this appears to have been part of the tarn in the past it was assumed firstly, that lake sediments would underlie the surface peat and secondly that this might provide a completer record than the short lake core. It was hoped that in addition to answering the key research questions of the project for this area, comparison of pollen, sediments and where present, diatoms in the core and corresponding monolith might help to clarify the process and background to the infilling of the tarn.

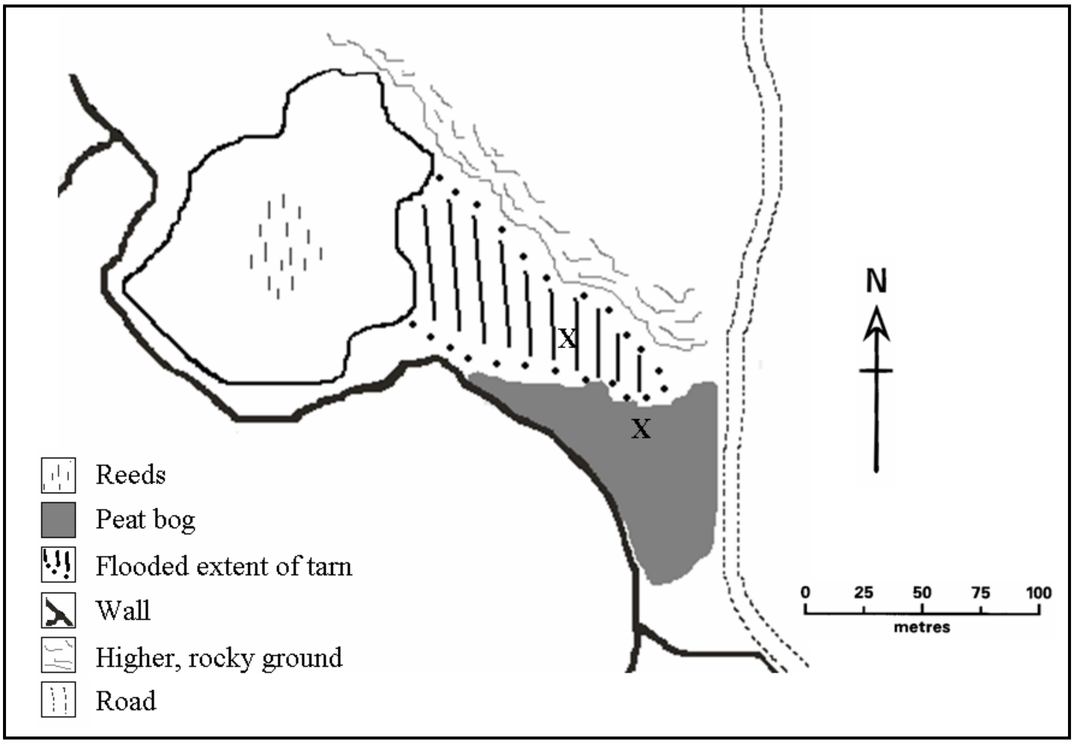
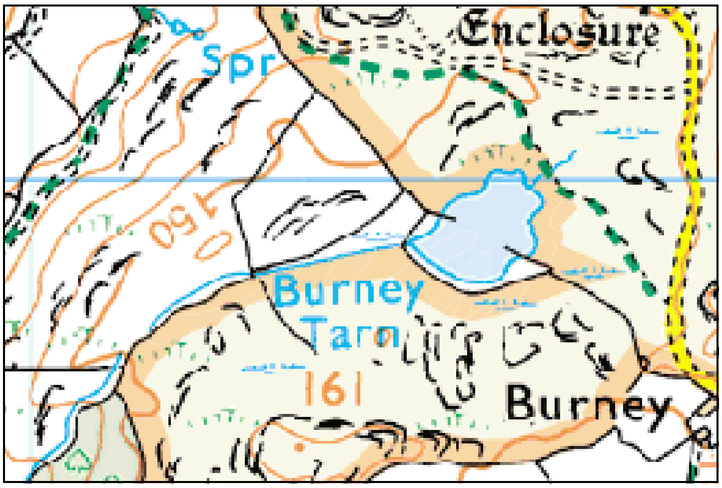
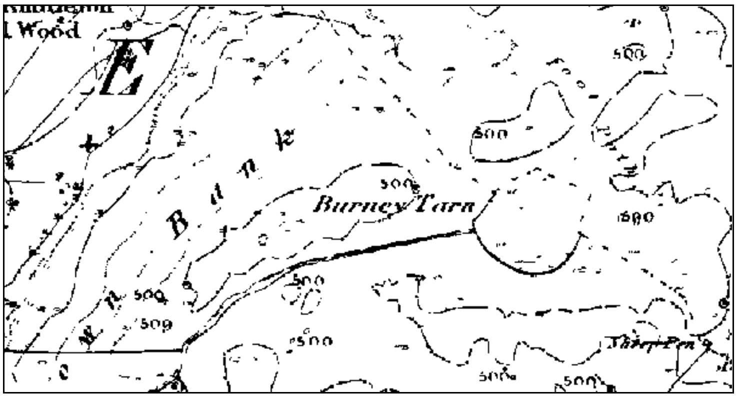



Figure 3.3: BYT and BYB site plan (bathymetry unavailable). All depths are in metres, X indicates the coring locations.



Map 3.7: Excerpt from OS map showing BYT and BYB (each grid square = 1 km)
(OS map produced in Digimap carto, 08/10/2007)


Image 3.6: Aerial photo of BYT (from Getmappingplc, 08/10/2007)



Map 3.8: Excerpt from 1850 Lancashire and Furness map, showing the former extent of BYT (from old-maps.co.uk, 08/10/2007).

Table 3.3: Sites and finds within 2 km of BYB and BYT, as contained in the National Monuments Record (NMR), English Heritage (accessed via *Web*GIS, 16/03/2009)

| **NMR number** | **Period** | **Site/find description** |
|---|---|---|
| SD 28 NE25 | ?Prehistoric/Non-Antiquity | Cairns shown on early OS map – 1957 survey failed to find them. Possibly natural rock outcrops that look like cairns. |
| SD 28 NE15 | Prehistoric | Remains of clearance cairns, length of stone bank and possible funerary cairn |
| SD 28 NE54 | Prehistoric<br><br>[Unknown] | Two cairns – made into kilns at unknown date |
| SD 28 NE38 | ?Mesolithic | ?Quartzite pebble hammerhead, Furness |
| SD 28 NE21 | ?Bronze Age | Earthwork – damaged cairn, probably a burial cairn |
| SD 28 NE10 | Bronze Age | Earthwork - round cairn |
| SD 28 NE18 | Bronze Age | Earthworks – clearance cairns plus possible burial cairn |
| SD 28 NE19 | Bronze Age | Earthworks – clearance cairns plus possible burial cairn |
| SD 28 NE20 | Bronze Age | Cairns (Heathwaite Fell), mostly clearance cairns for agriculture |
| SD 28 NE22 | Bronze Age | Small hut circle settlement; three circular platforms terraced into hillside, sunken hollow (?isolated hut) and small cairnfield |
| SD 28 NE23 | Bronze Age | Two funerary cairns, both disturbed |
| SD 28 NE24 | Bronze Age | Clearance cairns and two funerary cairns |
| SD 28 NE35 | Bronze Age | Earthwork – denuded round cairn |
| SD 28 NE4 | Bronze Age | Giants' Grave(s) - two funerary cairns – charred bone found in both during excavations (1842) |
| SD 28 NE42 | Bronze Age | Bronze axe found in Furness area |
| SD 28 NE5 | Bronze Age<br><br>[medieval] | Remains of settlement on Heathwaite Fell. Burial cairns and clearance cairns (large number) plus hut circle settlement (8 circular/oval platforms terraced into a steep slope). |
| SD 28 NE52 | Bronze Age | Group of eight cairns, thought to be funerary. Depressions in centres suggest some have been excavated. |
| SD 28 NE6 | Bronze Age<br><br>[Unknown] | Remains of hut circle and small cairnfield (five clearance cairns) |
| SD 28 NE7 | Bronze Age | Remains of group of cairns |
| SD 28 NW12 | Bronze Age | Perforated axe-hammer |
| SD 28 SE3 | Bronze Age | Earthwork - possible ring cairn |
| SD 28 NE11 | Bronze Age/<br>late prehistoric | Earthworks – possible cairn, clearance cairns and field system |
| SD 28 NE39 | Late Bronze Age | Bronze armlet |
| SD 28 NE50 | ?Iron Age | 'Celtic' bronze mask |
| SD 28 NE17 | ?Late prehistory | Earthwork remains of cairns - probably field clearance heaps |
| SD 28 NW3 | Late prehistory | Earthworks - possible cairns - small outcrops with light overburden of scree, possibly added to as result of stone clearance |

| NMR number | Period | Site/find description |
|---|---|---|
| SD 28 NE5 | Medieval<br><br>[Bronze Age] | Remains of dispersed settlement on Heathwaite Fell. Farmstead of five stone-walled enclosures (cultivation and stock control), four buildings within the farmstead and traces of ridge and furrow in fields. |
| SD 28 SW4 | Medieval/post-med | Hallstead (pre-1684?) farmhouse |
| SD 28 NW12 | C16$^{th}$ | Silver coins |
| SD 28 NW6 | C16$^{th}$ – 17$^{th}$ | Ashlack Hall – alleged site of bloomery |
| SD 28 SW12 | Early C19$^{th}$ | Course of tramway, opened 1809-15 to carry slate from Kirby Quarries, abandoned *c*.1955 |
| SD 28 NE51 | C20$^{th}$ | ?Slit trenches |
| SD 28 NE16 | Unknown | Site of seven alleged (probably clearance) cairns |
| SD 28 NE42 | Unknown | Grooved stone |
| SD 28 NE9 | Unknown | Circular pit, probably a quarry |
| SD 28 NE6 | Unknown<br><br>[Bronze Age] | Remains of rectilinear, stone-walled stock enclosure |
| SD 28 NE54 | Unknown<br><br>[prehistoric] | Three circular, stone-walled kilns on Heathwaite Fell. Two seem to have been constructed from former cairns. Used for making potash (from bracken/wood) or ‘kilnwood’ (dried timber). |

Image 3.7: BYT and surrounding landscape (from the southeast)


Image 3.8: BYT and flooded area (looking southwest from ridge shown in Figure 3.3)


Map 3.9: Ancient woodland in the vicinity of BYT/BYB 1:25000 (created in English Heritage *Web*GIS, 06/07/2009). BYT is in the centre.

### 3.5. Little Langdale Tarn (LLT)

LLT differs from most of the other sites studied in that it has substantial inflows relative to the size of the tarn, giving the site a catchment area of approximately 12 $km^2$ (Haworth *et al.*, 2003). Although local vegetation will still contribute to the pollen sum, it was hoped that this site would provide a more general pattern of vegetation change for the central Lake District, thus establishing a background signal against which to compare the local/extralocal data from LGT. Similarly comparison with BLT was expected to produce interesting results, as both sites probably accumulate pollen from a substantially wider area than nearby LGT, but from different catchments. The Greenburn Beck and tributaries of the River Brathay flow into the west side of the tarn, both of which were straightened and dredged in the 19th century AD (Haworth *et al.*, 2003). This is likely to have increased the velocity of water flowing through the tarn, possibly scouring away or mixing surface sediments where the streams flow in. For this reason cores were collected far from the points at which the streams enter, at a depth of 6.8 m (Figure 3.4). The tarn has a surface area of 65752 m (Haworth *et al.*, 2003) and reaches a depth of approximately 9.5 m, which was greater than the maximum depth attainable with the Livingstone corer.

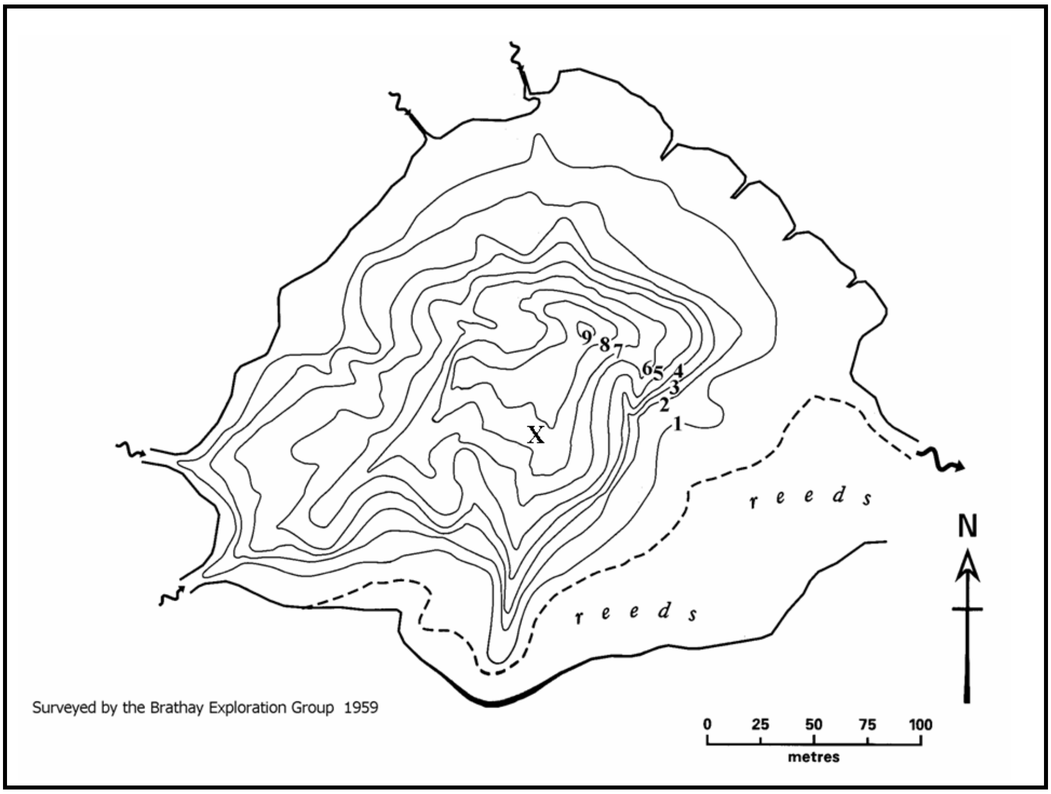
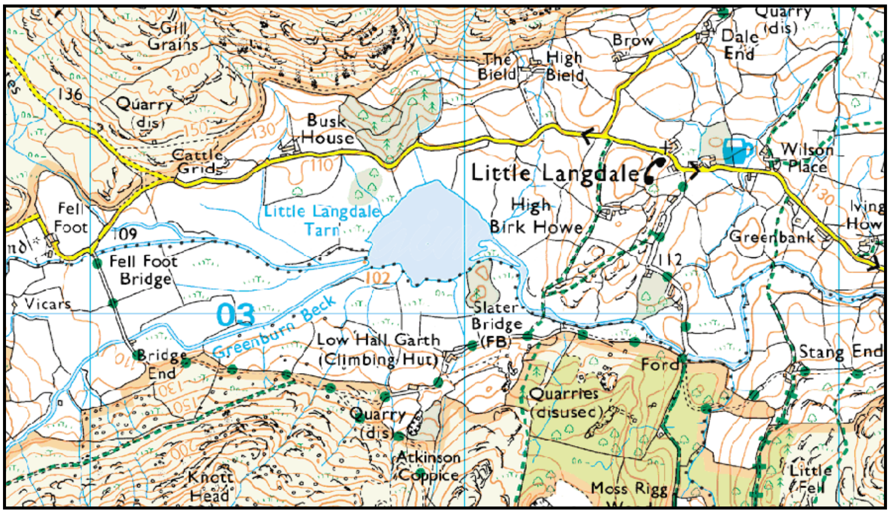



Figure 3.4: LLT bathymetry. All depths are in metres, X indicates the coring location (modified from Haworth *et al.*, 2003).

LLT lies in the Langdale valley at an altitude of 104 m OD, with steep fells to the north (Busk Pike and Lingmoor Fell) and south of the site (the Tilberthwaite Fells to the south-west and the Furness Fells to the south-east). The pattern of pastoral fields around the tarn appears to have changed very little since the nineteenth century (AD 1867) (Maps 3.10 & 3.11, Image 3.9) and several farmsteads are known to have existed in this area from at least the 18th century onwards (Table 3.4). Some parts of the valley are very wet, marked by patches of sedge, and the land is probably marginal in terms of crop-growing because of the likelihood of regular flooding. There are small clumps of trees near to the site and larger wooded areas to the north- and south-east that are considered to be ‘ancient’ (English Heritage NMR denotation), including coppiced woodland (Map 3.12).

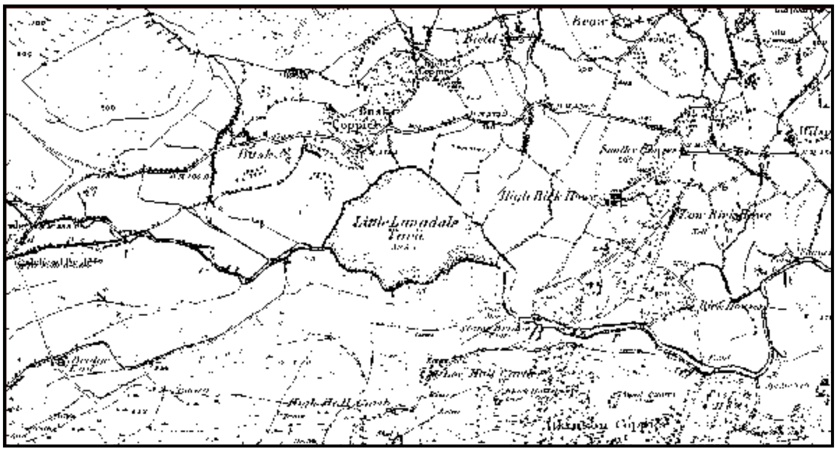
The landscape around the tarn is littered with the remains of mining and quarrying (Image 3.10), the earliest of which (Hawk Riggs Minse) is thought to be an artefact of Elizabethan copper-mining endeavours. There are a few prehistoric and Romano-British remains close to the tarn, but numerous medieval and post-medieval settlements, farmsteads, mines and bloomeries can be found within 2 km of the site (Table 3.4). As mentioned in the previous chapter there is also a ‘Thingmount’ or ‘Ting Mound’ to the west of the tarn’; a flat-topped mound that is thought to have been a place of assembly in the Norse period (Image 1.6) (Fell, 1973c; Newman *et al.*, 2004; E.H. NMR, 2009 and see Section 1.4.3). Despite being one of the few recognised early medieval monuments in the Lake District, the mound has never been excavated; there are no associated artefacts and there has been some debate over the nature of the site. It has been suggested that the terracing on the sides of the mound is agricultural, but this seems unlikely considering the similarity of the Little Langdale mound to other law tings (Fell, 1973c). Unfortunately the importance of the Ting Mound was not recognised until half of it had been destroyed for the construction of a concrete loading bay, but the remainder is a scheduled monument and has been fenced off.

Previous work at LLT by the Brathay Exploration Group identified a copper-enriched horizon dating to 1900, thought to originate from copper-mining activity in the area (Haworth et al., 2003). As geochemical analysis was carried out on just one sample it would be interesting to determine whether there is earlier evidence for copper enrichment at the site (Haworth, pers. comm.); unfortunately this was beyond the remit of the current project. Work on the recent sedimentological history of the tarn identified an increase in sediment accumulation, thought to consist mostly of eroded peat, as minor changes in the diatom flora indicate acidification (Hürrig, 1999, cited in Haworth *et al.*, 2003: 135). Although the BGS collected a series of lake sediment cores from LLT, to the author’s knowledge no palynological work has been carried out at the site and the earlier diatom and sediment records have not been examined.



Map 3.10: Excerpt from OS map showing LLT (each grid square = 1 km)
(OS map produced in Digimap carto, 08/10/2007)

Image 3.9: Aerial photo of LLT (from Getmappingplc, 08/10/2007)



Map 3.11: Excerpt from map of Cumberland, 1867, showing LLT
(from old-maps.co.uk, 08/10/2007)

Map 3.12: Ancient woodland in the vicinity of LLT 1:25000. LLT is in the centre (created in English Heritage *Web*GIS, 03/07/2009).

Image 3.10: LLT from Busk Pike (looking south)

Table 3.4: Sites and finds within 2 km of LLT, as contained in the National Monuments Record (NMR), English Heritage (accessed via *web*GIS, 15/03/2009)

| **NMR number** | **Period** | **Site/find description** |
|---|---|---|
| NY 30 SW17 | Late Bronze Age | Socketed bronze axe found on Low Fell, Little Langdale |
| NY 20 SE46 | Iron Age | Castle Howe nucleated hillfort, Little Langdale - earthwork remains of hut platforms, hut circles and rock cut ditches |
| LINEAR638 | Romano-British | Roman road from Ambleside to Ravenglass |
| NY 30 SW6 | Romano-British | Roman coin, 198 - 209 AD |
| NY 20 SE2 | Early medieval/ Norse | The Ting Mound/Thingmount thought to be a terraced 'moot' or 'law ting' of Norse origin |
| NY 20 SE4 | Medieval | Dispersed settlement and associated kiln at Long Intakes, Little Langdale. Building with enclosures, roadway, stone-built, circular kiln built into rise in ground (Hollin Crag) – possibly for corn drying. |
| NY 20 SE5 | Medieval | Dispersed settlement at Seven Intakes, also known as Vicars. One or two buildings within an enclosure, traces of smaller enclosure to south-west. |

| NMR number | Period | Site/find description |
|---|---|---|
| NY 30 SW58 | Medieval | The site of an ironstone bloomery in Atkinson's Coppice, Little Langdale. Bloomery, slag heap, two burning platforms and two ruined stone buildings on south bank of the River Brathay. |
| NY 30 SW7 | Medieval | Traditional site of a chapel at Chapel Mire, below the Bield in Little Langdale. Associated with land grants to the Priory of Conishead in the manor of Baisbrowne. |
| NY 30 SW8 | Medieval/ post-med | Minor farm building |
| NY 20 SE3 | Medieval/ post-med | Farmstead (probable) |
| NY 30 SW4 | Post-med | Hacket Forge – iron-working complex, north bank of the River Brathay, Little Langdale. Bloomery forge established *c*.1630 by conversion of two pre-existing fulling mills. Ores obtained from the Langdale Fells. In use until 1713 when briefly used as a finery (refining pig iron from Backbarrow blast furnace), not used after 1726. Weir, leat (two phases) and pond. Location of forge building is unknown - probably under present Forge Cottage. |
| NY 30 SW 74 | C16$^{th}$ | Barn related to Baysbrown farmhouse |
| NY 30 SW81 | C16$^{th}$ [?Early C20$^{th}$] | Hawk Riggs Minse - undisturbed copper mine with impressive hand-cut vertical opencut, thought to be Elizabethan. Small miner's hut nearby stands on the site of an earlier, more substantial hut. |
| NY 30 SW37 | C16$^{th}$ & 17$^{th}$ | Baysbrown - C17$^{th}$ house, C16$^{th}$ outbuilding |
| NY 20 SE47 | C16$^{th}$ & C17$^{th}$ | Fell Foot - house with a C16$^{th}$ north wing, main block built C17$^{th}$ |
| NY 30 SW 73 | C17$^{th}$ | Cow house related to Baysbrown farmhouse |
| NY 30 SW21 | C17$^{th}$ | Slater's Bridge, crossing the River Brathay |
| NY 30 SW27 | C17$^{th}$ | The Bield - house |
| NY 30 SW29 | C17$^{th}$ | Wilsons place – house |
| NY 30 SW30 | C17$^{th}$ | Dale End - house |
| NY 30 SW31 | C17$^{th}$ | Brow Head – house |
| NY 30 SW32 | C17$^{th}$ | Busk – house |
| NY 30 SW33 | C17$^{th}$ | High Hacket – house |
| NY 30 SW38 | C17$^{th}$ | High Birk Howe – house |
| NY 30 SW66 | C17$^{th}$ | Barn related to High Birk Howe (NY 30 SW38) |
| NY 30 SW67 | C17$^{th}$ | Barn related to High Birk Howe (NY 30 SW38) |
| NY 30 SW69 | C17$^{th}$ | Forge – house |
| NY 30 SW78 | C17$^{th}$ | Stone barn - adjoins Dale End to the south-west, built into the hillside |
| NY 30 SW79 | C17$^{th}$ | Dale End – house (Little Langdale) |
| NY 30 SW72 | Mid-C17$^{th}$ | Baysbrown farmhouse |

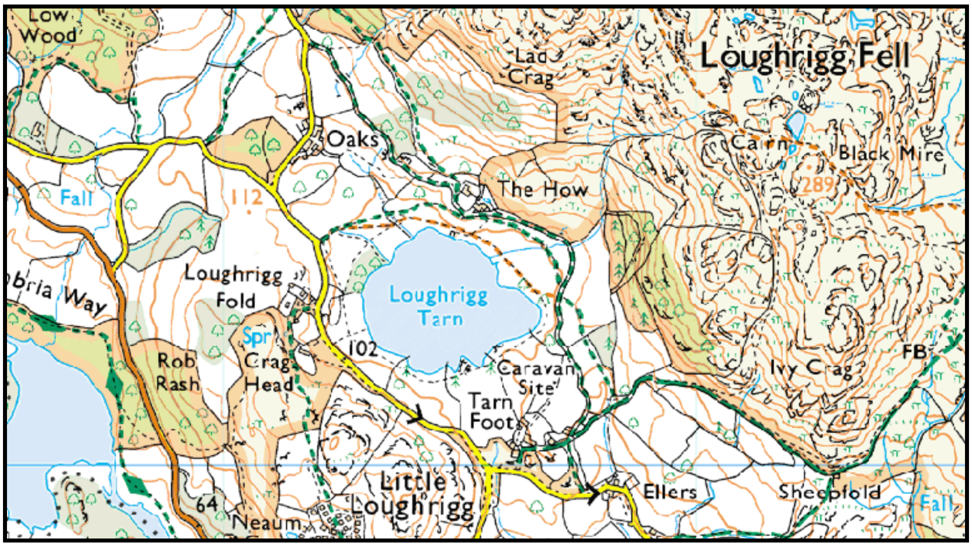
| NMR number | Period | Site/find description |
|---|---|---|
| NY 20 SE9 | ?Late C17th (possibly earlier) | Greenburn Mine - copper mine - at least five east-west copper veins, all mined. Uncertain when mining started, but documentary records show it was well-established by 1690 and that leases were available for prospecting/mining late C18th - early C19th. Period of intensive production mid-late C18th. Various owners C20th, closed by 1940. Extensive remains – buildings, dressing floors, shafts, adits, tramways and a dam. Accommodation block is C19th – foundations of earlier building survive. |
| NY 20 SE10 | ?Late C17th | Adit - level to Greenburn (copper) Mine (NY 20 SE9), north bank of Greenburn Beck |
| NY 20 SE11 | ?Late C17th | Flooded trial shaft to Greenburn Mine (NY 20 SE9), north side of Greenburn Beck |
| NY 30 SW48 | Late C17th | House, Little Langdale |
| NY 30 SW53 | Late C17th-18th | Post office in Little Langdale - formerly house |
| NY 30 SW68 | C18th | Stone barn, adjoins The Bield and has two rows of arrow slits and a higher corrugated roof (Little Langdale) |
| NY 30 SW56 | ?late C18th-present | Hodge Close Slate Quarry - very large open pit quarry, still in operation. Remains of a water-powered `blondin line' (aerial ropeway) and vertical lift. Parrock Quarry to north has the remains of a winding engine and inclined plane. |
| NY 20 SE26 | C19th | Greenburn Road - trackway constructed *c* 1845 to provide vehicular access to Greenburn Mine (NY 20 SE9) |
| NY 30 SW57 | C19th-present | Extraction pits and spoil heaps of slate quarry - still being worked |
| NY 30 SW81 | ?Early C20th<br><br>[C16th] | Hawk Riggs Minse - prospecting trenches connected with Hellen's Mine. Bothy, earthwork and prospecting pit. |
| NY 30 SW3 | Unknown | Site of U enclosure |

### 3.6. Loughrigg Tarn (LGT)

This is a mid-altitude (94 m OD) tarn with three very small inflows and one outflow, situated at the base of Loughrigg Fell, not far to the east of Elterwater (Map 3.13). Although the tarn is of similar size to LLT (73502 m$^2$ (Haworth *et al.*, 2003)), the lack of major incoming streams and the enclosed nature of the site, which is overshadowed by Loughrigg Fell to the north-east and Little Loughrigg to the south, should result in a relatively small catchment area. The land around the tarn is owned by the National Trust and currently consists of grazed pasture and deciduous woodland (Images 3.11 and 3.12). As with the other sites mentioned so far, the aerial photographs and historic maps suggest little change in the landscape during the last 100-200 years (Image 3.13, Maps 3.13 and 3.14).

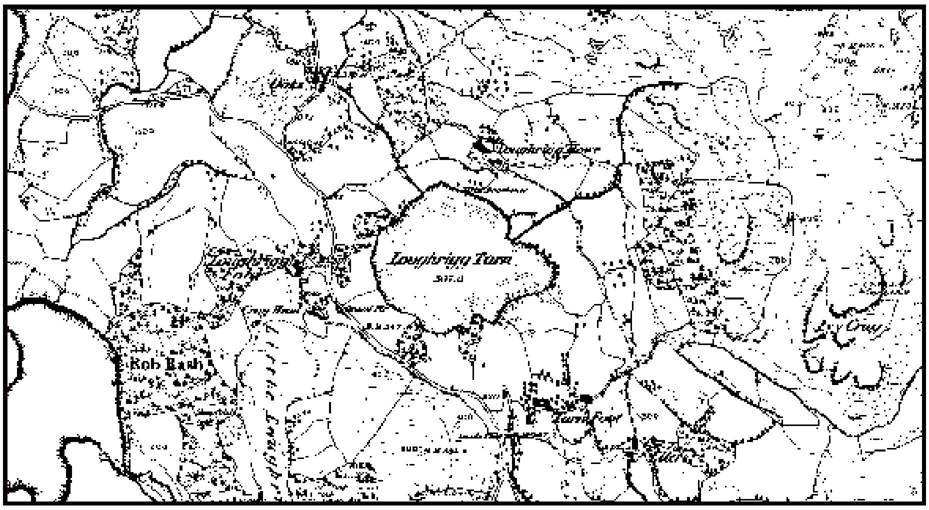
Image 3.11: LGT and surrounding pasture (Barry Forster, 2007)

Image 3.12: LGT from the southeast (coring – boat on the left) (Keith Barber, 2005)



Map 3.13: LGT 2007 (each grid square = 1 km) (OS map produced in Digimap carto, 08/10/2007)


Image 3.13: Aerial photo of LGT and surrounding area (from Getmappingplc, 08/10/2007)



Map 3.14: LGT nineteenth century (from old-maps.co.uk, 08/10/2007)

There are a number of settlements in this area and as mentioned previously some of these date to the medieval period or earlier (*e.g.* Ambleside). Galava Roman fort lies within 5 km of LGT and the Roman road from Ambleside to Ravenglass passes less than 2 km to the south of the site; with such significant Roman military remains in the area we might expect pronounced changes in the surrounding vegetation to have occurred during the Romano-British period. A few prehistoric artefacts have been found near the tarn and there are numerous medieval and later sites, but as is often the case there are no sites or finds known to date to the Dark Ages (Table 3.5). Most woodland in the surrounding landscape is marked as 'ancient' (Map 3.15), which agrees with Pennington's conclusion from work at nearby BLT, that following an early clearance phase (thought to occur in the Neolithic/Bronze Age), woodland regeneration occurred and there was little change until the present day (Pennington, 1965). To the author's knowledge, no published pollen diagrams exist for this site; a reference to unpublished data in Haworth *et al.* (2003) suggests a sequence similar to that at BLT, but in the absence of detailed pollen analysis or associated radiocarbon dates this is of limited use. A key reason for including LGT in the study (which also applies to BLT and LLT) was to determine whether high-resolution pollen analysis, combined with AMS radiocarbon dating and diatom counts, would highlight small-scale, short-term changes in the local/extralocal vegetation, supplementing knowledge of the human history of the central Lake District and clarifying the time-scale of changes identified through Pennington's (1965) work in this area.

Table 3.5: Sites and finds within 2 km of LGT, as contained in the National Monuments Record (NMR), English Heritage (accessed via *Web*GIS, 16/03/2009)

| **NMR number** | **Period** | **Site/find description** |
|---|---|---|
| NY 30 SW11 | Neolithic | Perforated stone axe hammer |
| NY 30 SW5 | Neolithic | Stone axe roughout found on rocky knoll near LGT |
| NY 30 SW9 | Neolithic | Perforated pebble macehead |
| NY 30 NW4 | Neolthic | Roughout (axe) found at High Close |
| NY 30 SW10 | Iron Age/ Romano-British | Rotary quern |
| LINEAR638 | Romano-British | Roman road from Ambleside to Ravenglass |
| NY 30 SW58 | Medieval | Site of medieval ironstone bloomery, Atkinson's Coppice, Little Langdale. Bloomery, slag heap, two burning platforms and two ruined buildings on the south bank of the Brathay. |
| NY 30 SW15 | Medieval/ post-med | Oval kiln with chamber and passage, Mireside, Skelwith |
| NY 30 SW60 | Medieval/ post-med | Charcoal burning platforms within Atkinson's Coppice |
| NY 30 SW12 | Post-med | Brow |
| NY 30 SW26 | Post-med | Post-medieval mill (possibly site of another too) |
| NY 30 SW59 | Post-med | Potash kiln near Colwith Bridge, Little Langdale |
| NY 30 NW115 | C16$^{th}$ | Barn near Loughrigg Terrace, north of church |
| NY 30 SW36 | C16$^{th}$,17$^{th}$ & 18$^{th}$ | Eltermere Hotel - late C16$^{th}$ hotel with 17$^{th}$ and 18$^{th}$ century additions. Formerly a house. |
| NY 30 SW 44 | ?C17$^{th}$ | Kitty Hall – house |
| NY 30 SW71 | ?C17$^{th}$ | Wisteria Cottage and Rose Cottage |
| NY 30 NW114 | C17$^{th}$ | High Close, house (part of house is C17$^{th}$) |
| NY 30 NW20 | C17$^{th}$ | Dale End (house), built 1661 |
| NY 30 NW45 | C17$^{th}$ | High Close – house |
| NY 30 NW78 | C17$^{th}$ | Dale End, barn built 1661. Related to Dale End House. |
| NY 30 SE42 | C17$^{th}$ | Fox How farmhouse |
| NY 30 SE43 | C17$^{th}$ | Brow Head Farm |
| NY 30 SW 42 | C17$^{th}$ | Loughrigg Howe – house |
| NY 30 SW 43 | C17$^{th}$ | Oaks – house |
| NY 30 SW 47 | C17$^{th}$ | Scroggs – house |
| NY 30 SW13 | C17$^{th}$ | Bull Close – house |
| NY 30 SW24 | C17$^{th}$ | Mill Brow – fulling mill recorded 1655 |
| NY 30 SW33 | C17$^{th}$ | High Hacket – house |
| NY 30 SW34 | C17$^{th}$ | High Colwith – house |
| NY 30 SW39 | C17$^{th}$ | Tarn Foot – house |
| NY 30 SW40 | C17$^{th}$ | Crag Head – house |
| NY 30 SW41 | C17$^{th}$ | Loughrigg Fold – house |
| NY 30 SW51 | C17$^{th}$ | House on Loughrigg How (street) |
| NY 30 SW61 | C17$^{th}$ | Corn mill recorded at Elterwater 1653. Incorporated to Elterwater Gunpowder Works (EGW)(NY 30 SW55) in 1824, closed 1930. |
| NY 30 SW70 | C17$^{th}$ | Bridge End – house |
| NY 30 SW75 | C17$^{th}$ | Bark house relating to Mill Brow Farmhouse (NE 30 SW76) |

| NMR number | Period | Site/find description |
|---|---|---|
| NY 30 SW76 | C17th | Mill Brow Farmhouse |
| NY 30 SW 46 & NY 30 SW54 | C17th and later | Britannia Inn – formerly a house, now a pub/inn (Elterwater) |
| NY 30 SW 45 | C17th+ | Elterwater farmhouse – post-medieval, built after 1692 |
| NY 30 SW52 | Mid- to late-C17th | House on Loughrigg How (street) |
| NY 30 SW49 | Late C17th | House Elterwater - house. |
| NY 30 NE6 | Early C18th (site C16th ) | House dating to 1702, ?built as replacement for house of 1565 |
| NY 30 SW35 | ?C18th | Low Colwith – house |
| NY 30 SW28 | C18th (earlier bridge at site) | Elterwater Bridge (crossing Langdale Beck), rebuilt 1702 |
| NY 30 NE15 | C18th/19th | Loughrigg Holme – C18th house with early C19th building work.  Home of Edward Quillinan, a poet who married Wordsworth's daughter Dora. |
| NY 30 SW62 | C18th-19th | Site of fulling mill, 1714, west of Elterwater Gunpowder Works (NY 30 SW55).  ?Demolished 1824 for gunpowder works. |
| NY 30 SW83 | ?Early C19th | Barn at Elterwater Park Farm |
| NY 30 NW105 | C19th | Cylinder Hill charcoal works, *c*1834-66, belonged to gunpowder works (NY 30 SW55) |
| NY 30 NW107 | C19th | Smithy built 1834 – 1859 (uncertain) by EGW |
| NY 30 SE32 | C19th | Fox How (house), built 1834, later home of Matthew Arnold |
| NY 30 NW106 | C19th-20th | Merzbarn – studio of artist Karl Schwitters (a refugee of Nazi Germany), built from remains of a burnt-down powder magazine constructed 1882, EGW. |
| NY 30 SW55 | C19th-20th | EGW, 1824-1930 |
| NY 30 SW63 | C19th-20th | Remains of weir across Langdale Beck. Belonged to old corn mill (NY 30 SW61) and subsequent gunpowder works (NY 30 SW55), also used by fulling mill (NY 30 SW6). |
| NY 30 SW64 | C19th-20th | Building was previously stables for gunpowder works (NY 30 SW55), Elterwater village |
| NY 30 SW65 | C19th-20th | House of manager of gunpowder works (NY 30 SW55), Elterwater village |
| NY 30 SE85 | Early C20th | White Craggs, Clappersgate – house |
| NY 30 NW3 | Unknown | Quern |
| NY 30 SE30 | Unknown | Three platforms, possibly for buildings/charcoal burning |

Sediment cores for LGT were collected towards the western side of the tarn at a depth of 6.7 m (Figure 3.5, Image 3.12).  The tarn reaches a maximum depth of 10 m, which is beyond the capabilities of the Livingstone corer.

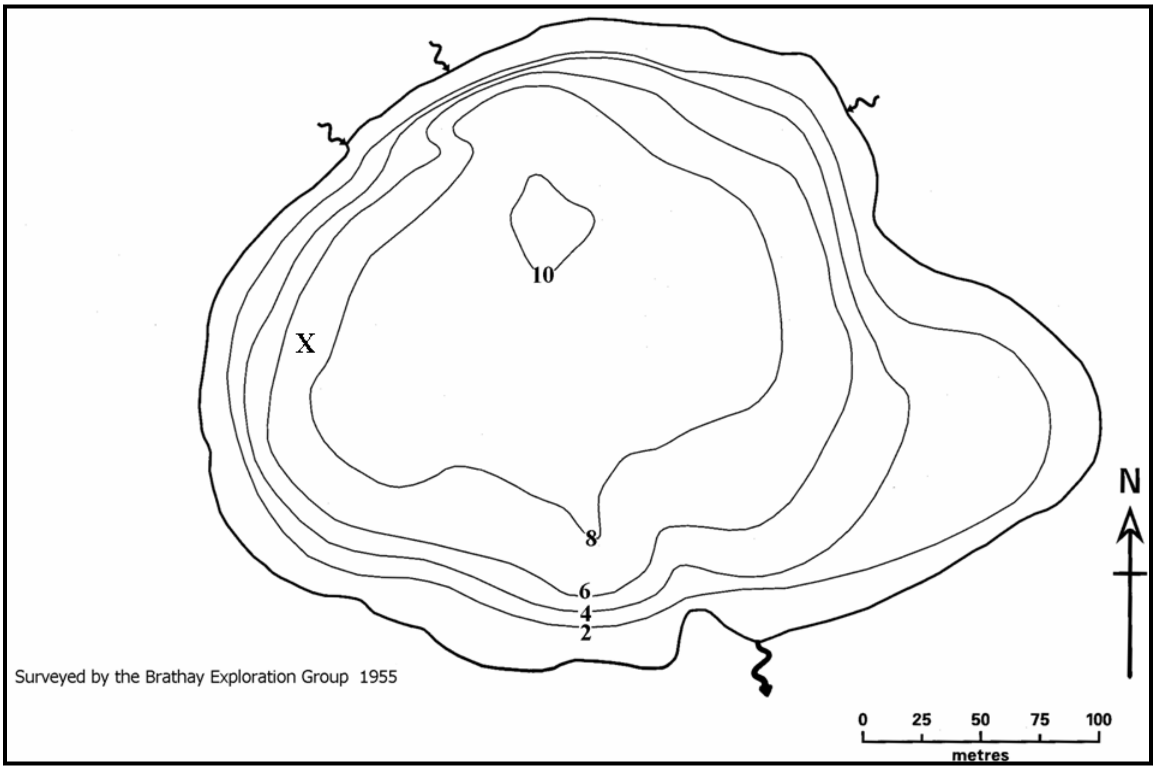



Figure 3.5: LGT bathymetry. All depths are in metres, X indicates the coring location.

Map 3.15: Ancient woodland in the vicinity of LGT 1:25000 (created in English Heritage *Web*GIS, 06/07/2009). LGT is in the centre.

### 3.7. Tewet Tarn (TWT)

TWT is the northernmost of the sites included in this study and lies to the east of Keswick at an altitude of 198 m OD. The surrounding landscape consists of pastoral grassland and moorland (Image 3.14) and there are several farms close to the site. Low Rigg rises to the south of the tarn and Blencathra (Saddleback) can be seen to the north/north-east, beyond the River Greta and the village of Threlkeld. Naddle Beck passes to the west and St John's Beck to the east. TWT sits upon a small hill and has no inflows and only a small, seeping outflow on the south side. Although the site is open rather than enclosed, the small size of the tarn (approximately 12000 $m^2$) should result in most of the airborne pollen originating from the local and extra-local vegetation. TWT is surprisingly shallow with patches of reed swamp around the periphery, reaching a maximum depth of 1.2 m near the centre. Little is known about the tarn and there appears to have been no previous palaeoecological work at the site. A Livingstone core was collected from close to the centre of the tarn (Figure 3.6).

Image 3.14: TWT, looking southwest

TWT is marked on historical maps (Map 3.16), suggesting that it is a true tarn and not merely a wet hollow despite its shallowness. Once again the nineteenth century pattern of fields and roads in the surrounding area is largely unaltered to the present day, though less woodland can be seen in the modern landscape. The most notable difference between old and current maps is the drastic reduction in the size of Ullock Coppice to the south-west of the tarn; few trees are visible in the modern aerial photograph (Image 3.15) and the coppice is no longer labelled on maps (*e.g.* Map 3.17). Burns Wood and Brundholme Wood to the north remain, however, and are both considered to be examples of ancient woodland (Map 3.18).

The site lies a little over a kilometre from Castlerigg stone circle, thought to date to the later Neolithic period and prehistoric finds are common in the area (Table 3.6). There is only one possible Romano-British find (an axe rough-out) from within 2 km of the site and no early medieval archaeology has been identified nearby. Substantial medieval earthworks around Threlkeld suggest a significant population by this time and it seems unlikely that the area was abandoned for the intervening period. There are numerous disused quarries and mines in the landscape around the site, including the nineteenth and twentieth century microgranite quarry at Threlkeld, now a scheduled monument (E.H. NMR, 16/03/2009).

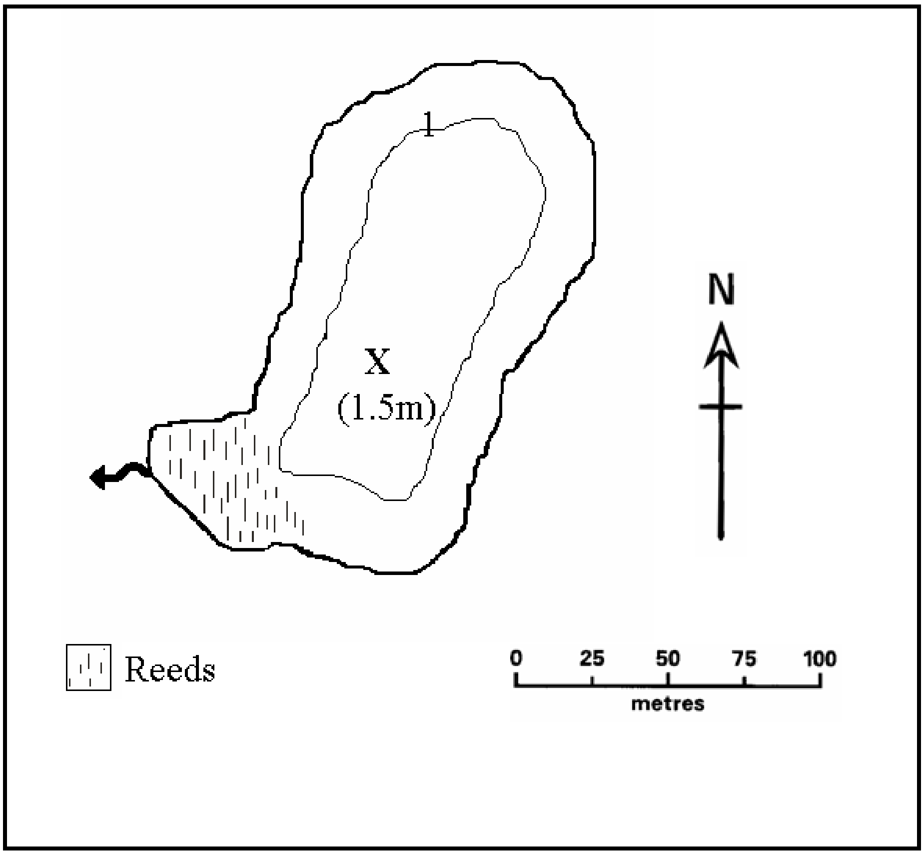
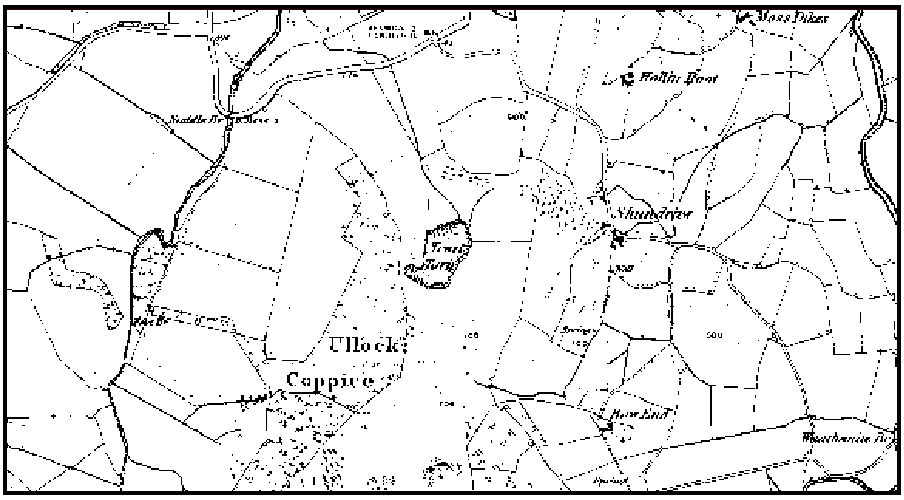
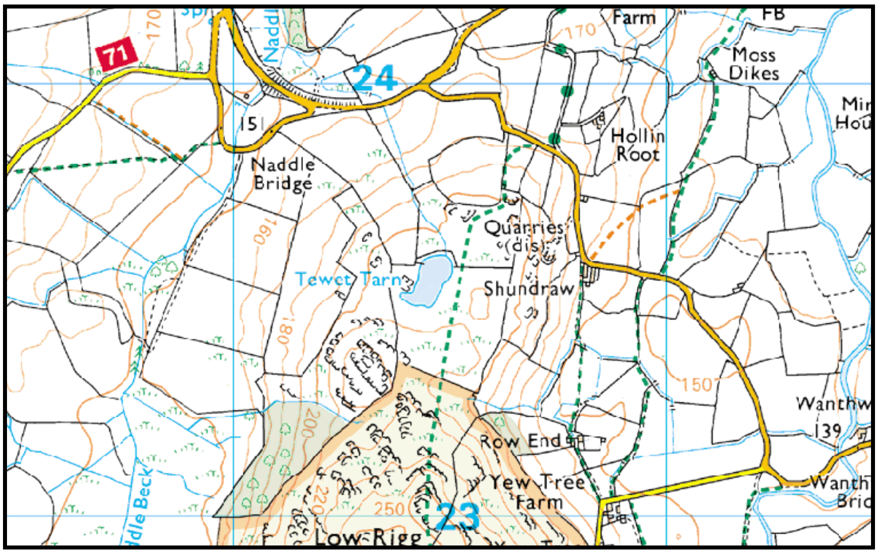



Figure 3.6: TWT bathymetry. All depths are in metres, X indicates the coring location.

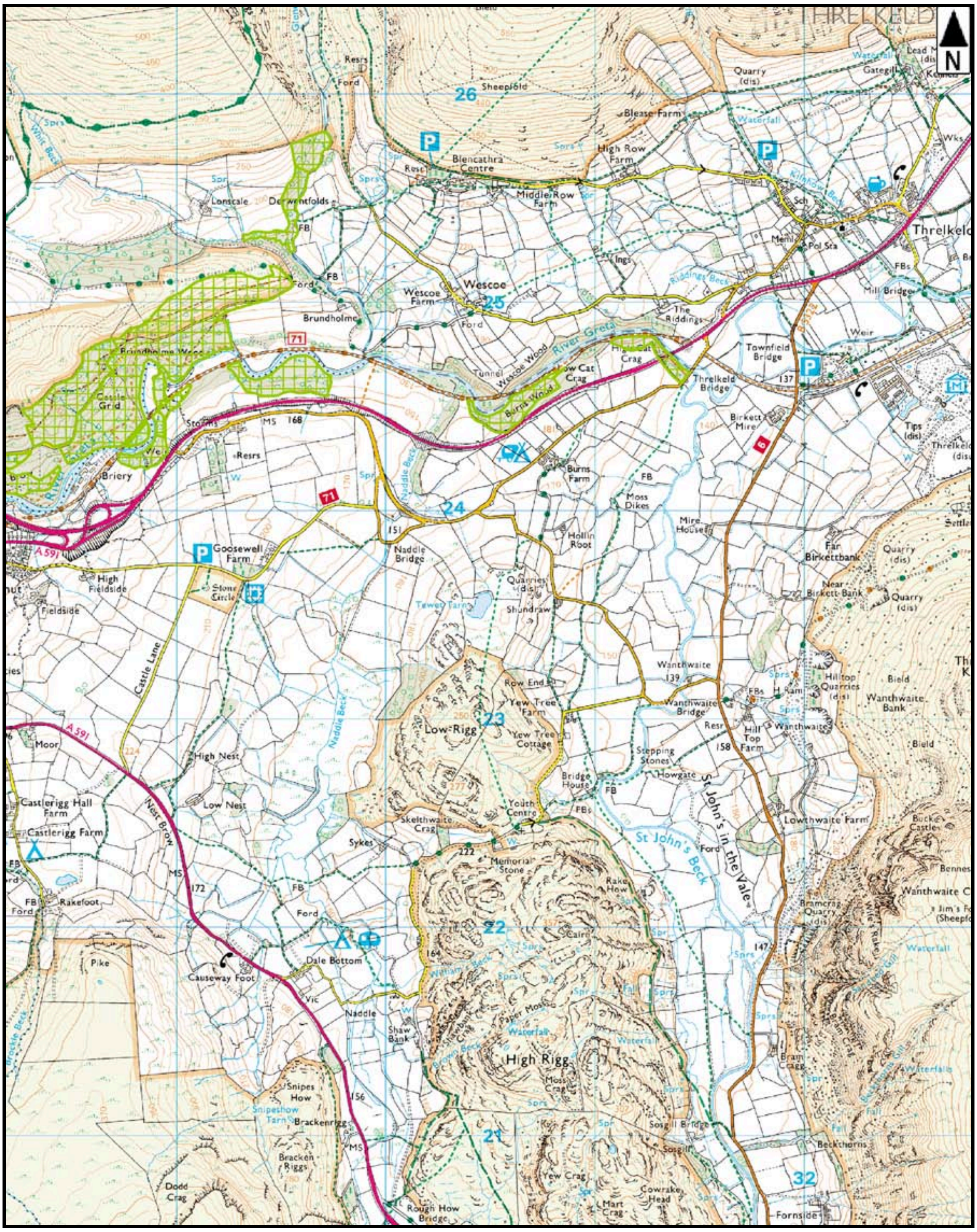


Map 3.16: Cumberland map from 1867 showing Tewet Tarn (old-maps.co.uk, 2007)


Image 3.15: Aerial photograph of TWT (Getmappingplc, 2007)



Map 3.17: Ordnance Survey map of TWT (each grid square = 1 km)
(OS map produced in Digimap carto, 08/10/2007)




Map 3.18: Ancient woodland in vicinity of TWT 1:25000 (Created in English Heritage *Web*GIS, 06/07/06/07/2009). TWT is in the centre.

Table 3.6: Sites and finds within 2 km of TWT, as contained in the National Monuments Record (NMR), English Heritage (accessed via *Web*GIS, 16/03/2009)

| NMR number | Period | Site/find description |
|---|---|---|
| NY 22 NE5 | Prehistoric | Two flint knives found at Latrigg |
| NY 22 SE10 | Neolithic | Stone axe found near Castlerigg Stone Circle (NY 22 SE1) |
| NY 32 SW3 | Neolithic | Polished stone axe found in St John's-in-the-Vale |
| NY 32 SW5 | Neolithic | Polished grey-green stone axe found on High Rigg |
| NY 32 SW6 | Neolithic | Polished grey-green stone axe found at Reckow |
| NY 32 SW4 | Neolithic/Bronze Age | Perforated stone hammer |
| NY 22 SE21 | Neolithic/early Bronze Age | Perforated stone adze found in River Greta (near the Forge, Keswick) |
| NY 22 SE1 | Late Neolithic/early Bronze<br><br>[late prehistoric] | Castlerigg Stone Circle. Stone circle and two cairns (either side of circle entrance) with shallow ditches around them. Two unpolished stone axes and one possible roughout have been found on the site. |
| NY 32 SW7 | Early Bronze Age | Flanged axe found in St John's-in-the-Vale |
| NY 32 SW2 | Bronze Age | Fragment of socketed Bronze spearhead, St John's-in-the-Vale |
| NY 32 SW8 | Middle Bronze Age | Rapier |
| NY 22 SE1 | Late prehistoric<br><br>[late Neolithic/early Bronze] | Pit and round cairn associated with Castlerigg Stone Circle |
| NY 22 SE33 | Prehistoric/Roman | Roughout axe |
| NY 22 NE10 | Medieval | Aerial photographs show boundaries – banks and ditches. ?Early intake. North of Brundholme Wood. |
| NY 32 SW16 | Medieval | Hospital or hermitage at St John's-in-the-Vale, early C13$^{th}$ to ?C16$^{th}$ |
| NY 32 NW6 | Medieval and post-med | Ridge and furrow in Threlkeld Parish. Some (post-medieval) are narrow and thought to be to improve grazing land rather than for cultivation. |
| NY 22 SE23 | C16$^{th}$ | Copper smelting works |
| NY 32 SW9 | C19$^{th}$ | Cockermouth, Keswick and Penrith Railway – opened 1865 to transport minerals, used by tourists soon after. Closed 1972, now dismantled. |
| NY 32 SW17 | C19$^{th}$-20$^{th}$ | Threlkeld Station – opened 1865, closed 1972 (Cockermouth, Keswick and Penrith railway (NY 32 SW9)) |
| NY 32 NW5 | Early C20$^{th}$ | Blencathra Centre, sanatorium 1903-4 |
| NY 32 SW19 | C20$^{th}$ | Site of WW2 pillbox near Birkett Mire |
| NY 32 SW20 | C20$^{th}$ | A Royal Observer Corps monitoring station, for spotting hostile aircraft |
| NY 32 SW21 | C20$^{th}$ | A Royal Observer Corps monitoring station, for spotting hostile aircraft |
| NY 22 SE14 | Unknown | Five spinning whorls of uncertain date |

# CHAPTER 4: RESULTS

The length of cores collected varied depending on the depth of sediment available at the sampling point. As explained in the previous chapter, each core was analysed for approximate organic carbon and inorganic carbonate content by loss on ignition (LOI) before carrying out further analysis. Cores were then sampled for SCPs (spheroidal carbonaceous particles) to establish the stratigraphic integrity and rate of accumulation for the uppermost sediments. The results presented below are divided by study site. The majority of radiocarbon measurements were provided by the NERC radiocarbon laboratory in East Kilbride under allocation no. 1251.1007 (2008). Two additional AMS radiocarbon determinations for LGT were acquired from Beta Analytic (2006). The data were calibrated using OxCal 4.1 (Bronk Ramsey, 2009) and the IntCal calibration curve (Reimer *et al.*, 2009) and are presented in Table 4.1.

Nomenclature for pollen types follows Bennett (1994); Latin names are used in the text, but a full list of species identified in this study including common names and basic ecological information is provided in Table 1A, Appendix 1. Taxa included in the 'age estimation' diagrams include species introduced at approximately known times (*Juglans regia* was introduced in the Romano-British period), cereals, as the majority of grains falling into this group do not occur prior to the Neolithic, and plantation trees, which should appear (*Picea*) and increase (*Pinus sylvestris*) in the nineteenth and twentieth centuries AD. *Ulmus* was initially included, but was removed as there is no clear indication of an elm decline at any of the sites. *Artemisia*-type was also plotted at first owing to Oldfield's suggestion that the advent of deep ploughing led to a loss of this plant (Oldfield, 1969), but as no evidence of this was found *Artemisia*-type has been excluded from the age estimated diagrams.

The Total Land Pollen (TLP) includes all arboreal, ericaceous and herbaceous types, with the exclusion of the wet/aquatic herbs Cyperaceae and Sparganiaceae owing to their prevalence in wetland habitats (including lake margins). Percentage diagrams for key arboreal and non-arboreal taxa (maximum presence of 2% or more of the TLP) are organised in taxonomic order, following Clapham *et al.* (1962), while anthropogenic indicators are grouped according to the categories in Table 1.6 (pp66-7). The groups used are based on ecological information and previous works identifying anthropogenic indicators. Species that occur in both arable and grazed/ruderal habitats are included in the broad category of 'arable/pastoral/ruderal taxa' (*e.g. Rumex* spp., *Plantago* spp.); although these types might be indicative of agriculture, in the absence of cereal types or weeds specific to arable fields it is possible that they represent pastoral land, or even natural clearings in some cases (Buckland & Edwards, 1984; Behre, 2007). *Corylus avellana*-type, Poaceae undiff. and *Pteridium aquilinum* are also plotted in the diagrams as these types tend to spread when land is cleared (Turner, 1964; Dimbleby, 1978; Behre, 1988; Edwards, 1993). All Poaceae grains with a diameter of 30 μm or greater were measured to aid and objectify identification of cereal types (after Andersen, 1979).

Diatom nomenclature follows Whitton *et al.* (2003), which should facilitate application of transfer functions if required in future. Authorities for identification are included in Table 4A, Appendix 4 in addition to common synonyms for the species, information concerning nutrient status (where available) as well as the maximum percentage of each type at the study sites. The implications of specific changes in pollen and diatom taxa are summarised briefly here and discussed in more detail in Chapters 5 and 6. All zones and descriptions in this chapter work from the lowest depth upwards as this makes more sense chronologically (*i.e.* working from the oldest to the youngest deposits). Table 4.1 and all diagrams referred to here can be found on pages 183 to 220 at the end of the chapter. Age-depth models for LGT and BFT are presented in the subsequent chapter.

## 4.1. Barfield Tarn (BFT)

The core analysed from BFT proved to be one of the most interesting studied and had the best defined sediment stratigraphy of any of the sites, being divided into 12 distinct layers/units. Sediment description (below) and LOI revealed that the sediments were very minerogenic with low organic content (Figure 4.1), although none of the sediments was found to be calcareous. The dry mass lost at 550˚C rarely exceeded 20% and for the middle and base of the profile was less than 10%. Higher concentrations of herbaceous fragments in more recent deposits are reflected in the increase in LOI towards the top of the core. Mass lost at 950˚C was less than 2% throughout most of the profile, only exceeding this in the sediments with higher organic content (Figure 4.1). The majority of the sediment was found to consist of greasy, clayey lake-mud, occasionally containing silt and sand. Tiny herbaceous fragments in some of the layers appear to originate from reeds *(Phragmites communis*), which grow around the edges of the tarn today, particularly in the shallow area to the northwest (Figure 3.1, Image 3.1). There are several thin layers of clay-dominated sediment that are likely to be products of inwash events, perhaps signalling disturbance of the catchment vegetation or soils (*e.g.*

clearance, ploughing, trampling). The simplified lithology is plotted in Figure 4.1.and full, shorthand sediment descriptions (following Troels-Smith, 1955) are provided in Appendix 4.

### 4.1.1. Sediment description

| | |
|---|---|
| 0 -14.5 cm | Unstratified, very wet, dark reddish-brown mud-clay. Slightly fibrous structure, rare inclusions of silt and herbaceous fragments (very small). Manifest/clear lower boundary. |
| 14.5 - 18.5 cm | Dark brown, homogeneous, slightly stratified clay-mud with diffuse lower boundary. |
| 18.5 - 22 cm | Unstratified, homogenous, black clay/silt-mud with rare particles of fine sand and tiny herbaceous fragments. Manifest/clear lower boundary (0.5-1 mm). |
| 22 - 29.5 cm | Dark brown, homogeneous mud-clay displaying slight stratification. Conspicuous lower boundary. |
| 29.5 - 33 cm | Unstratified, dark reddish-brown, homogeneous mud-clay with inclusions of silt and fine sand. Conspicuous lower boundary. |
| 33 - 35 cm | Brownish-black, homogeneous layer of clay-mud with inclusions of silt and fine sand. Conspicuous lower boundary. |
| 35 - 37.5 cm | Layer of homogeneous, dark brown, greasy mud-clay. Conspicuous lower boundary. |
| 37.5 - 43 cm | Homogeneous, dark reddish-brown mud-clay with tiny herbaceous fragments. Diffuse lower boundary and slight, discontinuous banding. |
| 43 - 62 cm | Brownish-black, homogeneous clay-mud with rare inclusions of fine sand and (?aquatic) herbaceous fragments. The sediment unit shows slight stratification with a conspicuous lower boundary (1-2 mm). |
| 62 - 80 cm | Dark reddish-brown, clay/silt-mud, with rare (?aquatic) herbaceous fragments and fine sand. The sediment is homogeneous and unstratified apart from a yellow, clay band (1 mm thick) at 75 cm. Diffuse lower boundary. |
| 80 - 93 cm | Unstratified, homogeneous, dark brown, silty mud, including rare (?aquatic) herbaceous fragments. Diffuse lower boundary (2-10 mm). |
| 93 - 115 cm (base of core – arbitrary lower boundary) | Unstratified, dark reddish-brown, silty mud, with a homogeneous structure and rare inclusions of fine sand and small (?aquatic) herbaceous fragments. |

### 4.1.2. Pollen analysis

There is more evidence for human impact on the vegetation at BFT than at any other site in this study. A range of arable, pastoral and ruderal indicator species are present throughout the core and there are clear phases where arboreal taxa decline significantly, suggesting clearance events. The assemblage is dominated by Poaceae undiff., *Alnus glutinosa*, *Betula* and *Corylus avellana*-type. There are several phases in which heathland species (*Calluna vulgaris* and *Erica*) expand with a corresponding reduction in tree pollen. Cyperaceae pollen is present consistently at approximately 1-5% of the total land pollen, peaking at around 10%, and probably originates from sedge growing around the margins of the tarn and incoming beck. Some Poaceae pollen may also have come from *Phragmites* (reeds) growing in these areas (Image 3.1, previous chapter). Figures 4.2 to 4.5 are the pollen diagrams for this site.

LPAZ (local pollen assemblage zone) 1: 115 (base of core)-97 cm:

The earliest deposits from BFT are characterised by approximately equal percentages of pollen from heathland, pastoral and arboreal taxa. Tree species are dominated by *A. glutinosa*, *Corylus avellana*-type, *Betula* and to a lesser extent, *Quercus*. *Pinus sylvestris* and *Ulmus* are present in very small quantities, while examples of *Hedera helix* and *Ulex*-type pollen were found towards the end of this phase. Heathland taxa consist mainly of *Erica* and *Calluna vulgaris*; *Vaccinium*-type and *Empetrum nigrum* are also present. Poaceae undiff. dominates the herbaceous pollen, followed by *Cichorium intybus*-type, *Filipendula*, *Potentilla*-type, Ranunculaceae undiff. and *Saxifraga stellaris*-type. *Avena/Triticum*-type and *Secale cereale* are present at this stage, as are many species indicative of clearance and grazing (*e.g. Urtica dioica*, Chenopodiaceae, Caryophyllaceae, *Rumex acetosella*, *Plantago lanceolata, Plantago media/major, Artemisia*-type/Asteraceae, *Pteridium aquilinum*). These taxa make up only a small proportion of the pollen assemblage, but their presence (particularly in conjunction with cereal pollen) indicates that farming was underway in the surrounding landscape. Arboreal pollen values for individual species are low enough to indicate a regional, rather than a local presence (*cf.* Huntley & Birks, 1983), suggesting an open landscape, though as will be discussed in the next chapter a small number of local trees could produce the same pollen signal as a distant forest in some situations (Jacobson & Bradshaw, 1981; Bunting, 2002). *Alnus glutinosa* pollen is likely to originate from trees growing close to the tarn or the incoming beck (*cf.* Pennington, 1964).

LPAZ 2: 97-75 cm:

This zone is marked by a dramatic decline in heathland taxa (*Erica* and *Calluna vulgaris*) and the expansion of trees and shrubs, particularly *A. glutinosa*, *Betula* and *Corylus avellana*-type. There is also a slight increase in *Quercus* and *Pinus sylvestris* and the first examples of *Ilex aquifolium, Fraxinus excelsior* and *Lonicera periclymenum* occur at this time. Arboreal pollen constitutes up to 70% of the TLP in zone 2, which is suggests that areas of local woodland were present. Agricultural indicator species (including cereal types and *Centaurea cyanus*) are found sporadically in this zone. While Poaceae declines, pastoral/ruderal taxa including *U. dioica, Rumex* spp. and *Plantago* spp. are present in varying proportions. The pollen assemblage during this time suggests continuation of farming in a relatively open landscape, though with more woodland than in the previous phase.

LPAZ 3: 75-61 cm

Heath species peak in LPAZ 3, with *Erica* and *Calluna vulgaris* expanding to constitute up to a third of the TLP. *Empetrum nigrum* reaches its maximum (2.2%), indicating that it was present locally as this species' production and dispersal properties are thought to be poor (Huntley & Birks, 1983). Arboreal taxa decline during this phase, most notably *Betula* and *A. glutinosa* and to a lesser extent *Corylus avellana*-type and *Quercus. Ulex*-type is present more consistently than previously, perhaps indicating the presence of gorse-scrub on heathland. There are no clear trends in the herbs during this phase, though the persistent presence of anthropogenic indicator species suggests that farming was still being practised in the surrounding landscape (Figure 4.4).

It is possible that the initial spike in *Calluna vulgaris*, accompanied by an increase in *Cichorium intybus*-type and peaks in Asteraceae and *Polypodium* (all resilient pollen/spore types) originates from inwashed peat/soil from the catchment area (*cf.* Edwards *et al.,* 2005; Leira *et al.,* 2007). Pollen concentrations are relatively low at this depth (Figure 4.5) suggesting poor preservation, though surprisingly there is a slight drop in unidentifiable pollen rather than an increase. This is discussed further in relation to radiocarbon dates (see section 4.1.4 and Chapter 5).

LPAZ 4: 61-39 cm:

All of the main tree species recover slightly from their decline in the previous zone, while heathland taxa are reduced to approximately 10-20% of the TLP. Ferns (Pteropsida monolete indet.) expand gradually and herbaceous taxa such as Poaceae, Asteraceae, *C. intybus*-type increase to over 40% of the TLP in total. Arable and pastoral indicators including *Centaurea cyanus, Urtica dioica, Rumex* spp., *Plantago* spp. and *Artemisia* are present together with all three cereal-type grains, suggesting agriculture and probably grazing was occurring around the site at this time.

LPAZ 5: 39-29 cm:

Arboreal pollen declines to a little over 20% of the TLP at the start of this zone, gradually rising again to peak at over 60% in LPAZ 6. All of the main tree and shrubs species are affected, most notably *A. glutinosa* and to a lesser extent *Betula* and *Corylus avellana*-type. Heathland taxa expand and there is a slight decline in pastoral and agricultural types at the start of the phase, which is particularly marked in *Ranunculaceae, Rumex acetosa, R. acetosella* and *U. dioica*. *Secale cereale* and *Hordeum*-type are absent for most of this phase, perhaps indicating changes in the type of crops being farmed; the persistent presence of *Avena/Triticum*-type together with an increase in the percentages of *Plantago* spp. and fern/bracken spores (Pteropsida monolete indet., *Pteridium aquilinum*) suggests that farming was still underway. The first examples of *Juglans regia* are found during this period.

LPAZ 6: 29-19 cm:

LPAZ 6 is characterised by an increase in *Betula* and *Alnus glutinosa* and a corresponding decline in heathland species (*Erica* and *Calluna vulgaris*), perhaps caused by colonising woodland expanding onto moorland/peat bogs. After a temporary drop (especially in Poaceae) herbaceous taxa increase gradually; agricultural/pastoral indicators are present throughout this zone and *Avena/Triticum*-type is present at most depths. *S. cereale* and *Hordeum*-type reappear towards the end of this phase, indicating cultivation of a mixture of cereal crops in the catchment area.

LPAZ 7: 19-0 cm:

The most recent phase at BFT features an initial peak in ericaceous taxa, followed by a decline in these and in the main tree species. There is a substantial expansion of herbs, especially Poaceae, and types associated with grazing and agriculture are present throughout (*Avena/Triticum*-type, *Hordeum*-type, *S. cereale, Centaurea cyanus, U. dioica, Plantago* spp.). Trees/shrubs associated with established deciduous woodland or hedges such as *Ulmus, Fagus,* *Ilex* and *Fraxinus excelsior* recur in this zone and *Picea* appears, presumably originating from 19th and 20th century AD forestry plantations. *Acer* is also present; native maple can be found in Westmorland (southern Lake District), but this could also represent sycamore, thought to have been introduced in the 15th to 16th centuries AD (Clapham *et al.*, 1962).

### 4.1.3. Diatom analysis

The diatom flora at BFT is very mixed in terms of nutrient status, with species representing a range of conditions present in the majority of samples. There are fewer diatoms indicative of high nutrient status than at the central Lakeland sites of BLT and LGT and the spectra are more similar to those at LLT. *Achnanthidium minutissimum* is dominant throughout much of the profile and *Brachysira vitrea*, *Eunotia* spp., *Fragilaria capucina* and *Tabellaria flocculosa* make substantial contributions to the assemblage. *Staurosira construens* is also important throughout most of the record, but virtually disappears from the uppermost zone. The diagrams have been divided tentatively into three main zones, one of which is split into two subzones (Figures 4.6 and 4.7). Further sampling would be beneficial to refine the diatom stratigraphy and will be carried out at a later date, but was not considered worthwhile in terms of the research questions for this project given the additional time required for analysis.

LDAZ (local diatom assemblage zone) 1: 115 (base of core)-76 cm

The earliest phase at BFT is dominated by *A. minutissimum;* unfortunately it has not been possible to define the likely nutrient status associated with this species with confidence owing to conflicting information in the literature (Table 4A). However, species of high to medium nutrient status (the most common of which are *F. capucina, S. construens, S. construens* var. *venter*) make up over 50% of the TTIC (total trophic indicator count; including only diatoms for which nutrient status could be established) at this time. *F. vaucheriae*, which falls in this category, is present throughout the zone, declining from a peak at over 10% of the TDC in the basal sample. *B. vitrea* and *Rossithidium pusillum* (both oligotrophic) are also present in significant quantities, the former increasing gradually towards the end of LDAZ 1 while the latter declines. The only examples of *Cyclotella meneghiniana, C. radiosa, Cocconeis placentula, Cavinula cocconeiformis* and *Cymbella aequilus* are found during this period.

LDAZ 2, subzone 2a: 76-60 cm

LDAZ 2 is characterised by the expansion of *Diatoma hymale, Eunotia incisa* and *E. pectinalis var. minor,* in conjunction with the first occurrences of *B. serians*, *E. arcus* and *Achnanthes divergens. Achnanthidium minutissimum* continues to make a substantial contribution to the assemblage, with only a temporary dip in this species at 64 cm depth. There is an overall increase in highly eutrophic to mesotrophic species during this phase, together with a gradual increase in oligotrophic to dystrophic diatoms. *B. vitrea* and *T. flocculosa* remain important. The highly eutrophic species *Cyclostephanos dubius* occurs only in this zone. LDAZ 2 is divided into subzones based on changes in several diatom species (particularly rare types).

Subzone 2a features the only examples of *Caloneis undulata, Achnanthes austriaca, Neidium bisculcatum* and *Planothidium oestrupii* found at the site, as well as short-lived peaks in *Navicula integra* and *Staurosirella pinnata. Staurosira construens var. venter* and *R. pusillum* decline and the first appearance of *Peronia fibula* occurs during this period.

LDAZ 2, subzone 2b: 60-29 cm

Several rare types are present only during this phase (*Encyonema hebridicum, Navicula krasskei, Nitzschia gracilis*) and some of those just towards the end of the zone (*Eunotia exgracilis, E. flexuosa, Gomphonema vibrio, Navicula harderi*). Diatoms of high nutrient status expand, particularly *Cyclotella pseudostelligera, Cymbella affinis* and *Nitzschia fonticola.* Both *E. pectinalis* and *E. exgracilis* are lost at this time. *S. construens* declines dramatically towards the end of the zone, countered by small peaks in *S. construens var. binodis. Tabellaria quadriseptata* also reaches its maximum value in this phase.

LDAZ 3: 29-0 cm

*Achnanthidium minutissimum* peaks at over 40% of the TDC at the start of this phase, falling to less than 10% shortly afterwards and rising again towards the surface. Several species associated with high to medium nutrient status decline at this time, most notably *Diatoma hymale* and *Staurosira* spp., which fall to their lowest values at the site. Oligotrophic species such as *B. vitrea, Psammothidium marginulatum* and *Peronia fibula* expand in this zone, with the former comprising over 15% of the TDC. *E. pectinalis* peaks temporarily at over 20% and *E. exigua* and *Pseudostaurosira brevistriata* return. The only examples of *Aulacoseira granulata, Caloneis lauta, Diploneis* undiff., *Gomphonema acuminatum var. brebissonii,* *Navicula phyllepta, N. rhynchocephala* and *Surirella linearis* occur in this zone.

### 4.1.4. Age estimation

SCPs were not found below 20 cm and exhibit peaks at 4 cm and 12 cm (Figure 4.1). The larger of these (4 cm) is thought to be the 'subsurface peak', which dates to the mid- to late-1970s in northern England. The base of the sequence is presumed to fall at 1850 ± 25 years AD (Rose *et al.*, 1995; Rose & Appleby, 2005). AMS radiocarbon dates for this site proved problematic, with an obvious reversal in the uppermost sample and the other two age estimates overlapping to the extent that the measurement at 73-75 cm is almost certainly reversed; both of these fall within the post-Romano-British/early medieval period and accumulation would need to have been exceptionally rapid in the intervening time for both to be correct. Despite these issues, the pronounced stratigraphy and clear developments in the pollen and diatom spectra suggest that the core has good integrity and the reversed radiocarbon dates seem likely to signal the presence of inwashed organic sediment. For the purposes of further interpretation, the basal date has been assumed to be accurate; this is supported by the expansion of heathland taxa during LPAZ 1, which is likely to signal the sixth century AD climatic downturn (*cf.* Barber, 1981; Blackford & Chambers, 1991; Mauquoy & Barber, 1999; Hughes *et al.,* 2000; Wimble *et al*., 2000; McDermott *et al.,* 2001; Barber *et al.,* 2003) and comparison with Pennington's (1981) age-depth model for BFT (see Figures 5.1 and 5.2). However, it could be argued that the material dated at this depth might also be a product of inwash; further radiocarbon or other means of independent dating for this core would be required to confirm this either way. This is discussed in more detail in Chapter 5 (Section 5.2) with reference to pollen types indicative of age (*e.g.* historical introductions), sediment type and changes in the diatoms, particularly those relating to disturbance in the catchment.

## 4.2. Blelham Tarn (BLT)

Only two distinct layers were identified at BLT. The sediment throughout the core consists of clayey, brownish-black mud with occasional silt and sand. Aside from a slight difference in colour according to the Munsell definitions (see Appendix 4), the only defining feature of the two sediment units is the presence of occasional herbaceous fragments (aquatics and rootlets) in the bottom half of the core; these are absent further up the core, but the boundary between the two layers is very diffuse and consequently ill-defined. The sediment has no notable structure, and neither visual inspection of the core nor loss on ignition data indicate the presence of inwash layers. LOI at 550˚C shows the core to be relatively minerogenic, with percentage dry mass lost equalling approximately 30% for the lower part of the sequence and dropping to around 20% in the upper half of the core (Figure 4.8), which reflects the lack of herbaceous fragments in the more recent sediments.

### 4.2.1. Sediment description

| | |
|---|---|
| 0 - *c.* 49 cm | Unstratified, homogeneous, brownish-black mud-clay. Rare particles of silt and sand. Very diffuse lower boundary (transitional zone greater than 10 mm). |
| *c.* 49 - 115 cm (base of core – arbitrary lower boundary) | Unstratified, brownish-black, homogeneous mud-clay, with rare inclusions of silt, fine sand and herbaceous fragments (including very infrequent rootlets). |

### 4.2.2. Pollen analysis

The pollen spectra from BLT are relatively complacent and dominated by taxa indicative of mixed deciduous woodland (Figures 4.9 to 4.11). Trees and shrubs constitute between 60 and 90% of the TLP, consisting mainly of (in approximately equal proportions) *Quercus, Betula, Alnus glutinosa* and *Corylus avellana*-type. *Ilex aquifolium* is present in most samples reaching a maximum of just over 3% of the TLP, suggesting a local presence, probably within the woodland understorey (*cf.* Huntley & Birks, 1983). Other arboreal taxa including *Fagus sylvatica, Fraxinus excelsior, Tilia* and *Ulmus* occur in small percentages, somewhat sporadically. *Hedera helix* was found in the upper half of the profile. *A. glutinosa* and Cyperaceae are present throughout the deposits and are likely to originate from wet areas around the lake margins or from the banks of the incoming streams (*cf.* Pennington, 1964).

Poaceae constitutes a maximum of 25% of the TLP, which is enough to suggest open woodland or cleared areas (Huntley & Birks, 1983), though it should be remembered that *Phragmites* growing at the lake margins is likely to contribute some of the 'grass' pollen within the assemblage. A limited number of cereal types and anthropogenic indicators are present (generally at less than 2% of the TLP); there is a slight expansion of these taxa in the most recent zone (LPAZ 2), suggesting grazing and perhaps agriculture in the catchment area. Ericaceous taxa are present in small quantities throughout the core; these never exceed 4% of the TLP and there is no evidence for an expansion of heathland species at the site. Owing to the limited diversity in the assemblages and the lack of clear patterns in the changes observed, the profile for BLT has been divided into just two local pollen assemblage zones (LPAZs), the earlier of which is split into two subzones.

LPAZ 1, subzone 1a: 115 (base of core)-85 cm:

The pollen spectrum in the earliest phase at BLT is dominated by arboreal taxa indicating mixed deciduous woodland, probably *Quercus*-dominated. Tree and shrub pollen makes up between 70 and 90% of the TLP at this time, suggesting relatively closed woodland. As mentioned previously, the most important arboreal species at the site are *Quercus*, *Betula*, *A. glutinosa* and *Corylus avellana*-type, with *Ilex aquifolium* also making a significant contribution to the pollen sum. *Ulmus*, *Tilia* and *Fraxinus excelsior* are present though rare. Ferns (mainly Pteropsida monolete indet., *Polypodium* and *Pteridium aquilinum*) constitute a substantial part of the assemblage during this phase, perhaps as woodland undergrowth together with Poaceae and a limited range of herbs. *Juglans regia* is found at a depth of 105 cm, indicating a date no earlier than the mid- to late- first century AD (Clapham *et al.*, 1962; Godwin, 1975; Huntley & Birks, 1983). A single grain of *Hordeum*-type in this phase may originate from cereal cultivation in the area, but corresponding low levels of agricultural/pastoral indicator species do not support significant local cultivation or grazing. *Hordeum*-type includes numerous wild grasses and is thus the least convincing of the cereal types as an indication of farming (see Section 1.5.2.1).

LPAZ 1, subzone 1b: 85-47 cm:

Arboreal taxa remain dominant at this time and there appears to be little change in the composition of woodland aside from a slight peak in *F. excelsior* and the loss of *Tilia*. There are subtle changes in the herbaceous taxa, including peaks in *Scabiosa columbaria*, *Saxifraga* *granulata*-type and Caryophyllaceae, the first occurrences of *Saxifraga stellaris*, *Potentilla*-type and *Solidago virgaurea*-type and the disappearance of Apiaceae, Rubiaceae and *Valeriana officinalis*. There is also an expansion of Poaceae, Cyperaceae and *Pteridium aquilinum* at this stage, corresponding to a slight decrease in arboreal pollen.

LPAZ 2: 47-0 cm:

This zone is characterised by the expansion of herbaceous taxa concomitant with a slight decline in arboreal species, particularly *Quercus*. Arboreal pollen falls to 60-70% in this period, while Poaceae reaches a maximum of around 25% of the TLP and anthropogenic indicators such as *Urtica dioica, Rumex acetosella, Plantago* spp. and *Cichorium intybus*-type increase. A single example of *Avena/Triticum*-type pollen was found in this period; although this suggests cultivation in the surrounding area, pastoral and ruderal indicators are far more common in the assemblage than those associated directly with agriculture. *Secale cereale* is also present, but this species' pollen is wind-dispersed and can be found some distance from the plant. Overall, the assemblage seems to represent a patchily wooded catchment area with some open, grazed land, much like the present-day landscape. The proximity of small patches of woodland to the tarn is likely to have masked evidence of grazing around the site (Tauber, 1967), meaning that the landscape might have been more open in the past than the data appear to suggest.

**4.2.3. Diatom analysis**

The diatom assemblage at BLT is dominated throughout by species indicative of moderate to high nutrient status, with eutrophic and highly eutrophic species making up over 50% of the flora throughout the record (Figures 4.13 and 4.14). Similarly to the pollen curves, the diatom spectra are relatively complacent; there are few significant changes in composition or abundance and the most notable development occurs at between 64 and 80 cm, where *Cyclostephanos dubius* declines, *Cyclotella pseudostelligera* expands and several rare types are lost. Further changes might be identified with smaller sampling intervals, but this was not thought worthwhile for the current project owing to problematic radiocarbon dates and the complacency of the pollen spectra.

LDAZ 1: 115 (base of core)-73 cm

The earliest phase at BLT is dominated by centric diatoms, especially

*C. pseudostelligera, C. radiosa* and *Cyclostephanos dubius. Cyclotella krammeri* comprises over 15% of the TDC in the basal sample, but is absent from the subsequent sample, while *Stephanodiscus hantzschii* and *C. meneghiniana* are present in small quantities. *Achnanthidium minutissimum, Brachysira vitrea, Pseudostaurosira brevistriata* and *Staurosira contruens* make a significant contribution to the assemblage. Rarer types present include *Navicula tenuicephala, Rossithidium pusillum, Tabellaria flocculosa* and *Neidium hitchcockii,* in addition to various species of *Navicula, Eunotia* and *Pinnularia.* Some species decline or disappear at approximately 88 cm, including *Pseudostaurosira brevistriata* and *Cymbella amphicephala.*

LDAZ 2, subzone 2a: 73-30 cm

*Cyclotella pseudostelligera* expands to around 40% of the TDC, while there is a reduction in *Cyclostephanos dubius, Stephanodiscus hantzschii* and *Cyclotella meneghiniana,* all of which are species associated with high nutrient status. *Brachysira vitrea* and *T. flocculosa* continue to make a significant contribution to the assemblage, while *Staurosira construens* declines dramatically from 64-48 cm depth.

This zone is divided into two subzones owing to the appearance of many rare types near the top of the core. *Cymbella aequilus* expands during subzone 2a, but remains rare, while *Asterionella formosa* increases to its maximum value. The only examples of *Gomphonema acuminatum var. coronatum* were found at this time. *Eunotia monodon* and *Cavinula cocconeiformis* also peak, declining rapidly towards the end of the period. Subzone 2a is characterised by an increase in species indicative of eutrophic conditions, though highly eutrophic taxa appear to decline.

LDAZ 2, subzone 2b: 30-0 cm

The key species are described above and show little change from their percentages in subzone 2a. *Pinnularia fibula* and *Psammothidium marginulatum* peak and many rare types only occur during this phase (*Stephanodiscus parvus, Denticula tenuis, Diatoma hymale, Encyonema silesiacum, G. acuminatum var. brebissonii, Neidium iridis, Pinnularia episcopalis, P. major, Synedra delicatissima*). *Nitzschia gracilis* and *Staurosira construens var. binodis* return in this subzone, which also sees an expansion of *Aulacoseira subarctica* and *Achnanthidium minutissimum.* There is a temporary increase in species associated with low nutrient status in subzone 2b at the expense of highly eutrophic to eutrophic types.

### 4.2.4. Age estimation

The SCP profile for BLT shows a prominent peak at 18 cm depth that is thought to represent AD 1978 ± 4 years (Rose *et al.*, 1995; Rose & Appleby, 2005), indicating rapid accumulation during recent decades as found by Van der Post *et al.* (1997) (Figure 4.8). SCPs disappear completely by 28 cm depth (*c* AD 1850) and *Picea* is absent in all but the subsurface sample, suggesting that the upper part of the core has reasonable integrity. The AMS radiocarbon dates for BLT were, however, entirely reversed.

The findings of Oldfield's (1970) work on the recent history of Blelham Bog (summarised in Chapter 3) may have some bearing on the dating problems encountered at BLT. An increase in flow-through can be inferred from the lowering of water levels that followed modification of one of the tarn's outflows in the 1800s. The initial increase in discharge is likely to have resulted in resuspension of sediments in the tarn, which could account for mixing and reversals in the sequence; it could be argued that the relative complacency of the pollen and diatom curves, together with the homogeneity of the sediment, supports this hypothesis. Alternatively, it is possible that 'old' dates arise from redeposited peat or organic sediment carried to the site by inflowing streams, or perhaps washed in from the slopes around the tarn, particularly if heavy grazing was underway in the catchment (*cf.* Van der Post, 1997). Also, the streamborne component of the pollen assemblage is likely to reflect vegetation patterns in a broad area, in which case the sensivity of the pollen signal to vegetation changes is somewhat 'dampened' (*cf.* Brown *et al.*, 2007); this could account for the complacency of the pollen curves, although it does not explain the lack of change in the diatom flora.

With the data available, it is not possible to distinguish between the two hypotheses above with confidence; the acquisition of further dating evidence might clarify the situation. However, all three of the radiocarbon dates (one of which was at the base of the profile) fall within the middle to later medieval period (Table 4.1), which implies that the material is in any case too recent to answer the research questions of this project. For this reason no further analyses were carried out following the receipt of radiocarbon measurements.

## 4.3. Burney Tarn (BYT) and Burney Bog (BYB)

The short core from Burney Tarn exhibits no stratigraphy and was found to be highly organic in character. The dark, peaty mud contains many reed fragments and LOI at 550˚C destroyed around 90% of the sediment throughout the lower part of the core (Figure 4.15). Organic content begins to decline above 12 cm and reaches a minimum of just under 60% at the surface; there was no obvious change in the sediment at this depth. SCPs were found throughout the core, meaning that the sequence is unlikely to extend beyond the mid-nineteenth century AD (*cf.* Rose & Appleby, 2005) (Figure 4.15). The large spike at 2 cm depth is probably the 1978 peak and the variability of concentrations throughout the core suggests the sediment is not mixed, but the likelihood that the material is very recent prevented further analyses (beyond SCP counts, LOI and sediment description) from being carried out on this site.

The monolith from BYB consists of fibrous, well-humified peat, becoming less humified towards the top of the profile and overlain by fresh *Sphagnum* peat. LOI at 550˚C destroyed approximately 95% of the peat throughout the sequence, reflecting the highly organic nature of the material (Figure 4.16). A skeleton pollen diagram was produced for this site and two radiocarbon dates were supplied by NERC.

### 4.3.1. Sediment description

**BYT:**

| | |
|---|---|
| 0 - 35 cm | Homogeneous, unstratified, reddish-black, greasy organic clay/silt-mud, with many small herbaceous fragments, especially of reeds (*Phragmites communis*). |

**BYB:**

| | |
|---|---|
| 0 - 9 cm | Very wet, brown (light), fresh, unhumified *Sphagnum* peat. Unstratified, becoming mixed with fibrous humified peat in the diffuse lower boundary. |
| 9 - 28 cm | Slightly humified, reddish-black, fibrous peat. Unstratified and very wet. Diffuse lower boundary (2-10 mm). |
| 28 - 70 cm | Wet, unstratified, well-humified, reddish-black peat. Rare inclusions of wood and grass fragments, more frequent tiny herbaceous/woody particles. Slightly fibrous structure. |

### 4.3.2. Pollen analysis (BYB only)

The pollen profile from BYB is dominated by tree species, particularly *Alnus glutinosa*, which constitutes 65% of the TLP in the earliest phase (Figure 4.17 and 4.18). *Betula, Quercus* and *Corylus avellana*-type are also important, making a substantial contribution to the assemblage until LPAZ 3, when arboreal taxa decline sharply at the same time as a dramatic expansion of Poaceae. The concentration data show a severe decline in all pollen and spore types in the most recent deposits (Figure 4.19), which is most likely a reflection of the change to fast-growing *Sphagnum* peat close to the surface in contrast with the compacted, humified deposits below.

LPAZ 1: 70 (base of monolith)-50 cm

The earliest phase at BYB is dominated by *Alnus glutinosa*, presumably growing on the bog itself or at the margins of the bog/tarn. *Quercus, Betula* and *C. avellana*-type all make a significant contribution to the assemblage, suggesting a largely wooded landscape; few herbs are present at this stage and Poaceae (which might in any case originate from *Phragmites* growing in and around BYT) constitutes less than 15% of the TLP. The presence of woodland is supported by the occurrence of *Ulmus, Hedera helix* and *Lonicera periclymenum,* although these taxa are rare.

A slight increase in Poaceae, accompanied by a peak in ferns (Pteropsida monolete indet. and *Polypodium*) and the appearance of a small number of pastoral indicators (Ranunculaceae, Caryophyllaceae, *Rumex acetosa*, *Trifolium*-type) occurs towards the end of this phase, but there is little to suggest significant clearance or farming-related activity in the vicinity of the site at this time. A single example of *Juglans regia* was found at 56 cm, suggesting a Romano-British or later date at this depth (Clapham *et al.,* 1962; Godwin, 1975; Huntley & Birks, 1983).

LPAZ 2, subzone 2a: 50-38 cm

Tree species remain dominant at over 60% of the TLP throughout this phase, which is characterised by the expansion of heathland taxa (*Erica, Calluna vulgaris* and to a lesser extent, *Vaccinium*-type) and a gradual increase in Poaceae. A wider selection of anthropogenic indicator species is present during this period, including *Hordeum*-type, Chenopodiaceae, *Plantago lanceolata, Campanula*-type and *Artemisia*-type, suggesting grazing and perhaps agriculture in the area. The increase in heathland species is probably indicative of changing vegetation on BYB rather than a spread of heath within the surrounding landscape; *Calluna vulgaris* tends to grow in better-drained areas and the decline in Cyperaceae and *Alnus glutinosa* at this time supports drier conditions on the bog surface.

LPAZ 2, subzone 2b: 38-26 cm

Towards the end of LPAZ 2 there is a notable rise in herbaceous pollen, particularly of

Poaceae, which peaks at 80% of the TLP towards the end of this period. *Potentilla*-type, *Rosaceae* undiff., Rubiaceae and anthropogenic indicator species such as *Plantago* spp., *Centaurea nigra* and *Cichorium intybus*-type also increase and the presence of *Secale cereale* and arable weeds (*Centaurea cyanus* and *Polygonum*) suggests an open landscape within which both grazing and cultivation were underway. Tree and shrub species decline towards the end of this phase, possibly as a result of anthropogenic clearance to make land available for farming.

LPAZ 3: 26-0 cm

The final phase at BYB is characterised by a dramatic expansion of herbaceous taxa (especially Poaceae, although this might originate from reeds to some extent) at the expense of woodland and heathland species. *A. glutinosa* is virtually absent in this period and *Corylus avellana*-type, *Quercus* and *Betula* are much reduced, although *Quercus* and *Betula* recover towards the top of the profile. *Fagus sylvatica* makes a significant contribution to the assemblage and the first examples of *Fraxinus excelsior* occur, while *Ulmus* dwindles. *Pinus sylvestris* expands in this zone and the only examples of *Picea* were found near to the bog surface, signalling the establishment of 19$^{th}$-20$^{th}$ century conifer plantations in the region. Similarly, the increase in *Fagus sylvatica* is likely to reflect planting of beech at this time (*e.g.* Pearsall & Pennington, 1973; Barber, 1981).

Arable, pastoral and ruderal indicators are still present at this time, suggesting a continuation of farming in the local area. The subsurface sample indicates grazing rather than agriculture, featuring peaks in *Rumex* spp. and *Urtica dioica* in conjunction with the loss of cereal-types and arable weeds and a dramatic reduction in *Plantago* spp. There is a slight resurgence of heathland taxa from a depth of 8 cm upwards.

### 4.3.3. Diatom assessment

Samples taken at regular intervals throughout the monolith were assessed for diatom content, partly to determine whether the basal, humified peat might have been deposited as lake sediment (based on the assumption that the bog formed within the former, more extensive basin of BYT). The samples were not analysed fully as only *Eunotia* spp. were found and these provide little ecological information (Table 4A, Appendix 4). There was no discernible change in the species present in any of the samples assessed.

### 4.3.4. Age estimation

SCPs were found to peter out between 30 and 40 cm depth, with a rather diffuse peak at *c* 20 cm marking 1978 ± 4 years (Rose *et al.*, 1995; Rose & Appleby, 2005) (Figure 4.16). This suggests that the unhumified *Sphagnum* peat at the top of the monolith has accumulated very recently, perhaps in the last 10-20 years. Unlike the other study sites, BYB exhibits a clear expansion of *Pinus sylvestris* towards the surface, particularly noticeable after the SCP maximum at 20 cm. The two radiocarbon dates for BYB are in chronological order, but indicate either severe compression of the sediments or truncation between 50 and 69 cm depth. The basal age estimate is mid-Holocene/Mesolithic while that at 50-52 cm is post-medieval-to-present day. There are dramatic changes in several pollen types during this period, with *Alnus glutinosa* declining from 62 to 40% of the TLP between 70 and 56 cm depth and substantial peaks in Pteropsida monolete undiff. and Cyperaceae undiff. It is impossible to identify the truncation point exactly without higher resolution analysis, although a grain of *Juglans regia* at 56 cm indicates a Romano-British or later date at this depth (suggesting that truncation occurred below this point). As the study period is very unlikely to be represented in the deposits, or if so, highly compressed and of limited value, no further work has been carried out on the material.

### 4.4. Little Langdale Tarn (LLT)

The core from LLT was relatively minerogenic with estimated organic content (LOI at 550˚C) rarely exceeding 30% and declining to less than 10% in the greasy clay layer at 74.5-86 cm (Figure 4.20). The latter is thought to be derived from inwashed, eroded sediment from the catchment. The sediment core was found to consist of greasy clay and silt with herbaceous fragments, consisting of aquatics/reeds and rootlets. A spike in estimated carbonate content at 60 cm may indicate another inwash episode, though there is no obvious change in the sediment at this depth. None of the sediments was found to be calcareous.

### 4.4.1. Sediment description

| | |
|---|---|
| 0 - 14 cm | Unstratified reddish-black mud-clay with many small herbaceous fragments. Fibrous structure with silt inclusions and more frequent (though rare) herbaceous rootlets (?aquatic) and a conspicuous lower boundary. |
| 14 - 74.5 cm | Reddish-black silt/clay-mud with homogeneous structure and no stratification. Far fewer herbaceous fragments than in underlying sediment (though still present), occasional particles of fine sand. Clear lower boundary (manifest). |
| 74.5 - 86 cm | Brownish-black, greasy clay-mud. Unstratified, homogeneous sediment unit with very diffuse lower boundary. |
| 86 - 150 cm | Brownish-black, homogeneous clay-mud with rare (?aquatic) herbaceous fragments and even less frequent inclusions of silt and fine sand. Unstratified. |

### 4.4.2. Pollen analysis

The pollen spectra from LLT are very complacent and not readily divisible into zones (Figures 4.21-4.23). The assemblage constitutes (on average) 40-50% arboreal taxa, 30-40% herbaceous taxa and 10-20% heathland species; the percentages fluctuate, but most changes are short-lived and not indicative of clear developments in the local/regional vegetation. Pollen concentrations at LLT fluctuate throughout the core (Figure 4.24), possibly reflecting variability in the accumulation of streamborne pollen at the site, which may increase as a result of flood events or periods of heavy rain because of the increased rate of flow into the tarn (*cf.* Brown *et al.*, 2007). The dominant species/types throughout most of the sequence are *Quercus, Betula, Alnus glutinosa, Corylus avellana*-type, *Erica, Calluna vulgaris* and Poaceae. *Ulmus, Salix, Ilex aquifolium* and *Fraxinus excelsior* are found in small quantities in most samples, while *Fagus sylvatica, Tilia* and *Hedera helix* occur less frequently. Ferns (Pteropsida monolete indet., *Cryptogramma crispa, Polypodium* and *Pteridium aquilinum*) make a significant contribution to the assemblage with values equivalent to 15-40% of the TLP. *C. crispa* tends to grow on scree slopes (Clapham *et al.*, 1962) and probably originates from the numerous quarries in the vicinity of LLT (Image 3.10, p122). Arable, pastoral and ruderal indicator species are present throughout the profile, though somewhat sporadically (Figure 4.23), and pollen of herbs representing a range of habitat-types including wetlands, dry pastures and rocky areas (*e.g. Saxifraga* spp., *Filipendula, Potentilla*-type, Rosaceae undiff., *Valeriana* spp., *Scabiosa columbaria*) demonstrates the large and varied catchment area of the site.

The general lack of variation in the LLT pollen spectra might be linked to the nature of the site. As mentioned in the previous chapter, LLT has significant inflows and was therefore expected to ‘sense’ changes in the regional vegetation to a greater extent than most of the other study sites. It is possible that changes in the regional vegetation have been inconsistent across the area resulting in little overall change in regional pollen (*i.e.* that one area is cleared as another is afforested) and that ‘dampening’ of the signal discussed in relation to BLT might also be occurring here. Unfortunately, as at BLT the alternative explanation is that the action of inflowing and outflowing streams has caused resuspension, mixing and redeposition of both sediment and pollen (see Section 4.4.4). Considering the assemblage as a whole, the pollen spectra suggest a mosaic of mixed woodland, heath, grazed and cultivated land. Regardless of whether the sediment is mixed or not, the representation of numerous habitat types within the pollen profile highlights the importance of obtaining small-scale, local/extralocal pollen records when trying to decipher long and short-term vegetation changes for a specific location.

### 4.4.3. Diatom analysis

The diatom spectra for LLT show far more variation than those for pollen and include species representing a range of habitats, but dominated by taxa indicating low nutrient status environments (*Brachysira vitrea* and *Tabellaria flocculosa*) (Figures 4.25 and 4.26). Species of high nutrient status are relatively uncommon at this site in comparison to the other central Lakeland tarns (BLT and LGT), with centric diatoms rarely constituting more than 2% of the TDC. There is a rise in taxa indicative of high to medium nutrient status in the most recent sediments, suggesting an increased input of organic material at this time. The constant flow of water through the tarn is likely to have a diluting effect on phosphorous or organic material entering from the catchment, perhaps contributing in the site’s low nutrient status and the minerogenic nature of the sediment.

LDAZ 1, subzone 1a: 150-118 cm

A wide range of species is present in the earliest deposits, dominated by taxa associated with oligotrophic and oligotrophic to dystrophic environments (most notably *T. flocculosa* and *B. vitrea*). There is a clear change from the basal sample to that at 144 cm, with many species declining or disappearing entirely (*e.g. Achnanthidium minutissimum, Asterionella formosa, Navicula subtilissima, Pseudostaurosira brevistriata*) and *T. flocculosa* increasing dramatically from 13 to 38% of the TDC. This can be seen in Figure 4.26 as a significant reduction in medium to high nutrient status taxa. Centric diatoms make up a very small percentage of the TDC (*c* 2%) during this phase and are dominated by *Cyclotella pseudostelligera.* Other species that make a significant contribution are *Frustulia rhomboides, Psammothidium marginulatum, Staurosira construens* and *T. quadriseptata.*

LDAZ 1: subzone 1b: 118-72 cm

The key species are unchanged from the previous subzone, although *B. vitrea* expands gradually throughout this period. There are, however, significant developments in terms of the less common species. *F. rhomboides* and *A. formosa* decline, while there are increases in *Achnanthes* undiff., *Achnanthidium minutissimum, Encyonema silesiacum, S. construens var. binodis* and *Pseudostaurosira brevistriata.* The rare types (present at less than 2% of the TDC at their maximum value) also change; there are rises in *Eunotia* spp., some of which occur only in this subzone (*E. pectinalis var. undulata, E. praerupta var. inflata*), *Rossithidium pusillum* and *Gomphonema gracile* decline and *Pinnularia major* is lost. The first examples of *C. radiosa* and *P. abaujensis* appear at this time and *Denticula tenuis, Cyclostephanos dubius, P. interrupta* and *Sellaphora pupula* return; these taxa were present in the basal sample of subzone 1a, but not in subsequent samples.

LDAZ 2: 72-28 cm

LDAZ 2 is characterised by an increase in *B. vitrea,* which contributes 25-40% to the TDC throughout the period. *D. tenuis, Pinnularia* spp., *N. radiosa, Cymbella affinis, Encyonema silesiacum* and *Caloneis undulata* expand in this zone, while *F. rhomboides* peaks at approximately 20% of the TDC at 48 cm depth. *T. flocculosa* declines significantly together with *T. quadriseptata* and many of the rare types (*G. acuminatum var. coronatum, Eunotia glacilis, Cyclostephanos dubius, Cyclotella radiosa, Staurosirella pinnata*). *N. hoeflori* and *N. medioconvexa* are present only in this phase, which also sees the temporary loss of *Staurosira construens var. binodis.* There is a gradual increase in *Peronia fibula* and *E. curvata,* particularly towards the end of the period.

LDAZ 3: 28-0 cm

The most dramatic changes at LLT occur in this most recent phase; species that peaked in the previous zone decline, including *Caloneis undulata, F. rhomboides* and *B. vitrea,* which falls to less than 20% of the TDC. *Asterionella formosa, E. curvata, P. fibula, Pinnularia* spp. and *T.*

*flocculosa* all increase and the highest abundances of *Cymbella affinis, E. incisa, Fragilaria crotonensis, Nitzschia gracilis, Pinnularia viridis* and *Surirella biseriata* occur at this time. *C. cesatii* and *Navicula rhynchocephala* are found only in this phase. There is a slight increase in centric diatoms, especially *Cyclotella pseudostelligera,* which reaches values of *c* 7% of the TDC. Several of the rare types (*Amphora* sp., *Stauroneis anceps, S. phoenicenteron, Surirella linearis*) return in the subsurface sample, in many cases peaking at their maximum values. Overall, these changes indicate an increase in the tarn's nutrient status, with diatoms indicative of oligotrophic and oligotrophic to dystrophic habitats declining while those suggesting eutrophic to mesotrophic environments expand.

### 4.4.4. Age estimation

SCPs were found to be absent by 38 cm, marking the mid-nineteenth century AD (Figure 4.20). A spike at 22 cm might represent 1978 ± 4 years (Rose *et al.,* 1995; Rose & Appleby, 2005), but the nature of the profile suggests mixing in the upper part of the core. SCP concentrations increase dramatically soon after the first carbonaceous particles appear and remain high, rather than rising gradually throughout the 1800s and more rapidly in the mid- to late-1900s. Another possible explanation is that the deposits were scoured and thus truncated by increased flow-through in the nineteenth century, when the tarn's inflows (the River Brathay and the Greenburn Beck) were dredged and straightened (Section 3.5, Chapter 3).

*Picea* pollen, which can be carried long distances owing to its morphology, but might also originate from plantations in the last 200 years, was found up to a depth of 88 cm in the core. In addition, the three AMS age estimates for LLT were in reverse order; the date at the base of the core is early medieval, that at 110-112 cm is Romano-British to early medieval and the uppermost date is late Bronze Age. Although the radiocarbon dating problems could be related to inwash of 'old' organics, the complacency of the pollen curves, combined with the anomalous SCP profile, indicate that the deposits at LLT have suffered resuspension and mixing in the past and that the integrity of the core has been compromised. This site differs from BLT, in that while the pollen appears complacent, the diatom spectra exhibit zoning; a possible explanation for this is that mixing only affects sediment up to a limited depth at any given time. Where both pollen and diatoms have undergone partial mixing, dramatic changes in the diatom species present owing to developments in the water chemistry of the tarn are more likely to be detected than subtle increases or decreases in a relatively constant set of pollen types. As in the case of BLT, further analyses were not carried out following the acquisition of radiocarbon dates for LLT.

### 4.5. Loughrigg Tarn (LGT)

LOI suggests that the core contains approximately 40% organic material below 32 cm depth, above which organic content declines, reaching a minimum of little over 20% near the surface (Figure 4.27). Estimated carbonate content is less than 5% throughout the core and there are no obvious indications of inwash either visible in the core or evident in the LOI data. The first 2 cm of the core were too wet and unconsolidated to sample. The remainder of the core consists of minerogenic, clayey sediment, with variable silt content and occasional sand inclusions. No identifiable plant remains were found within the sediment.

#### 4.5.1. Sediment description

| | |
|---|---|
| 2 - 5 cm | Olive-black, homogeneous clay-mud with occasional silt and fine sand inclusions. The sediment unit is unstratified and homogeneous, with a diffuse lower boundary. |
| 5 - 8.5 cm | Slightly stratified, homogeneous, olive-black mud-clay. There are rare particles of silt and fine sand and the surface appears to be mottled. Diffuse lower boundary. |
| 8.5 - 21 cm | Dark brown mud/silt-clay, darkens slowly on exposure to air. Unstratified and homogeneous, with rare inclusions of fine sand. Very diffuse lower boundary. |
| 21 - 29 cm | Brownish-black, homogeneous clay-mud with occasional silt-sized particles. Unstratified, lower boundary very diffuse. |
| 29 - 164 cm | Homogeneous, reddish-black clay-mud with rare inclusions of silt and fine sand. Unstratified. |

#### 4.5.2. Pollen analysis

The pollen spectra from LGT evince a heavily wooded landscape, with arboreal taxa constituting up to 90% of the TLP (Figures 4.28 and 4.29). Tree species are dominated by *Quercus, Betula, Alnus glutinosa* and *Corylus avellana*-type, while *Ulmus, Fagus sylvatica, Salix, Ilex aquifolium* and *Fraxinus excelsior* all make a significant contribution to the assemblage. Two phases in which Poaceae, *Pteridium aquilinum* and other anthropogenic

indicator species expand have been identified, which are thought to reflect clearance for agriculture/grazing within the catchment (Figure 4.30). Species classed specifically as arable weeds were not found and there are very few examples of cereal-type grains in the assemblage, so it seems likely that grazing was more commonly practised than crop cultivation in this area. Pollen of ericaceous taxa (mostly *Calluna vulgaris* and to a lesser extent, *Erica*) is present in surprisingly small quantities throughout the core. *Filipendula* is also consistently present, perhaps originating from wet meadows or swampy areas close to the site, which are also likely habitats for
*A. glutinosa* and the small amount of *Salix* found throughout the profile.

Pollen concentrations were found to be relatively low at this site, although there are substantial peaks near the base of the profile (Figure 4.31). The lowest values occur just below the surface and from approximately 80-110 cm; samples were taken at 2 or 4 cm resolution throughout this phase, but preservation within the 'missing' samples was found to be too poor and species representation too biased for a meaningful pollen count to be obtained.

LPAZ 1: 164 (base of core)-123 cm

The earliest phase at LGT is characterised by mixed deciduous woodland, probably dominated by *Quercus,* which makes up between 20 and 30% of the assemblage at this time. *Betula, A. glutinosa* and *Corylus avellana*-type also contribute substantially to the TLP and *Ulmus, Fraxinus excelsior*, *Fagus sylvatica* and *Tilia* are all present. There is a temporary expansion of ferns (Pteropsida monolete indet., *Polypodium* and *Pteridium aquilinum*) during this phase, concomitant with a slight increase in herbs that might indicate small-scale clearance. Herbaceous taxa constitute less than 20% of the TLP throughout LPAZ 1, though species associated with clearance/farming are found even at this early stage. Ranunculaceae, *Rumex* spp. and *Plantago* spp. are present, though rare, while others including *Hordeum*-type, *Urtica dioica,* Chenopodiaceae, *Centaurea nigra* and *Artemisia*-type occur sporadically, perhaps indicating limited pastoral (and possibly agricultural) activity within a predominantly wooded landscape.

LPAZ 2: 123-89 cm

This zone features the first major expansion of herbaceous and agricultural/pastoral taxa at the site in conjunction with an overall reduction in tree and shrub species, although arboreal taxa still account for over 60% of the TLP during this period. The latter does not appear to affect any one taxon consistently, although *Quercus* falls to a little over 10% of the TLP from *c.* 100 cm upwards. Poaceae reaches an average of 15% of the TLP and anthropogenic indicators including *Rumex* spp., *Plantago lanceolata* and *Cichorium intybus*-type peak within this zone. Ferns also expand, with *Pteridium aquilinum,* considered to be an indicator of clearance, attaining values equivalent to 5% of the TLP. There is a rise in *Calluna vulgaris* towards the end of this phase indicating a slight expansion of heathland.

The assemblage suggests clearance for grazing and possibly agriculture within the catchment; the absence of arable weeds and the rarity of *Hordeum*-type cereal pollen, which includes numerous wild species (see Tables 1.4 and 1.5, pp65-6) suggests pastoral activity rather than crop cultivation at this time. A single grain of *Juglans regia* was found in this zone, perhaps indicating a Romano-British or later date. This single grain is probably a product of contamination, as discussed in Section 4.6.4 and in Chapter 5.

LPAZ 3, subzone 3a: 89-71 cm

LPAZ 3 is characterised by an increase in arboreal pollen, particularly of *A. glutinosa* and less consistently of *Quercus* and *Fraxinus excelsior. Ulmus*, *Fagus*, *Salix* and *Ilex* are present in small percentages (generally less than 2% of the TLP) and there are sporadic occurrences of *Tilia* and *Hedera helix. Betula* and to a lesser extent *Corylus avellana*-type decline from previous levels, concomitant with the expansion of *Quercus* in zone 3a, perhaps indicating succession from colonising woodland to mixed deciduous woodland. Poaceae, anthropogenic indicators and ferns (Pteropsida monolete indet., *Pteridium aquilinum*) are much reduced from the previous zone and far fewer herbs are present overall. *Plantago lanceolata* is, however, present throughout this zone (with the exception of one sample at 40 cm depth) and other herbs indicative of grazing or disturbance are present, though at low levels/sporadically. These include *Rumex* spp., *Urtica* spp., *Cichorium intybus*-type and *Artemisia*-type.

At first glance, the pollen assemblage suggests that woodland regeneration was occurring at this time and that farming had ceased or was much reduced within the catchment. The validity of this interpretation is discussed further in Chapters 5 and 6 in relation to the diatom and sedimentary records and the results of pollen simulation experiments. The distinguishing features of subzones 3b to d are reported below.

LPAZ 3, subzone 3b: 71-65 cm

Subzone 3b is defined by a short-lived expansion of *Quercus*, which peaks at over 30% of the TLP at this time. *Alnus glutinosa* and *Fraxinus excelsior* are reduced temporarily in this subzone and there is a brief fall in Poaceae at 68 cm.

LPAZ 3, subzone 3c: 65-48 cm

*Quercus* declines to previous levels (as in subzone 3a) in this subzone, while *A. glutinosa* recovers. *Betula* increases at the end of this phase.

LPAZ 3 subzone 3d: 48-25 cm

Subzone 3d features another expansion of *Quercus*, less dramatic than that in subzone 3b, but reaching average levels of 25% of the TLP from 42 cm upwards. *F. excelsior* attains consistent values of *c* 3-5% of the TLP at this time, declining towards the end of LPAZ 3. Values in this range are high enough to suggest that *F. excelsior* is a significant component of woodland at this time (*cf.* Anderson, 1970; Huntley & Birks, 1983). Anthropogenic indicator species fall to their lowest cumulative percentage at this time, which suggests abandonment of farmland in the catchment. *Corylus avellana*-type is almost unvarying throughout this subzone, constituting approximately 15% of the TLP. Poaceae begins to increase at around 26 cm depth, followed by its dramatic expansion in LPAZ 4.

LPAZ 4: 25-0 cm

The final stage of vegetation development at LGT is characterised by a major expansion of herbaceous taxa, especially those related to grazing and disturbance (*Urtica* spp., *Rumex* spp., *Plantago* spp., *Centaurea nigra*, *Cichorium intybus*-type). With the exception of *Trifolium*-type, all of the anthropogenic indicators found at LGT occur in this zone. *Avena/Triticum*-type and *Hordeum*-type are present, though sparse, hinting at the possibility of local crop cultivation, but specific arable weeds were not found and only one grain was classified definitively as *Avena/Triticum*-type.

Arboreal taxa decline dramatically to less than 40% of the TLP, affecting all tree and shrub species apart from *Salix*, which is not primarily a woodland plant (Huntley & Birks, 1983) and *Fagus sylvatica*, which attains its highest percentage at 16 cm depth and is present throughout LPAZ 4. This probably reflects recent (*i.e.* 1800 onwards) planting of beech in the area (*e.g.* Pearsall & Pennington, 1973; Barber, 1981). Overall, the assemblage indicates large-scale woodland clearance in the area for grazing or mixed farming. There is also a slight expansion of the main heathland species at this time (*Calluna vulgaris* and *Erica*) and both *Vaccinium*-type and *Empetrum nigrum* reappear in the assemblage.

**4.5.3. Diatom analysis**

The diatom assemblage at LGT is dominated by centric species and indicates moderately to highly eutrophic conditions, with diatoms of low nutrient status constituting less than 10% of the TTIC throughout much of the profile (Figures 4.32 and 4.33). There are five clear phases of change in the flora as described below.

LDAZ 1: 164-132 cm

The earliest phase at LGT is characterised by high percentages of centric diatoms, particularly *Cyclotella pseudostelligera*, *Cyclotella radiosa* and *Cyclostephanos dubius. Aulacoseira subarctica* and *Aulacoseira* undiff. are also important, together constituting around 20% of the TDC in this zone. *Pseudostaurosira brevistriata* makes a significant contribution to the assemblage, while *Staurosira construens* rises from less than 1% of the TDC to a peak of over 15% at 144 cm, declining towards the end of this phase. Rare types include *Achnanthes depressa* and *Caloneis undulata*, both of which are present in LDAZ 1 but absent in LDAZ 2. The only examples of *Epithemia sorex*, a diatom indicative of eutrophic conditions, were found in this period at LGT.

LDAZ 2: 132-89 cm

LDAZ 2 sees a decline in the highly eutrophic diatom *Cyclostephanos dubius*, concomitant with an increase in eutrophic to mesotrophic flora (*e.g. Asterionella formosa, Aulacoseira subarctica, S. construens var. binodis*) and a slight expansion of species associated with poor nutrient conditions (*Frustulia rhomboides*, *Tabellaria flocculosa*). *Fragilaria crotonensis* and *Synedra* spp. also increase and this is the only phase in which *Eunotia diodon* is found. *Navicula subtilissima* and *T. quadriseptata* expand, perhaps indicating an increase in humicity and some degree of acidification. *Cocconeis placentula* is present in very low percentages throughout this zone.

LDAZ 3: 89-43 cm

This zone is characterised by the expansion of most centric diatoms (*Cyclostephanos dubius* and *Cyclotella pseudostelligera, C. radiosa)* with the exception of *A. subarctica,* which drops to less than 20% of the TDC. *P. brevistriata* increases gradually throughout this period after an initial decline. The first examples of *Stauroneis phoenicenteron* and *Cavinula cocconeiformis* appear in this zone, while *Achnanthidium minutissimum, N. subtilissima* and *Tabellaria* spp. are much reduced. These changes suggest an increase in nutrient status, perhaps on account of inwash of organic material caused by disturbance in the catchment. *Staurosirella pinnata* virtually disappears at this time.

LDAZ 4: 43-20 cm

This zone exhibits a dramatic increase in eutrophic-to-mesotrophic and mesotrophic-to-oligotrophic diatoms at the expense of high nutrient status species. Most centric diatoms fall significantly throughout this period, most notably *Cyclotella pseudostelligera*, which drops to its lowest value at less than 10% of the TDC. *Stephanodiscus parvus* (eutrophic-to-mesotrophic) increases together with *N. radiosa, F. crotonensis, Frustulia rhomboides* and *Sellaphora pupula.* The only examples of *N. soehrensis* and *Cymbella affinis* are found at this time. *Staurosira construens* expands gradually to peak at more than 20% of the TDC by the end of the zone.

LDAZ 5: 20-0 cm

The final phase at LGT sees the return of *Stauroneis phoenicenteron* and *Cavinula cocconeiformis,* the rise of *Rossithidium pusillum* and significant increases in *A. minutissimum* and *N. subtilissima.* A gradual decline in *Staurosira construens* is countered by a rise in *S. construens var. binodis* (both high to medium nutrient status species). *F. rhomboides* also declines, while *A. subarctica* drops dramatically, but peaks at approximately 20% of the TDC in the subsurface sample. *Cyclotella pseudostelligera* increases substantially towards the surface, while *Sellaphora pupula* and *Fragilaria crotonensis* are lost. There is an increase of species associated with low nutrient status in the first part of this zone, followed by a rapid expansion of diatoms indicative of high nutrient status in the most recent period[1].

[1] Higher resolution sampling might allow this zone to be divided further, but this was beyond the scope of the current project owing to the recent date of the material at this depth.

### 4.5.4. Age estimation

SCPs were found to be largely absent below 24 cm, but a very small number of carbonaceous particles were found in samples up to 40 cm depth, dating this period to *c* AD 1850 (Figure 4.27). The substantial peak at 12 cm is thought to mark AD 1978 ± 4 years (Rose *et al.,* 1995; Rose & Appleby, 2005). A larger number of radiocarbon determinations are available for LGT than for any of the other study sites (Table 4.1), and apart from a reversal at 100-102 cm, which is thought to result from inwashed organic material (see Section 5.3, Chapter 5), the dates were found to be in the correct sequence. *Juglans regia,* a Romano-British introduction (Clapham *et al.,* 1962; Godwin, 1975; Huntley & Birks, 1983) was found at 102 cm depth, suggesting a *Terminus Post Quem* (*TPQ*) of AD 69 (see Section 1.4.2) or later. However, this single grain is probably an artefact of contamination, unless sediment accumulation was remarkably slow in the later Iron Age (*i.e.* between the AMS date at 115-117 cm and the inferred Romano-British date at 102 cm) and very rapid throughout the Romano British and early post-Roman periods (from the *J. regia TPQ* to the early medieval AMS date at 60-62 cm). If (with the exception of the reversed measurement) the radiocarbon dates are accepted as an accurate reflection of the date at which the pollen assemblage was deposited, the *J. regia TPQ* is difficult to justify. This is discussed further in Chapter 5.

The AMS dates for LGT range from the Bronze Age (1612-1433 cal. BC) at the base of the core to the early medieval period (cal. AD 576-677) at 60-62 cm depth (Table 4.1). This site has provided some of the most interesting results produced by this study and is discussed in greater detail in the following chapter.

## 4.6. Tewet Tarn (TWT)

The core from TWT was problematic as a large reed stem was present approximately halfway down the core, which had evidently caused some disturbance at this depth if not in the over- and underlying deposits. Unfortunately, despite numerous attempts it was not possible to obtain a second core from the tarn. LOI shows a significant increase in organic content below 32 cm, where the mass lost at 550˚C rises from approximately 40% to over 90%, declining gradually and then dramatically towards the base of the core (Figure 4.34). This corresponds with the sediment description; most of the profile consists of clayey lake mud with small reed and aquatic plant fragments, but the section with high organic content contains a significant quantity of large reed fragments (*Phragmites communis*). This sudden change in the nature of the sediment suggests a truncation event, which is supported by both the radiocarbon dates (Table 4.1) and the palynological data (Section 4.6.2).

### 4.6.1. Sediment description

| | |
|---|---|
| 0 – 29.5 cm | Homogeneous, reddish-black, greasy clay-mud. Unstratified, with rare herbaceous fragments (both large and small (Dg and Dh in Table 2.1), fine sand and silt-sized particles. Lower boundary very diffuse. |
| 29.5 - 64 cm | Fibrous, reddish-black mud-clay with many large herbaceous fragments derived from reed stems (*P. communis*). Occasional small herbaceous inclusions, fine sand and silt particles. The sediment is unstratified and the lower boundary is very diffuse. |
| 64 - 68 cm | Reddish-black organic clay-mud with rare inclusions of fine sand and herbaceous fragments. Laminations are faintly visible. Transitional layer with homogeneous structure and a conspicuous lower boundary. |
| 68 - 72 cm | Brownish-black, homogeneous mud-clay with rare particles of fine sand. Slightly stratified, with conspicuous lower boundary. |
| 72 - 77 cm | Homogeneous, reddish-black (dark), greasy, organic clay/silt-mud with rare herbaceous fragments. Unstratified |

### 4.6.2. Pollen analysis

As intimated above, the core from TWT is almost certainly truncated. The pollen assemblage changes abruptly at 46 cm and 39 cm, both of which fall within the section disturbed by reed stems. The lower part of the core suggests more gradual vegetation change and appears to be an intact sequence, but radiocarbon dates from the base of the core show the assemblage to be late-glacial in date; far earlier than would be expected at less than a metre depth and unfortunately covering a period irrelevant to the research questions in this project. Four palynological zones have been identified and are described below, though only LPAZs 1 and 2 are thought to run consecutively (Figures 4.35 and 4.36).

LPAZ 1: 77 (base of core)-61 cm

The first phase at TWT is dominated by *Betula* and Poaceae, which constitute 20%-40% and a little over 20% of the TLP respectively. Herbaceous taxa increase from *c* 50-60% of the TLP during this phase at the expense of *Betula*. High percentages of *Artemisia*-type and other species associated with open ground suggest a tundra environment with colonising *Betula* woodland. Incidentally, some of the open-ground indicators found in this phase are considered to be arable/pastoral taxa when found in more recent deposits (*e.g. Centaurea cyanus, Urtica dioica, Rumex* spp., *Plantago media/major*); this raises the question of whether the species are reliable anthropogenic indicators where the prehistoric/historical context is unknown, leading to issues of circularity in interpretation. High levels of *Myriophyllum alterniflorum* are found during this and the subsequent zone (up to 500% relative to the TLP) together with other aquatics (*Potamogeton natans*-type, *M. spicatum, Menyanthes trifoliata*), suggesting that the tarn was extant by the late-glacial period, despite its shallow profile (Figure 3.6, p133).

LPAZ 2: 61-46 cm

This zone is marked by a dramatic decline in *Artemisia*-type and Poaceae undiff. and a reduction in herbaceous pollen in general. Cyperaceae undiff. and *Myriophyllum alterniflorum* are also much reduced, while *Betula* expands to a maximum of 70% of the TLP, indicating the arrival of colonising birch woodland. There is a single example of Chenopodiaceae towards the end of this phase and *Fraxinus excelsior* first appears in this zone. *Calluna vulgaris* is also present though rare. Sampling is sparse during this phase as further analyses were abandoned following receipt of unexpectedly early radiocarbon dates; further work on this section of the core may be carried out at a later date.

LPAZ 3: 46-39 cm

There is a substantial decline in arboreal taxa at this time, while Poaceae – perhaps originating from *Phragmites* growing at the tarn margins – and Cyperaceae peak in this phase. A dramatic decline in arboreal taxa together with peaks in *Pteridium aquilinum, Artemisia*-type and Caryophyllaceae suggests a clearance event, although there are few other anthropogenic indicators present (*Rumex acetosa* and *U. dioica,* but these are rare). Aquatics are virtually absent throughout this period. This part of the profile covers the section in which large reed stems were found and in which the sediment is thought to have been disturbed to some extent, making interpretation of the pollen data of questionable value.

LPAZ 4: 39-0 cm

In the most recent phase at TWT Poaceae declines to a little less than 20% of the TLP and woodland taxa expand dramatically, especially *Quercus, Alnus glutinosa and Corylus avellana*-type. *Fagus sylvatica* and *Ulmus* are also present during this period, when the first examples of

*Picea* are found, indicating the instigation of nineteenth century plantations. *Betula* recovers from its previous decline, though making a far smaller contribution to the TLP than in LPAZ 2. There is also an expansion of anthropogenic taxa (*Plantago* spp., *Rumex* spp.) in conjunction with rare occurrences of *Avena/Triticum*-type and *Hordeum*-type. It seems likely that limited farming was occurring in the surrounding landscape at this time, despite arboreal taxa constituting around 80% of the TLP throughout the zone. This is particularly noteworthy as the landscape around TWT consists of open, grazed land at present; it is possible that the high levels of arboreal pollen come from woodland to the north or from Ullock Coppice to the south-west, which is shown on nineteenth century maps (Map 3.16, p134), but seemingly absent or much reduced in the present (*e.g.* Map 3.17 and Image 3.15, p134).

**4.6.3. Age estimation**

The radiocarbon dates and SCP profile obtained for TWT show that the sudden change in vegetation between LPAZ 2 and 3 represents either a lengthy hiatus in deposition or truncation of the profile (Figure 4.34). Carbonaceous particles were found to disappear between 30 and 40 cm, while the substantial spike in concentration at 20 cm is thought to be the 1970s peak (Rose *et al.*, 1995; Rose & Appleby, 2005). This suggests that the upper half of the sediment core has accumulated within the last 200 years. The two AMS age estimates for TWT indicate that the lower part of the core was deposited in the Lateglacial to early Holocene (Upper Palaeolithic in terms of British archaeology), which is supported by the apparent succession from tundra-like vegetation (*e.g.* relatively high levels of *Artemisia*-type and other herbs of open ground) in LPAZ 1 to colonising birch woodland in LPAZ 2 (Figures 4.35 and 4.36). Pollen concentrations are very low at the base of the core and increase dramatically from LPAZ 3 onwards, lending further support to the truncation hypothesis (Figure 4.37). Further work on the Lateglacial/early Holocene section of the core might be carried out at a later date (for example, increasing the resolution of pollen samples, measuring the *Betula* grains to see whether *B. nana* is present and examining the diatom flora), but was not relevant to the research questions of this project. It seems very likely that the tarn has been dredged or otherwise scoured of deposits, perhaps in the late eighteenth/early nineteenth century AD (considering the SCP curve). No records of this were found while seeking potential sites, but considering the present-day landscape, it is possible that former landowners dredged the tarn to use it as a source of drinking water for sheep or other animals.

*Picea* was found in the recent deposits and not in earlier sediments, but a single SCP was found at 70 cm depth.  SCPs are only produced by combustion at high temperatures associated with industrial burning of fossil fuels and are not produced by 'natural' fires (Rose & Appleby, 2005).  Although carbonaceous particles are occasionally encountered in pre-industrial deposits, possibly associated with smelting or ceramic production (Rob Craigie, pers comm.), at this depth and time (Palaeolithic) and considering the problems with the core from TWT, the SCP is more likely to result from contamination.

**4.7. Summary of results**

The most useful sites examined were BFT and LGT; the cores from BYT and BLT were found to be too recent to answer the research questions and the latter, together with LLT, appears to have suffered mixing, making the meaning of pollen and diatom spectra from these sites questionable.  BYB and TWT are either truncated or severely compressed; considering the radiocarbon dates and SCP data from these sites, the early medieval part of the sequence is either so brief as to be of no interpretive value, or (more likely) missing altogether.

Although the radiocarbon dates for BFT are somewhat problematic, the sequence appears intact and reversals are thought to be the result of inwashed organic sediment/peat from the catchment area.  The pollen assemblage shows strong evidence of agricultural activity throughout the period investigated.  LGT benefits from a good chronology and produced pollen and diatom spectra that suggest a stark contrast with the landscape history of BFT.  Pollen modelling and simulation techniques have been used in order to explore possible landscape reconstructions for both of these sites in the following chapter.

Table 4.1. AMS radiocarbon dates for all of the study sites

| SITE | Date identifier | Depth/cm | Radiocarbon age (2 sigma ranges) | Calibrated radiocarbon age/years BP | Calibrated radiocarbon age cal AD/BC |
|---|---|---|---|---|---|
| BFT | SUERC-17773 | 40-42 | 1785 +/-38 | 1821-1607 | cal AD 129-344 |
| BFT | SUERC-17772 | 73-75 | 1498 +/-38 | 1515-1306 | cal AD 435-644 |
| BFT | SUERC-17771 | 112-114 | 1523 +/-38 | 1520-1340 | cal AD 430-610 |
| BLT | SUERC-18137 | 55-57 | 1022 +/-35 | 1052-800 | cal AD 898-1150 |
| BLT | SUERC-18138 | 85-87 | 777 +/-35 | 763-666 | cal AD 1188-1285 |
| BLT | SUERC-18139 | 112-114 | 739 +/-37 | 734-571 | cal AD 1216-1380 |
| BYB | SUERC-17775 | 50-52 | 171 +/-35 | 295-present | cal AD 1655-1950 |
| BYB | SUERC-17774 | 67-69 | 6195 +/-38 | 7244-6986 | 5295-5037 cal BC |
| LGT | SUERC-17783 | 60-62 | 1399 +/-38 | 1374-1274 | cal AD 576-677 |
| LGT | LGRGTNO1/100 | 100-102 | 3360 +/-40 | 3692-3480 | 1743-1531 cal BC |
| LGT | SUERC-17782 | 115-117 | 2421 +/-36 | 2700-2349 | 751-400 cal BC |
| LGT | SUERC-17781 | 153-155 | 3084 +/-36 | 3378-3215 | 1429-1266 cal BC |
| LGT | LGRGTNO2/164 | 162-164 | 3240 +/-40 | 3561-3382 | 1612-1433 cal BC |
| LLT | SUERC-17780 | 63-65 | 2636 +/-38 | 2845-2719 | 896-770 cal BC |
| LLT | SUERC-17778 | 110-112 | 1608 +/-36 | 1593-1405 | cal AD 357-545 |
| LLT | SUERC-17776 | 142-144 | 1451 +/-36 | 1400-1297 | cal AD 551-654 |
| TWT | SUERC-17785 | 55-57 | 9922 +/-44 | 11602-11230 | 9653-9281 cal BC |
| TWT | SUERC-17784 | 74-76 | 12082 +/-51 | 14085-13779 | 12136-11830 cal BC |

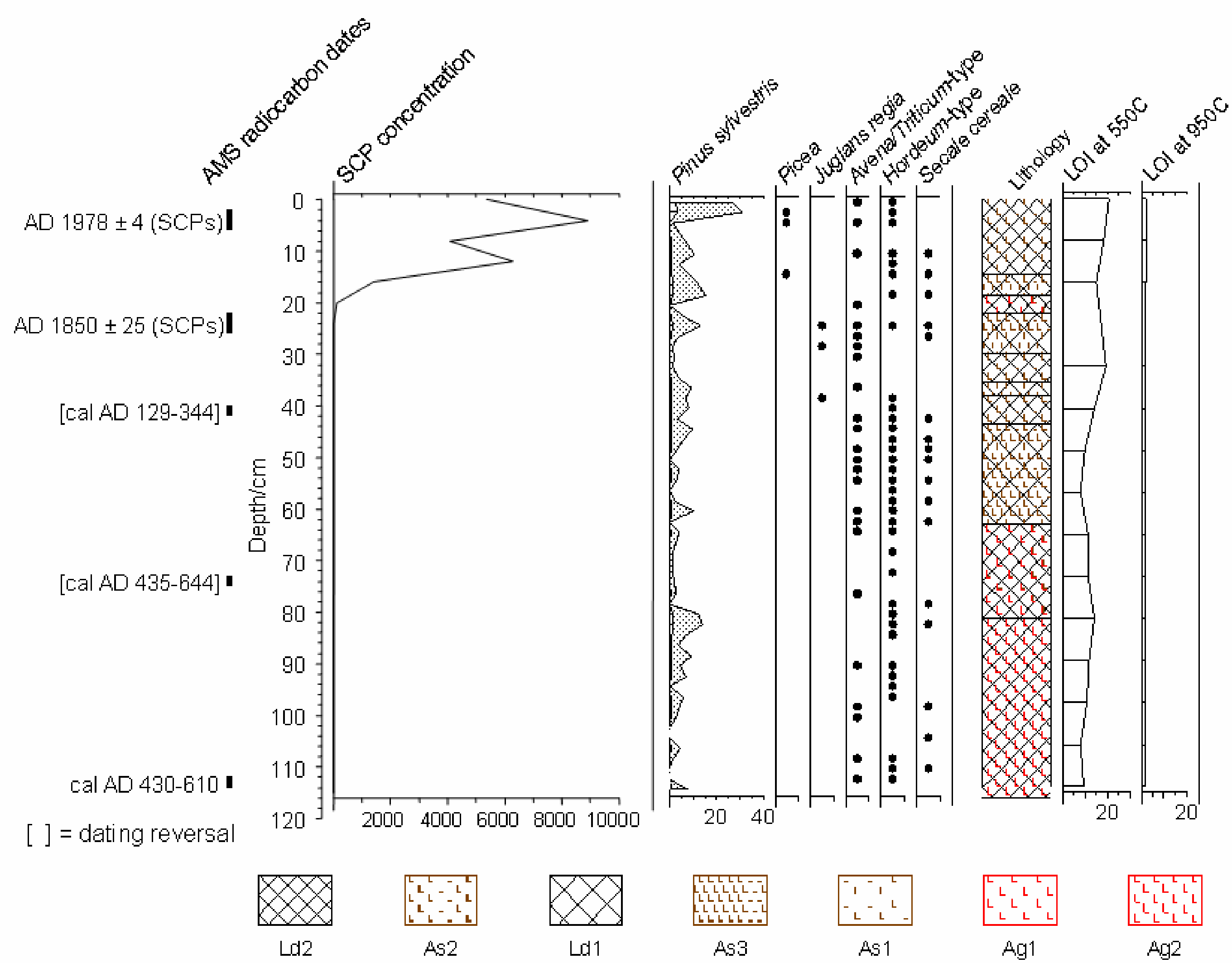



Figure 4.1: BFT age estimation, lithology (see Table 2.1 for components) and LOI. *P. sylvestris* exaggerated by a factor of 10. Nomenclature for pollen types follows Bennett, 1994.

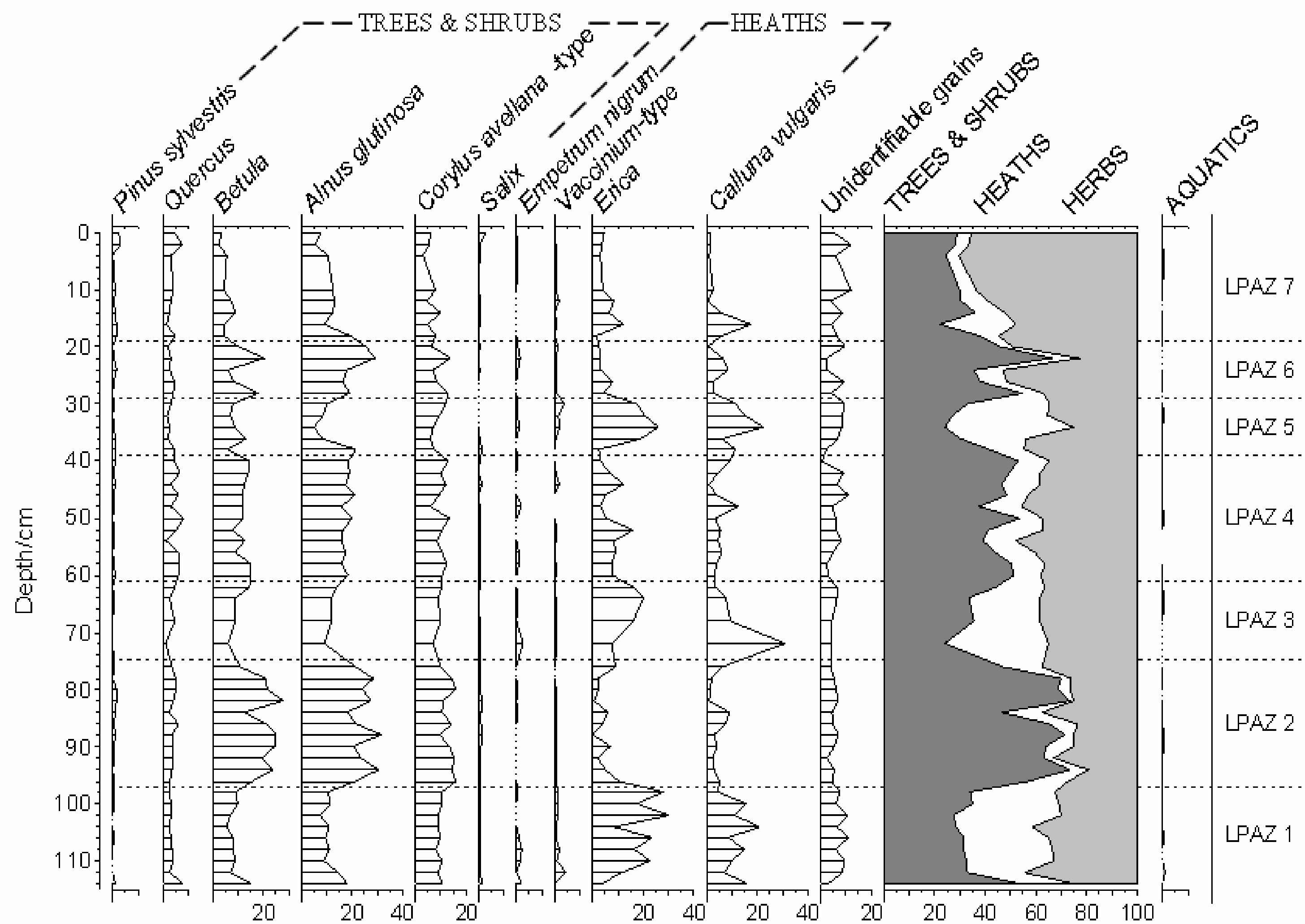



Figure 4.2: BFT pollen percentage diagram showing key arboreal and ericaceous types (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

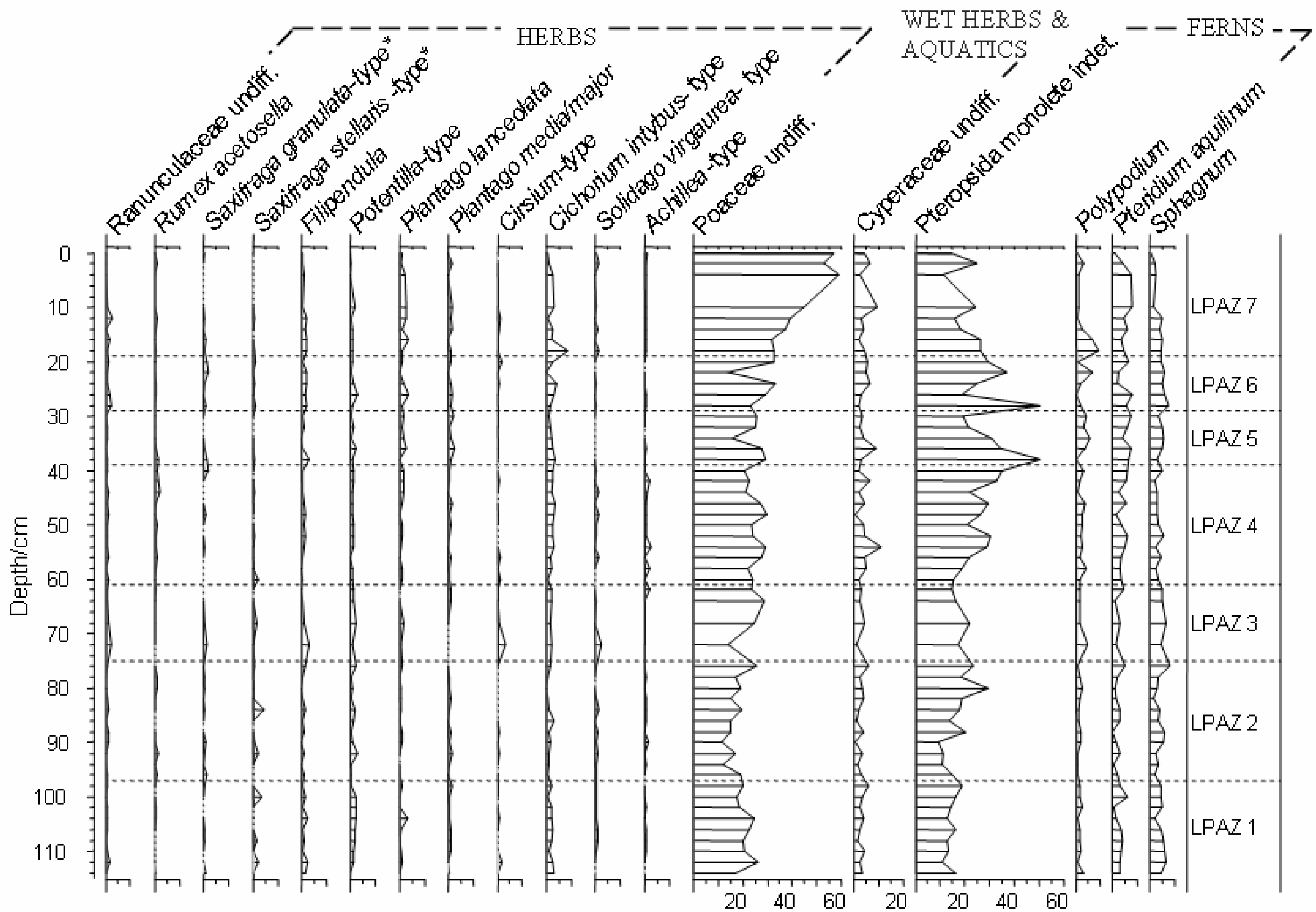



Figure 4.3: BFT pollen percentage diagram showing key non-arboreal pollen and spores (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

*subject to confirmation

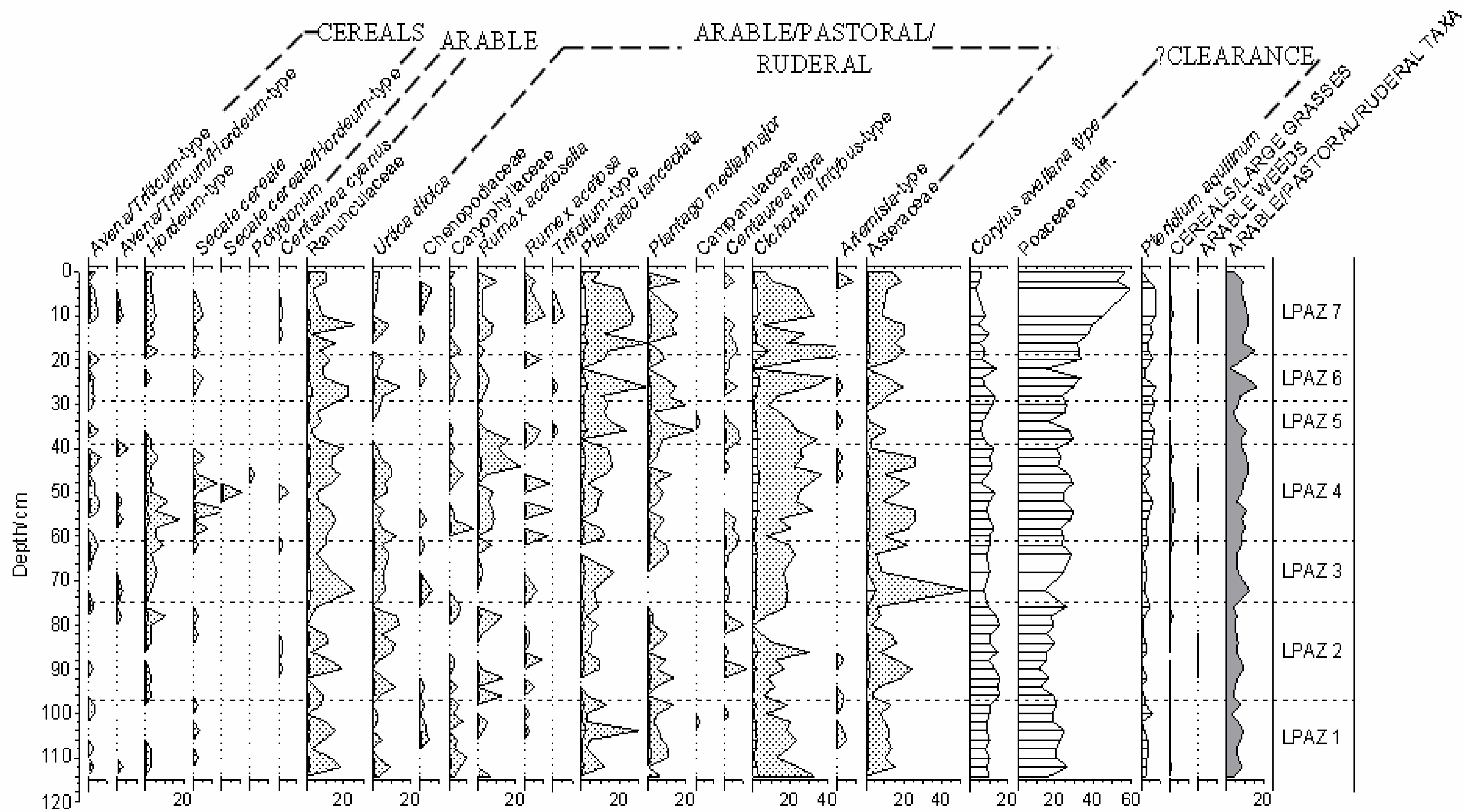



Figure 4.4: BFT pollen percentage diagram showing anthropogenic indicator species. Stippled graphs are exaggerated by a factor of 10. Asteraceae includes all members of this family that are not plotted separately (*e.g. Solidago virgaurea*-type is included, but *Artemisia*-type is not). Nomenclature follows Bennett, 1994.

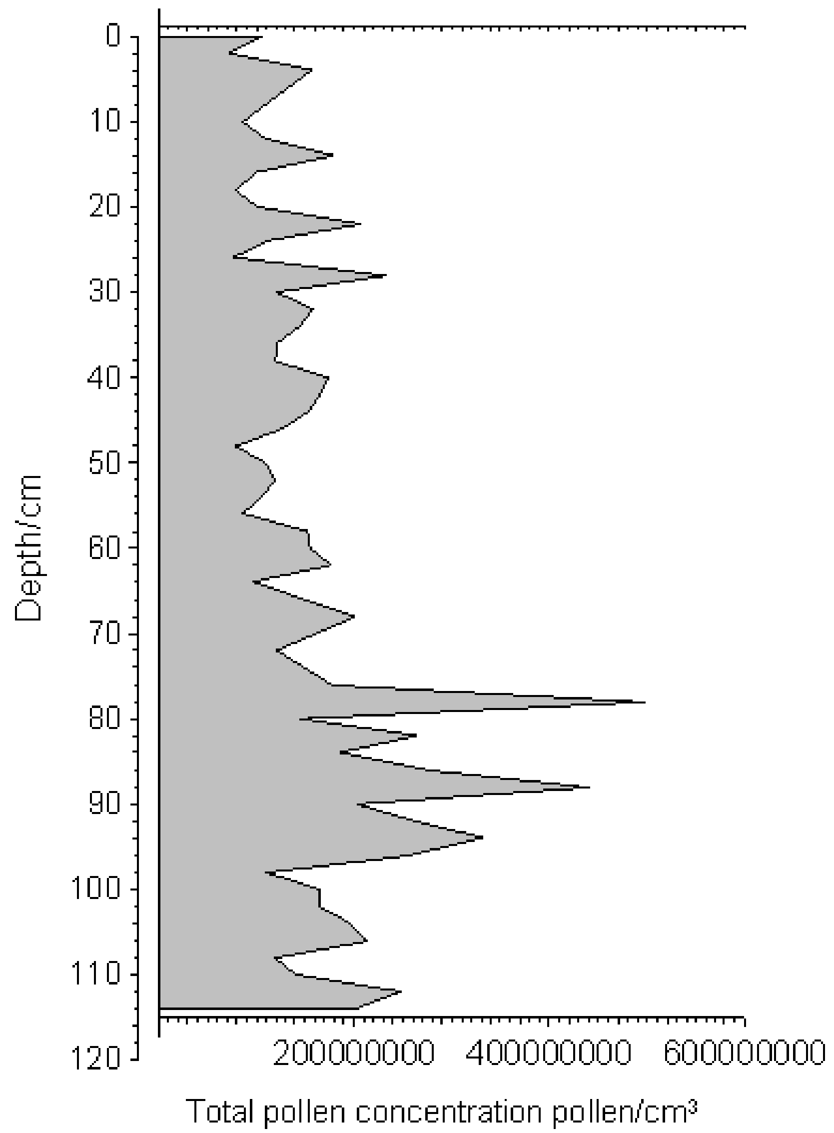



Figure 4.5: BFT total pollen concentration diagram based on the TLP. Scale is $1x10^{-5}$.

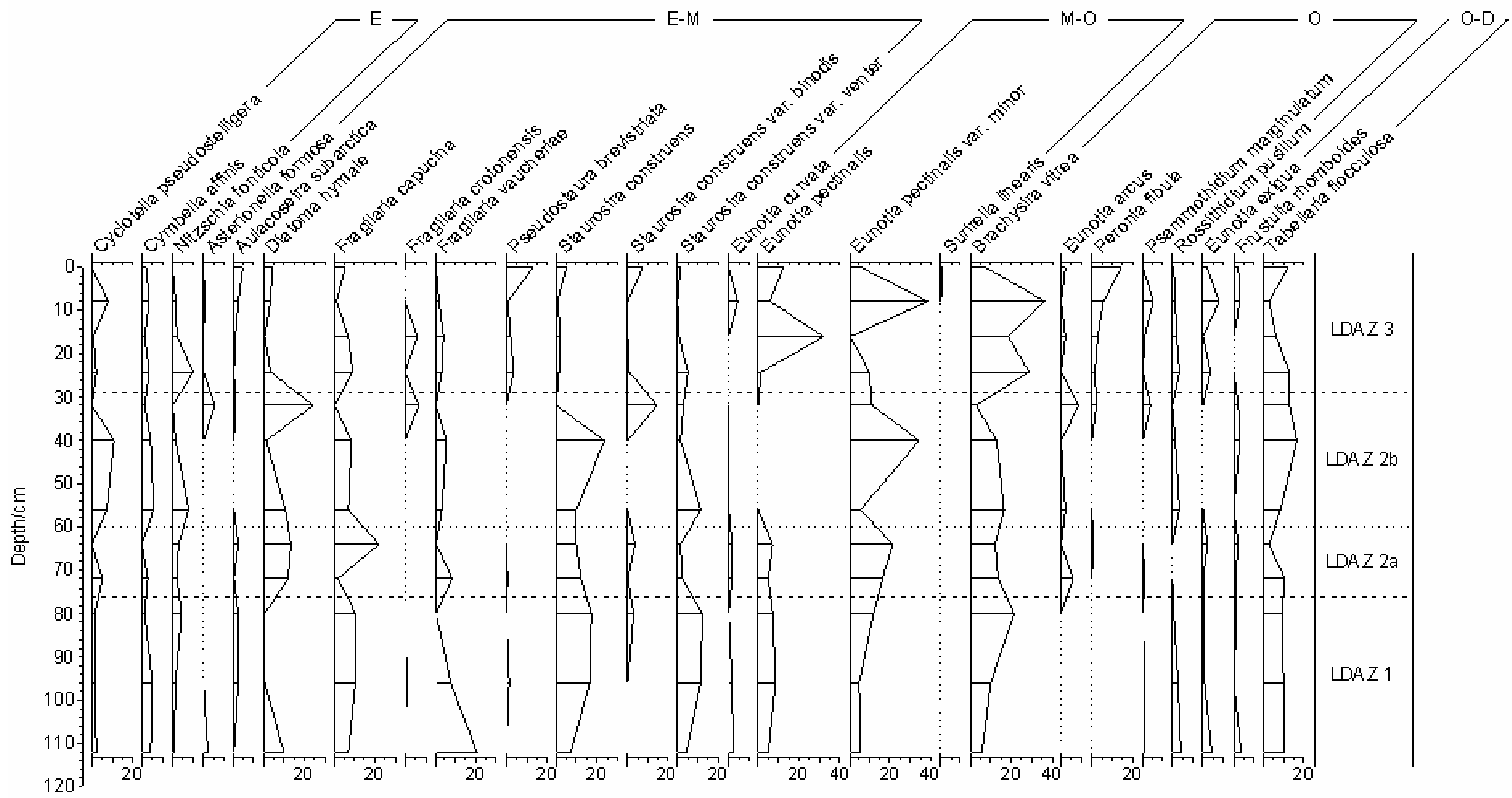
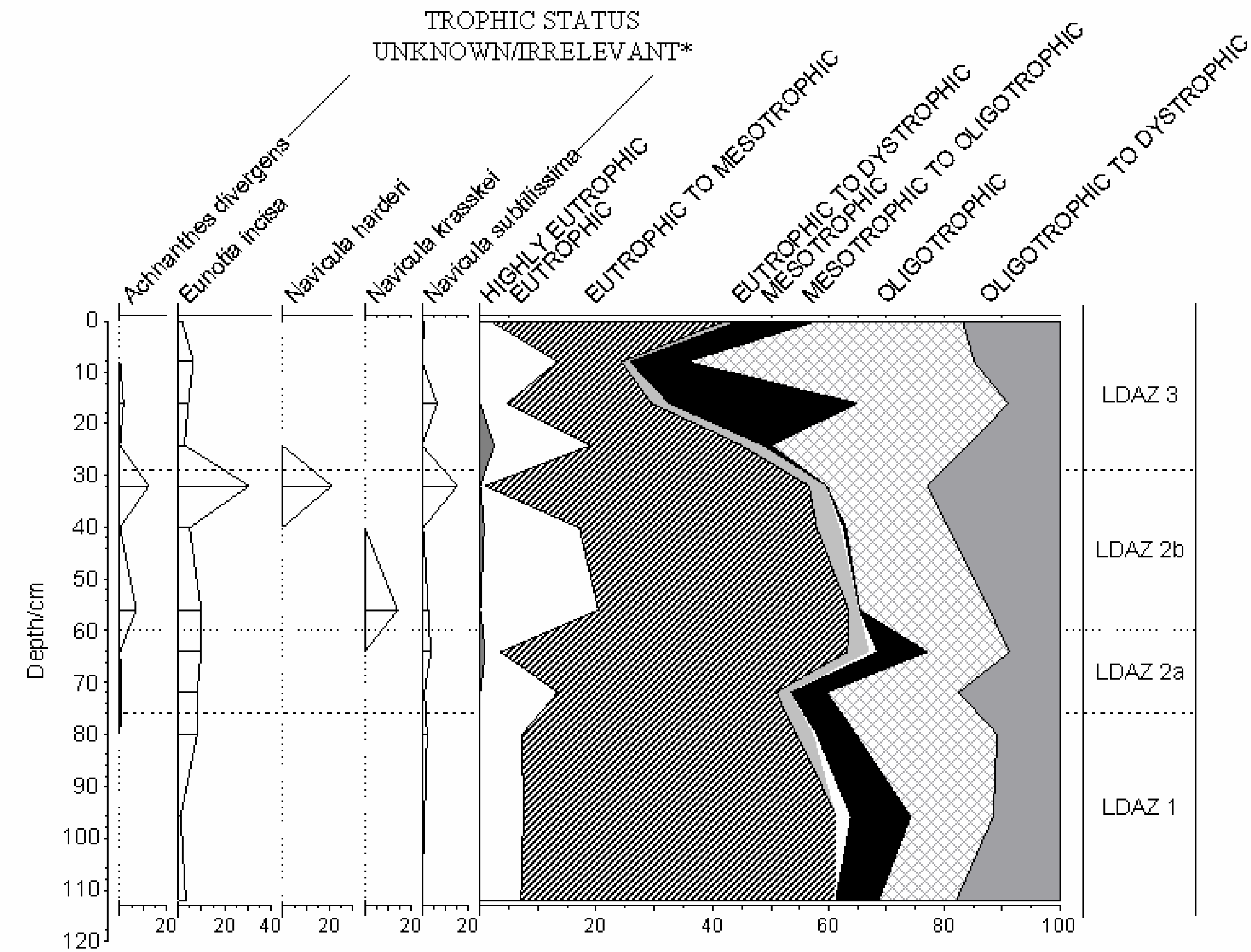



Figure 4.6: BFT diatom percentage diagram showing key trophic indicator species. Nomenclature follows Whitton *et al.,* 2003. Group designations are: E – eutrophic; M – mesotrophic; O – oligotrophic, D – dystrophic (E-M – eutrophic to mesotrophic, etc).




*'Irrelevant' (*sensu* Denys, 1991-2) means that nutrient status is not thought to impact on the diatom's distribution significantly.

Figure 4.7: BFT diatom percentage diagram showing key species (present at maximum 2% or more of the TDC) for which trophic information is unknown/irrelevant and cumulative trophic group percentages.

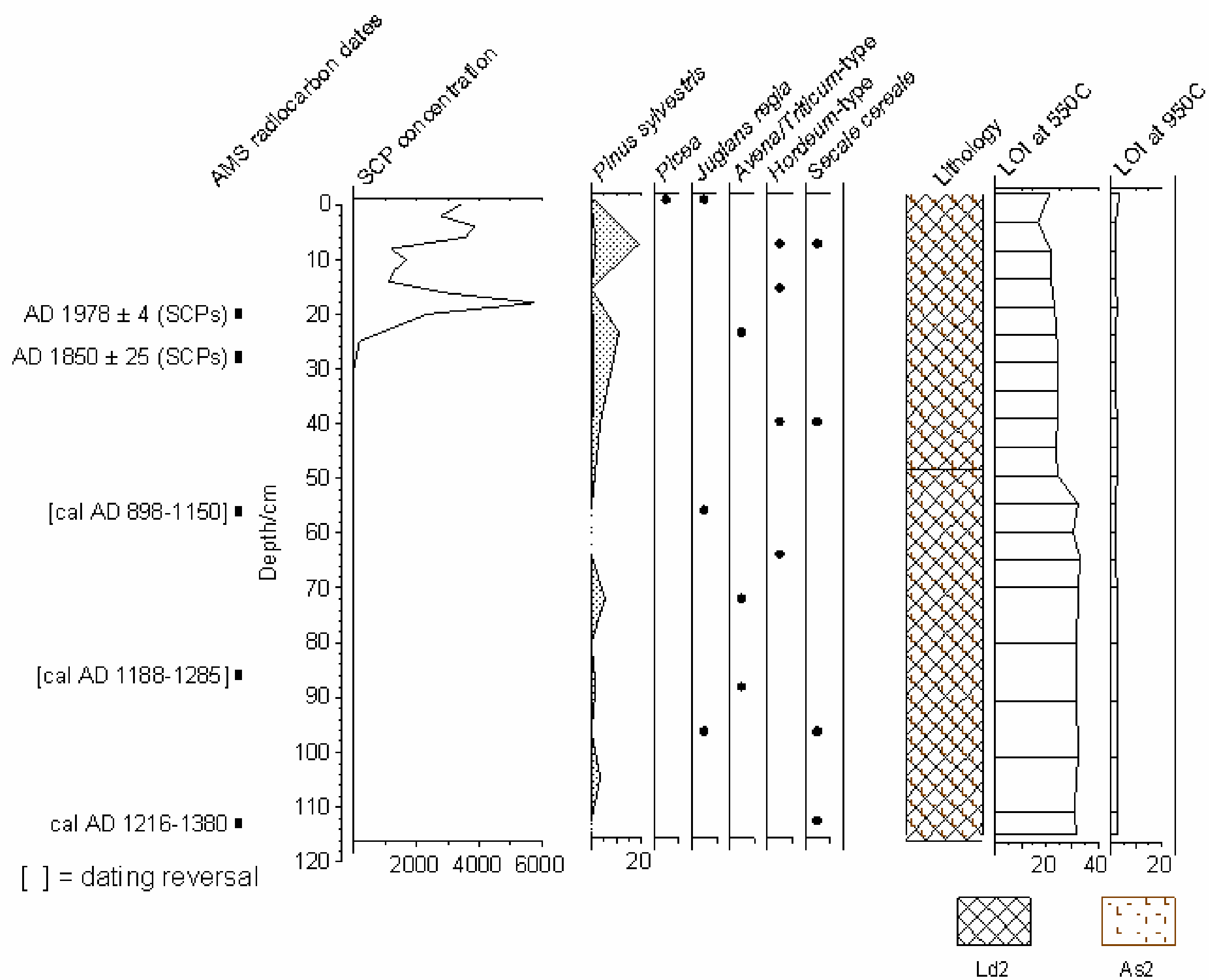



Figure 4.8: BLT age estimation, lithology (see Table 2.1 for components) and LOI. *P. sylvestris* exaggerated by a factor of 10. Nomenclature for pollen types follows Bennett, 1994.

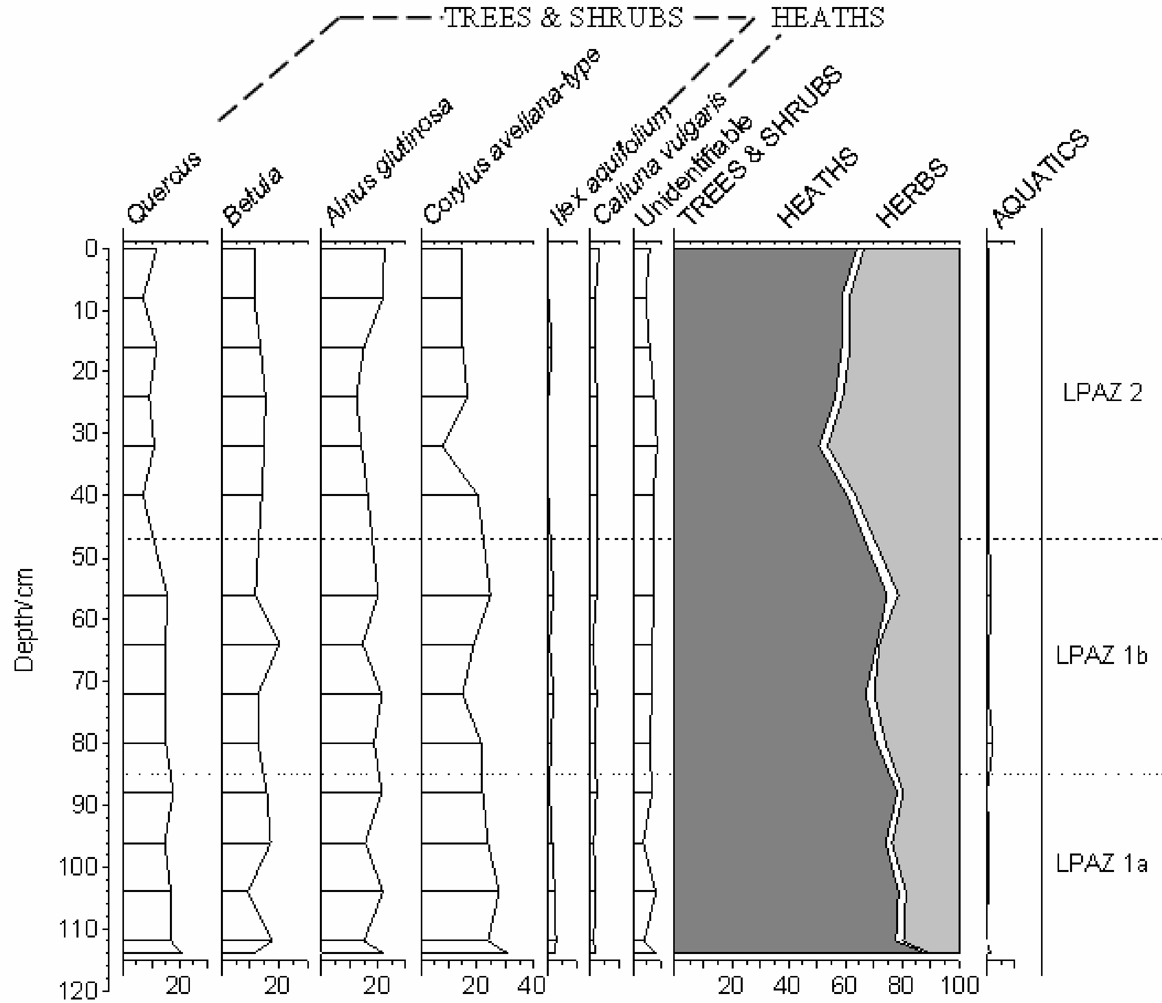



Figure 4.9: BLT pollen percentage diagram showing key arboreal and ericaceous types (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

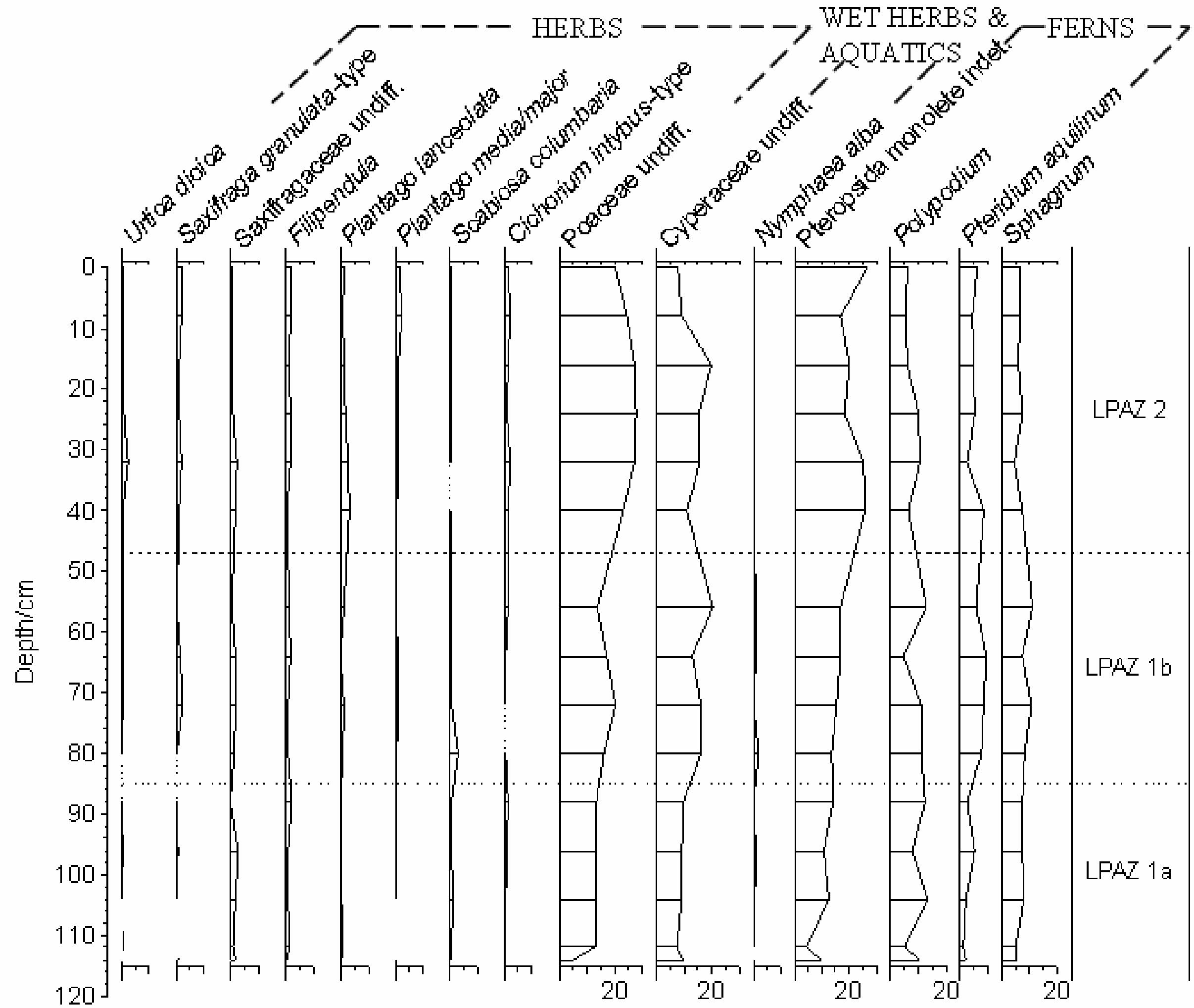



Figure 4.10: BLT pollen percentage diagram showing key non-arboreal pollen and spores (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

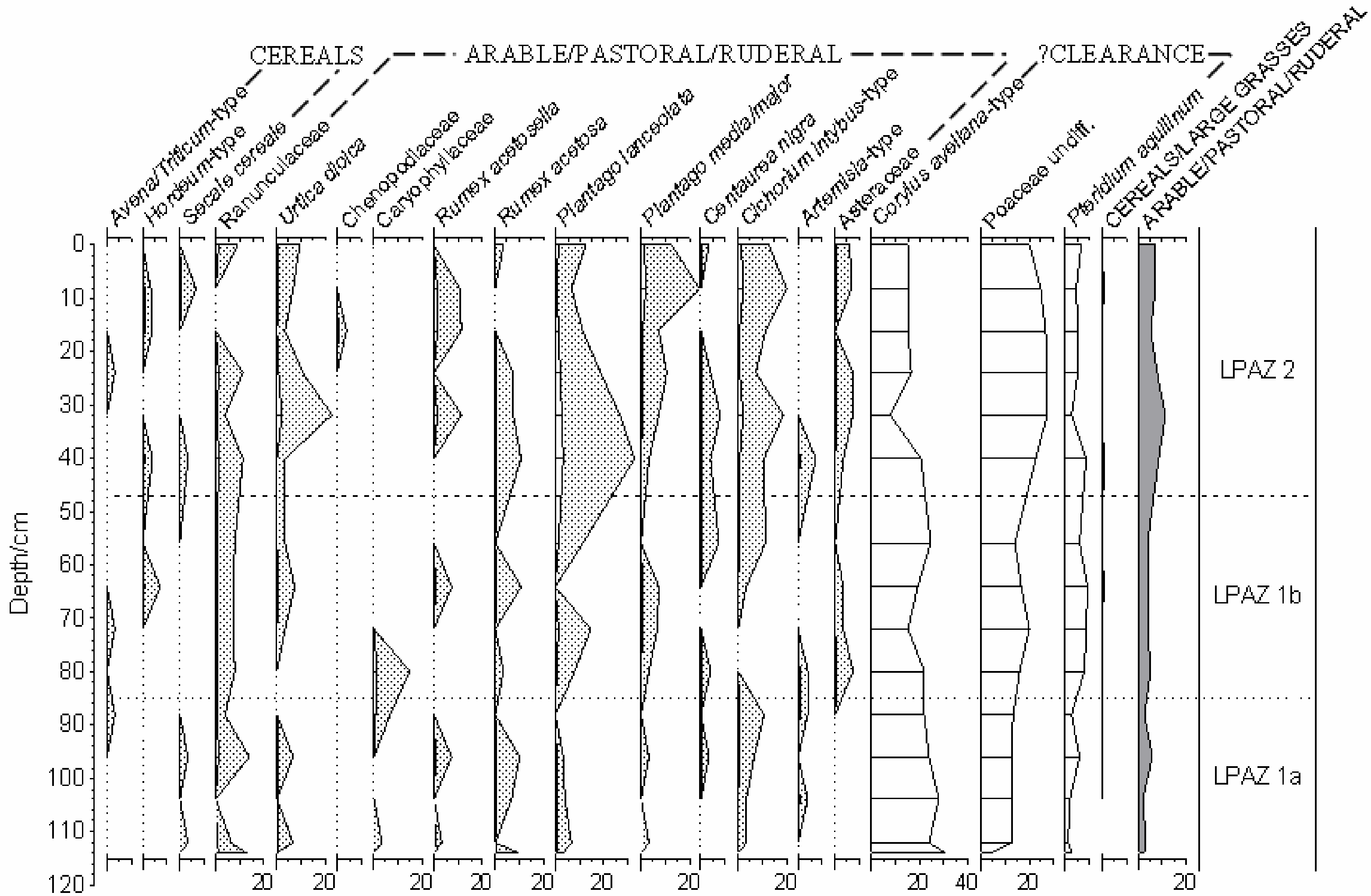



Figure 4.11: BLT pollen percentage diagram showing anthropogenic indicator species. Stippled graphs are exaggerated by a factor of 10. Asteraceae includes all members of this family that are not plotted separately (*e.g. Solidago virgaurea*-type is included, but *Artemisia*-type is not). Nomenclature follows Bennett, 1994.

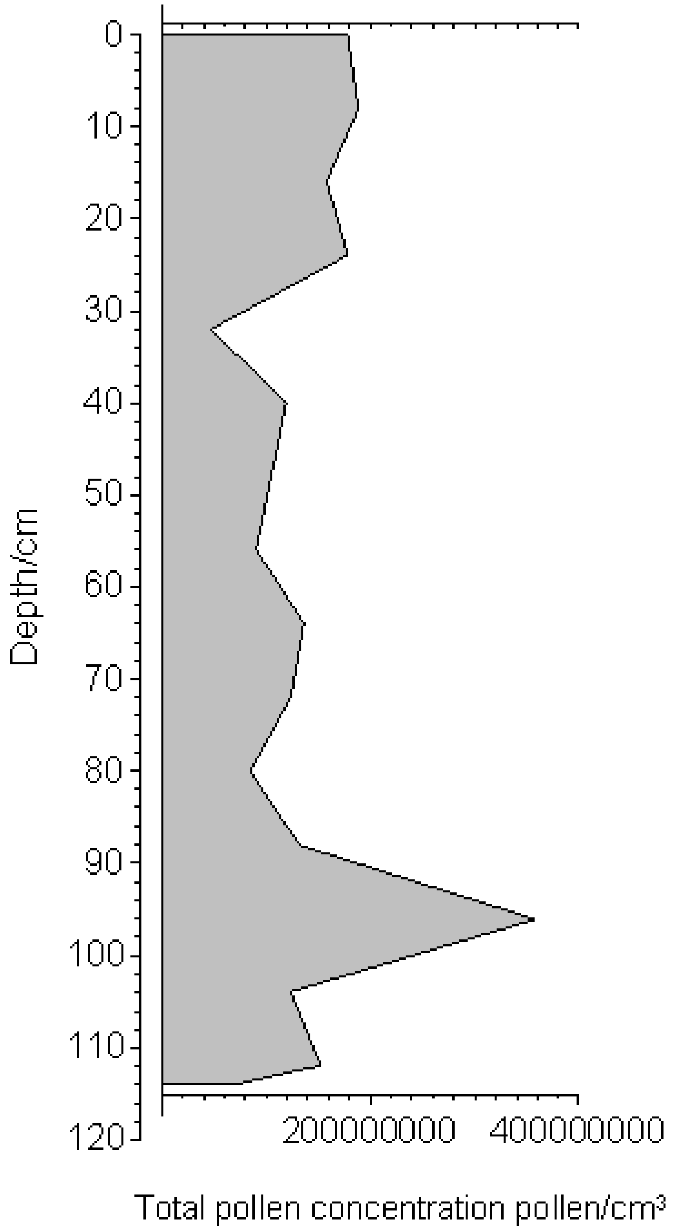



Figure 4.12: BLT total pollen concentration diagram based on the TLP. Scale is $1x10^{-5}$.

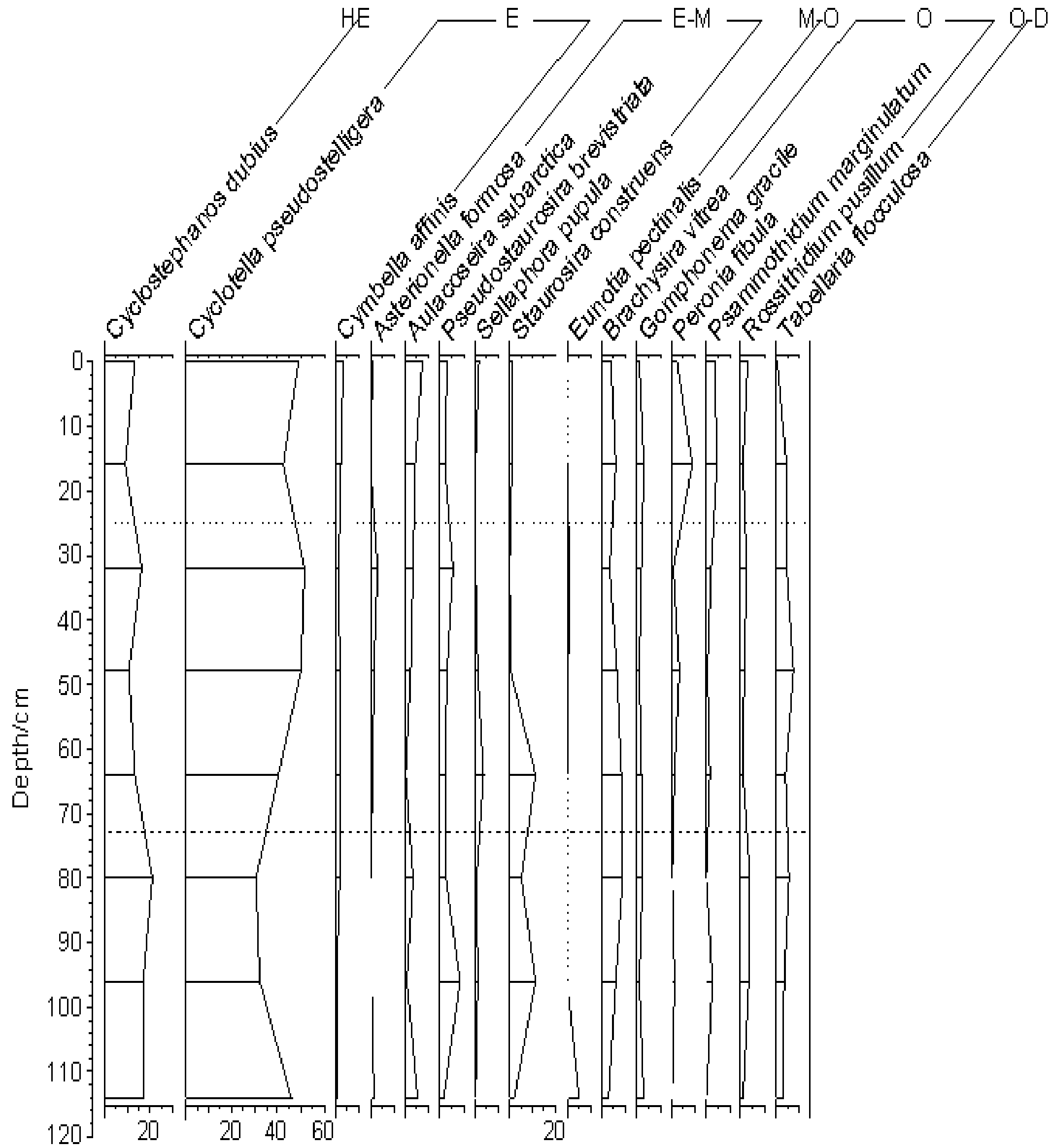
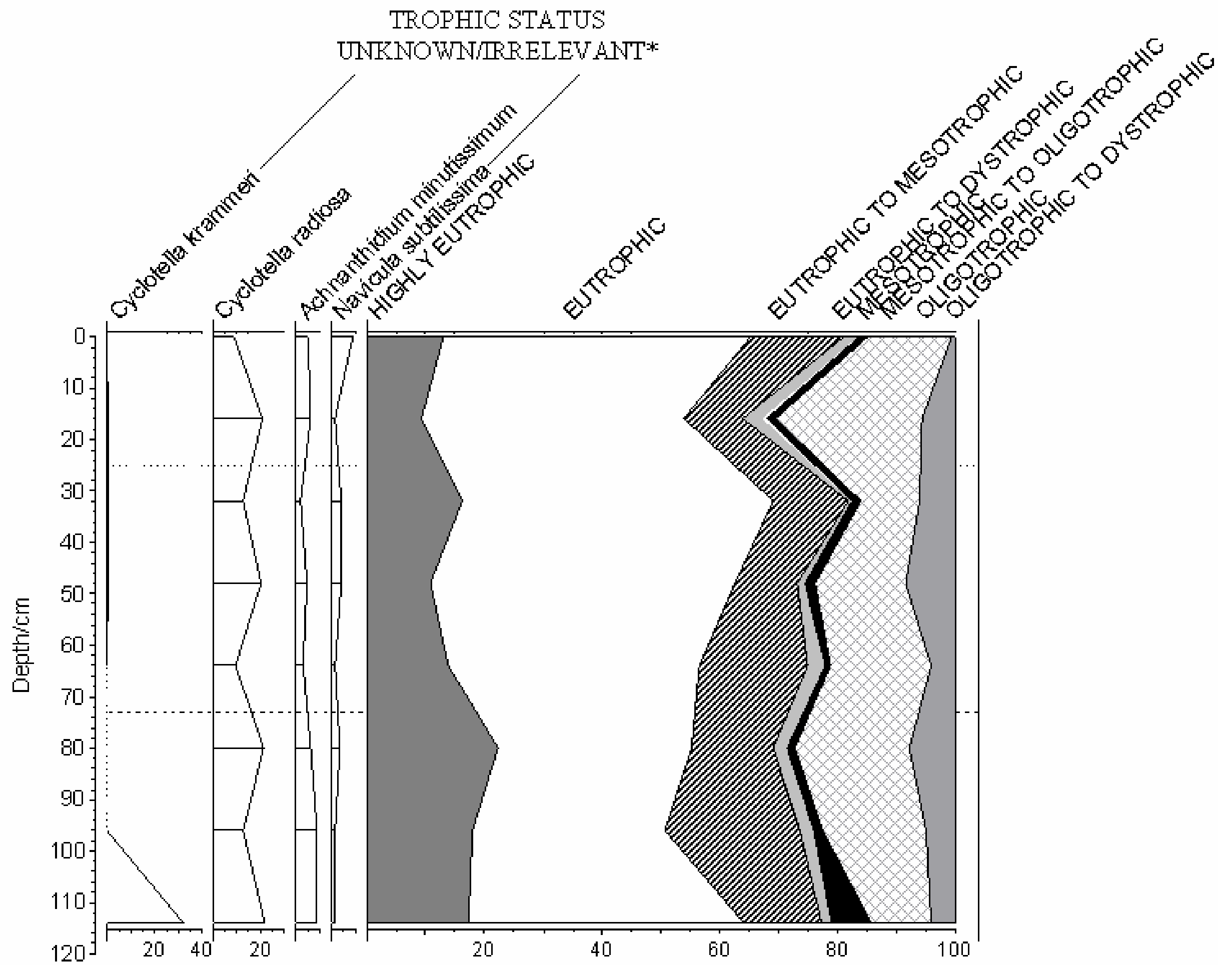



Figure 4.13: BLT diatom percentage diagram showing key trophic indicator species. Nomenclature follows Whitton *et al.,* 2003.

Group designations are: HE – highly eutrophic; E – eutrophic; M – mesotrophic; O – oligotrophic, D – dystrophic (E-M – eutrophic to mesotrophic, etc).




*'Irrelevant' (*sensu* Denys, 1991-2) means that nutrient status is not thought to impact on the diatom's distribution significantly.

Figure 4.14: BLT diatom percentage diagram showing key species (present at maximum 2% or more of the TDC) for which trophic information is unknown/irrelevant and cumulative trophic group percentages.

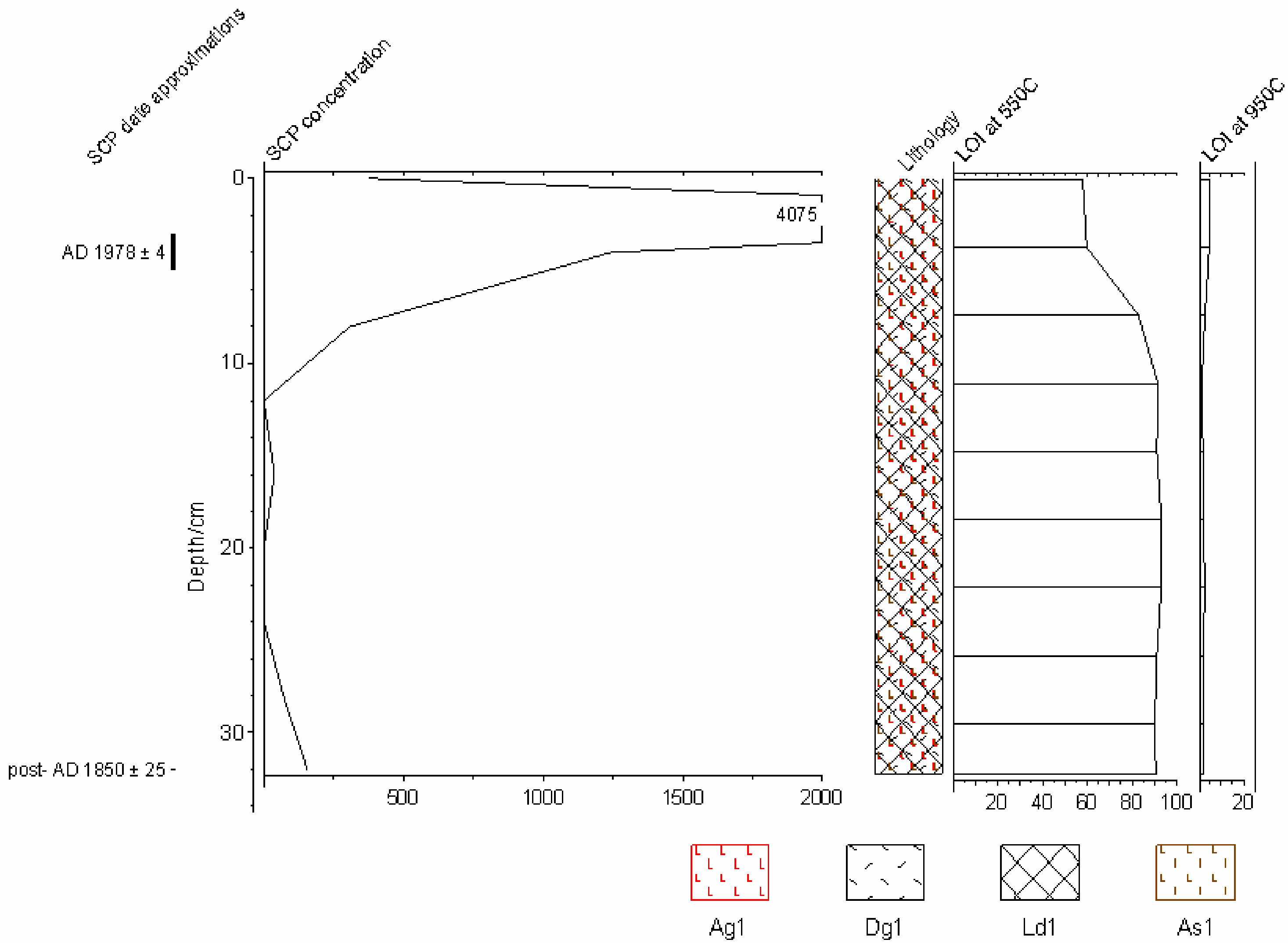



Figure 4.15: BYT age estimation, lithology (see Table 2.1 for components) and LOI. *P. sylvestris* exaggerated by a factor of 10. Nomenclature for pollen types follows Bennett, 1994.

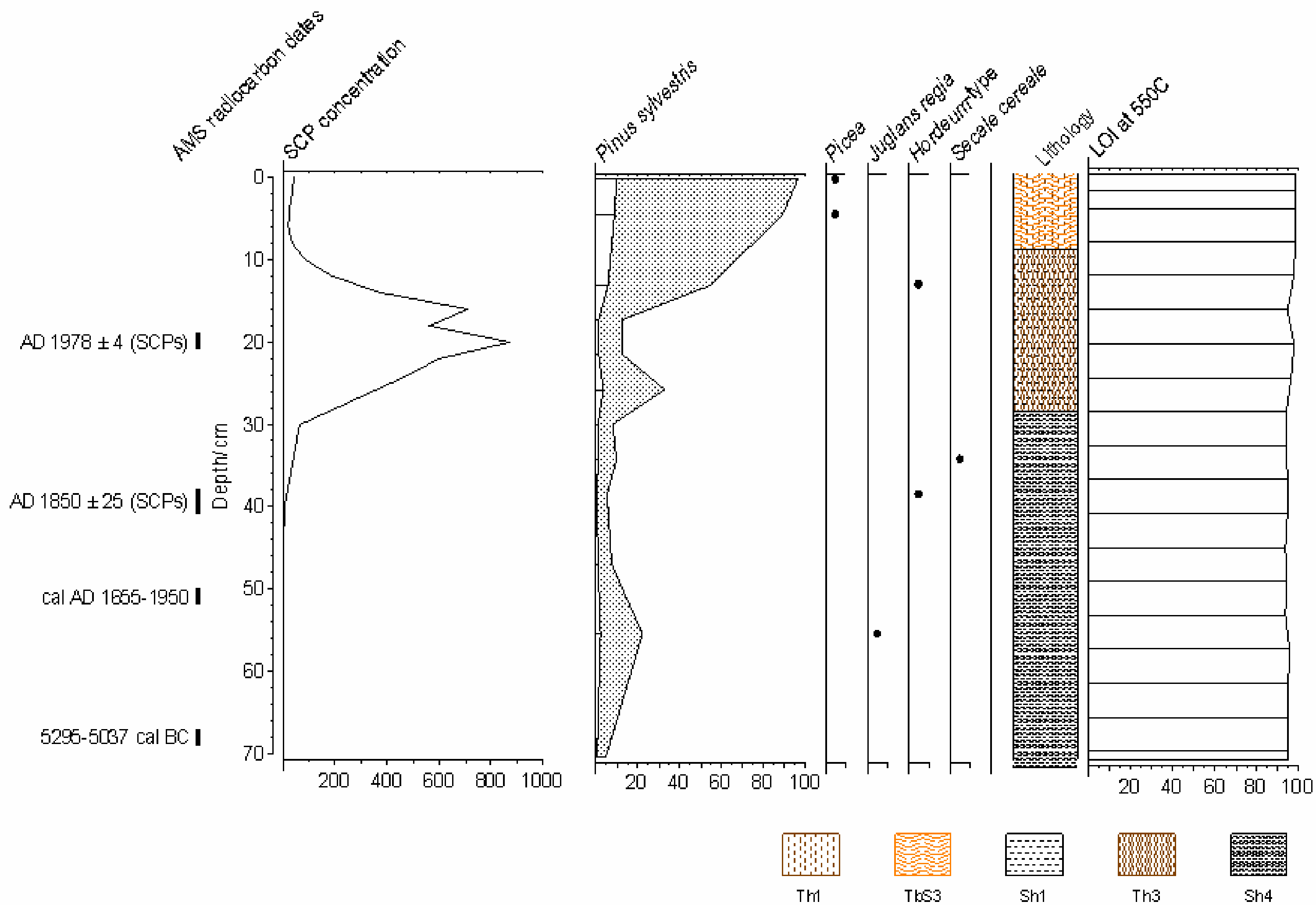



Figure 4.16: BYB age estimation, lithology (see Table 2.1 for components) and LOI. *P. sylvestris* exaggerated by a factor of 10. Nomenclature for pollen types follows Bennett, 1994.

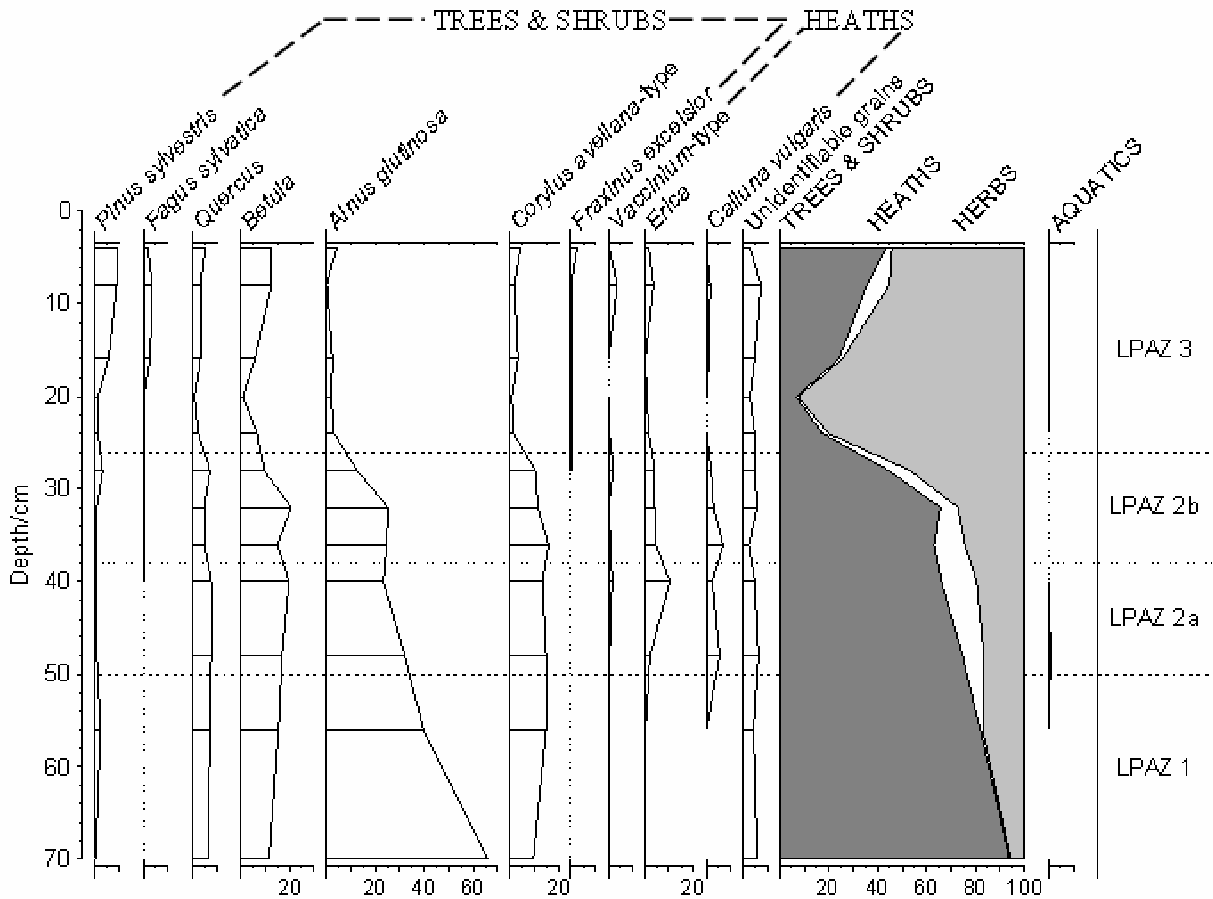



Figure 4.17: BYB pollen percentage diagram showing key arboreal and ericaceous types (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

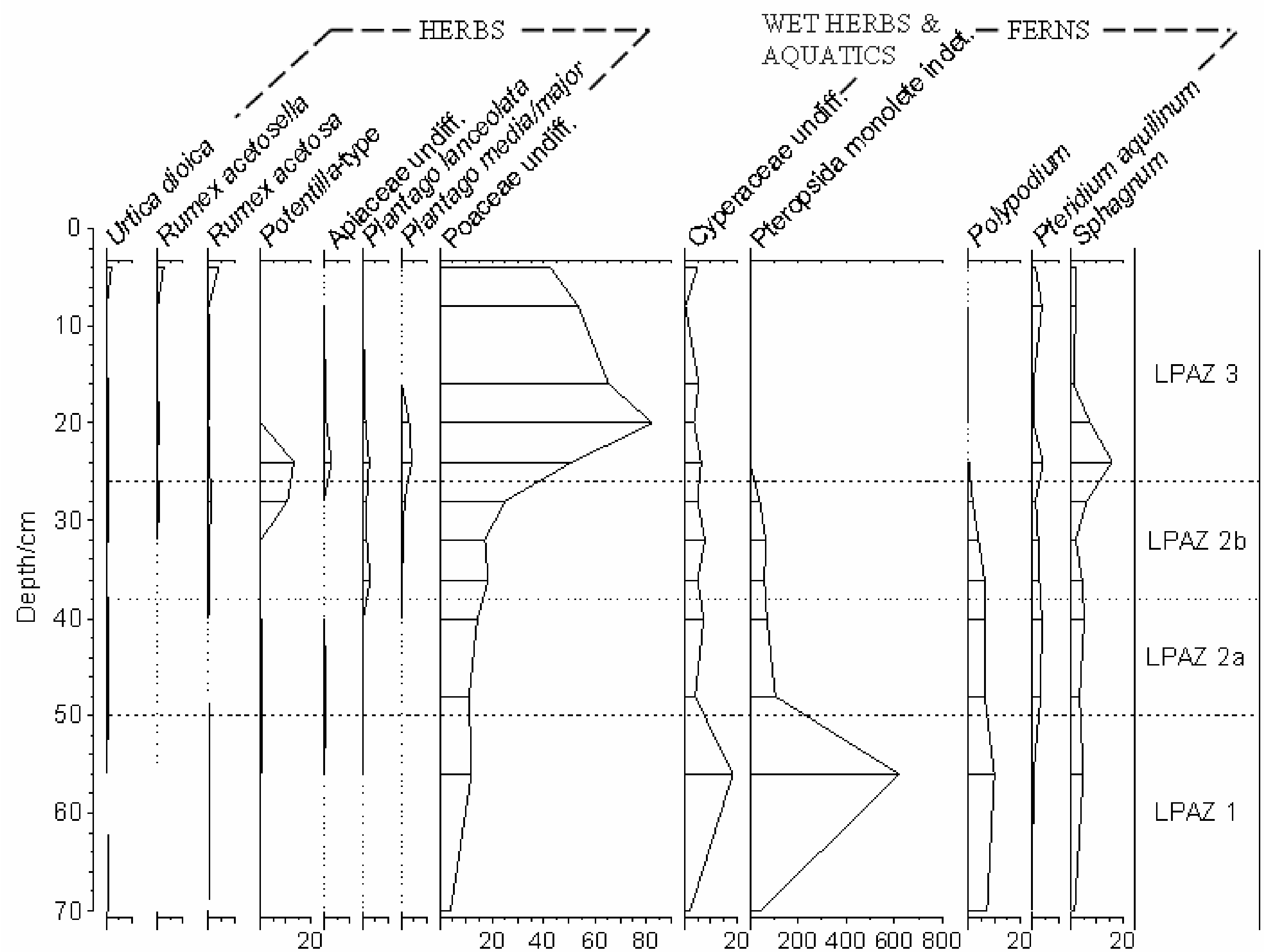



Figure 4.18: BYB pollen percentage diagram showing key non-arboreal pollen and spores (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

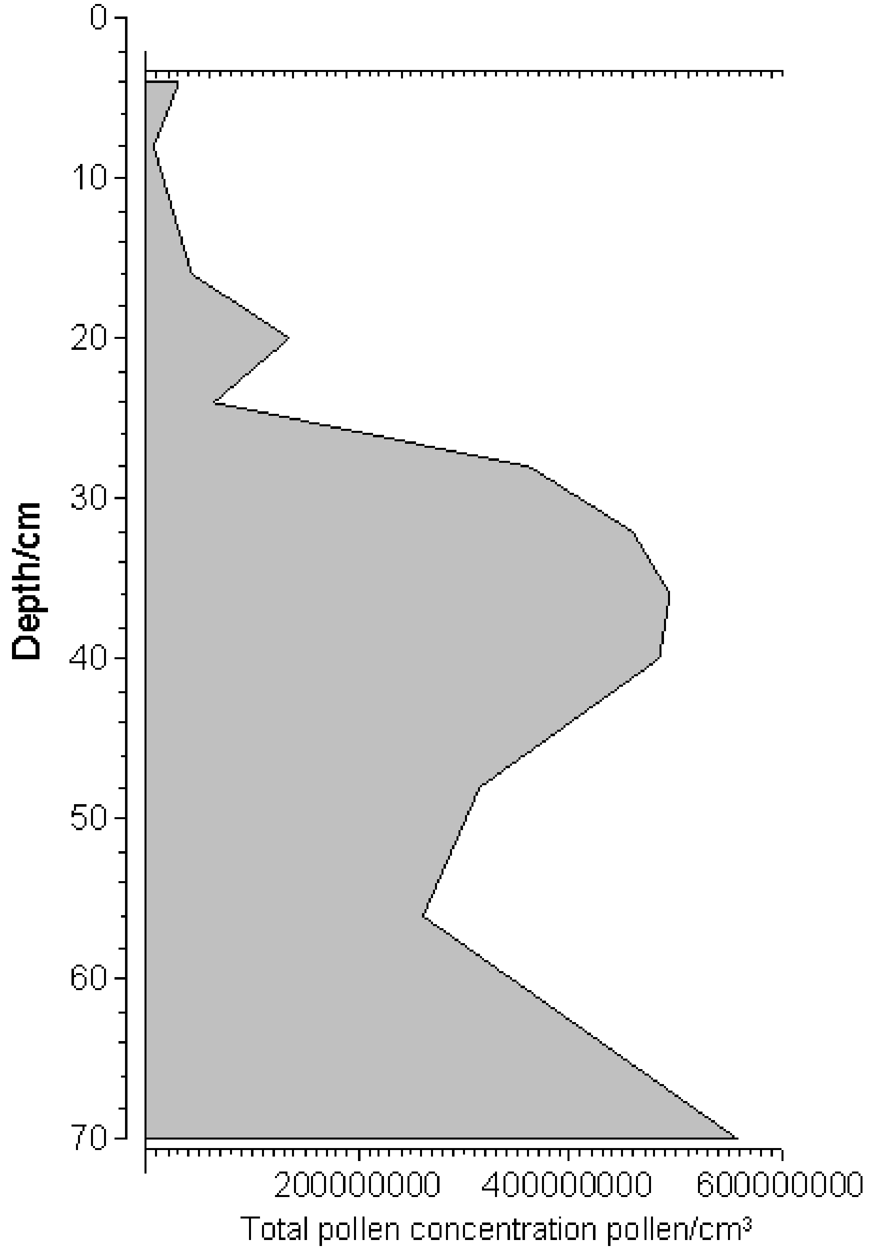


Figure 4.19: BYB total pollen concentration diagram based on the TLP. Scale is 1x10$^{-5}$.

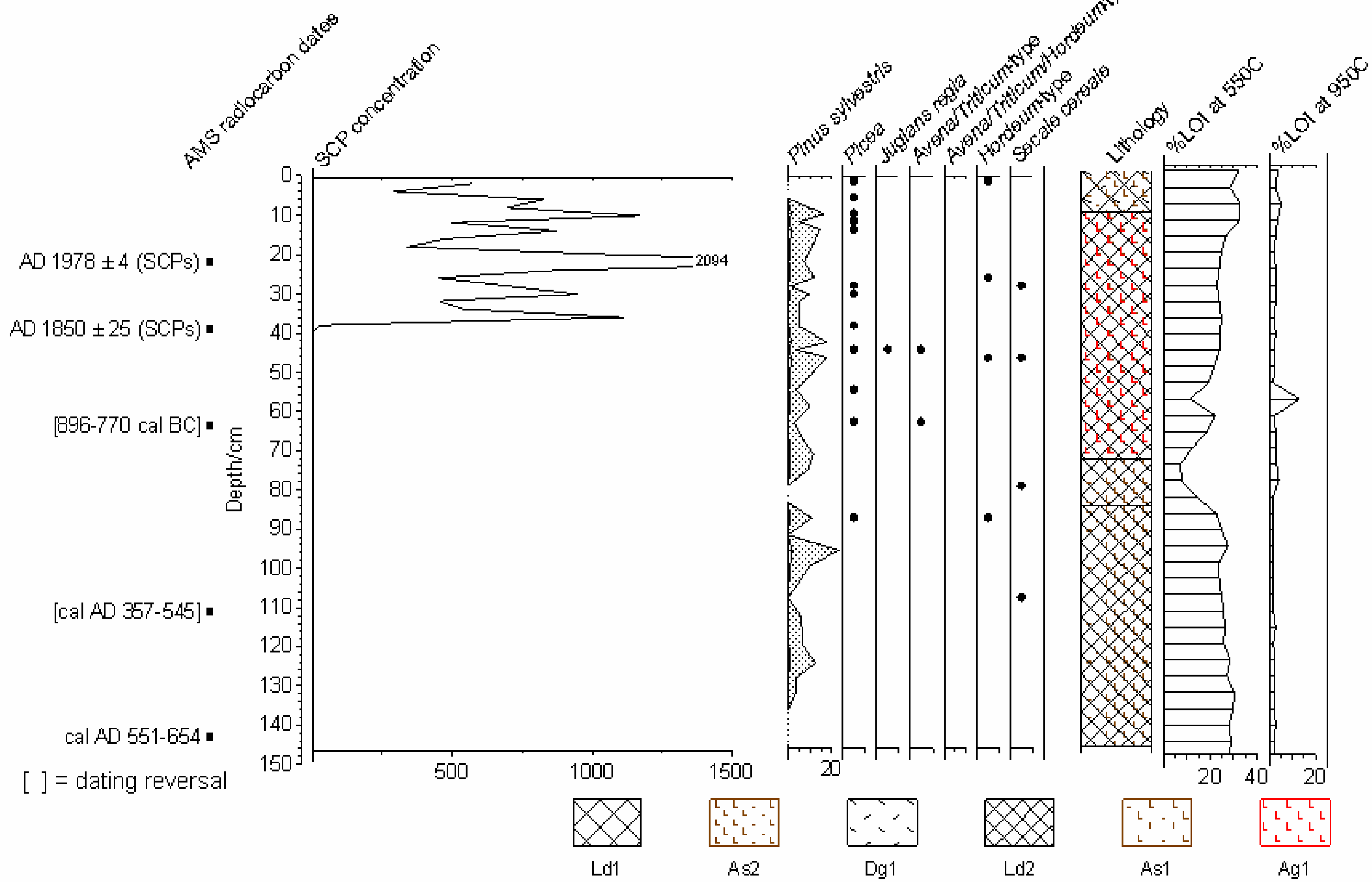



Figure 4.20: LLT age estimation, lithology (see Table 2.1 for components) and LOI. *P. sylvestris* exaggerated by a factor of 10. Nomenclature for pollen types follows Bennett, 1994.

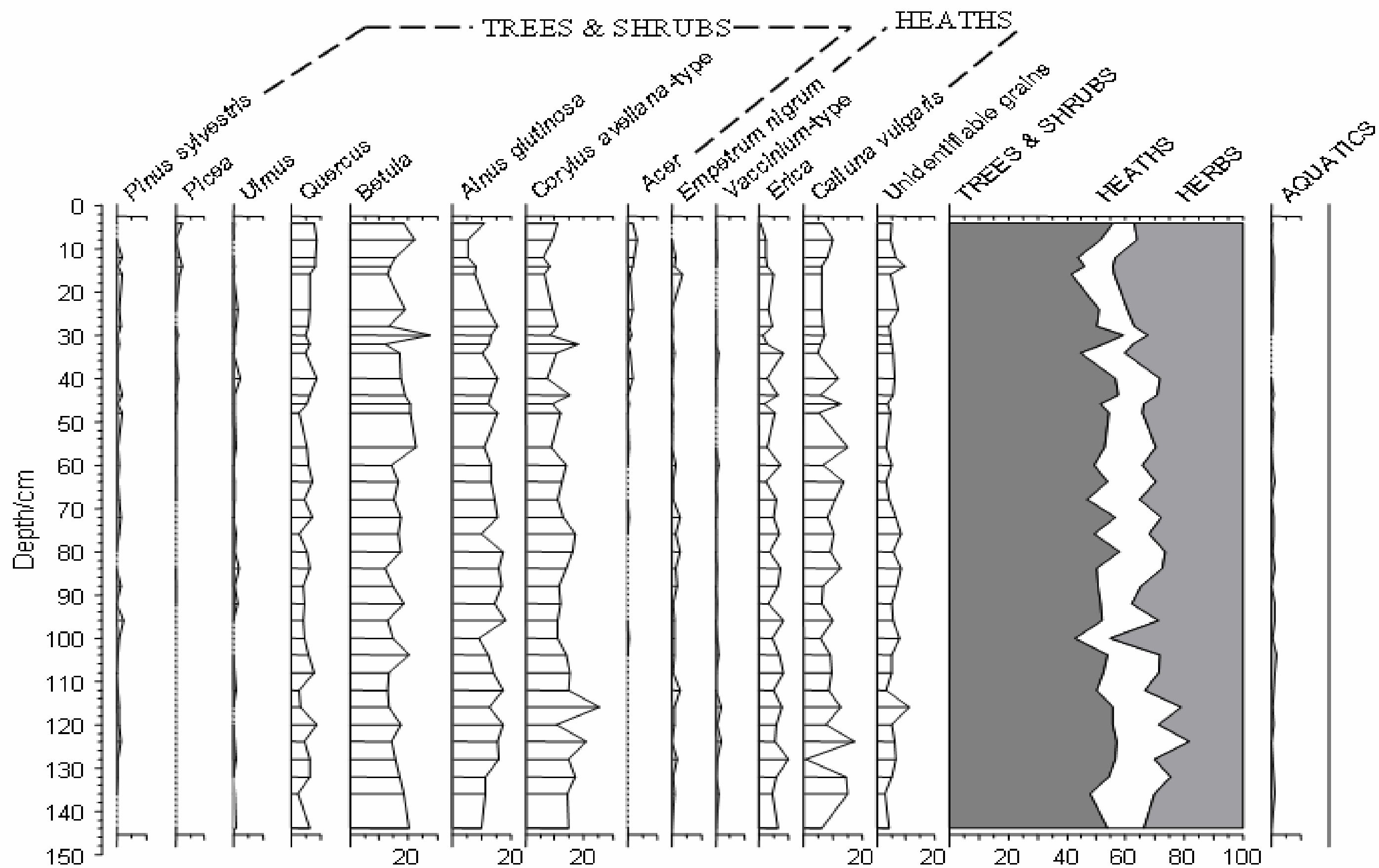



Figure 4.21: LLT pollen percentage diagram showing key arboreal and ericaceous types (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

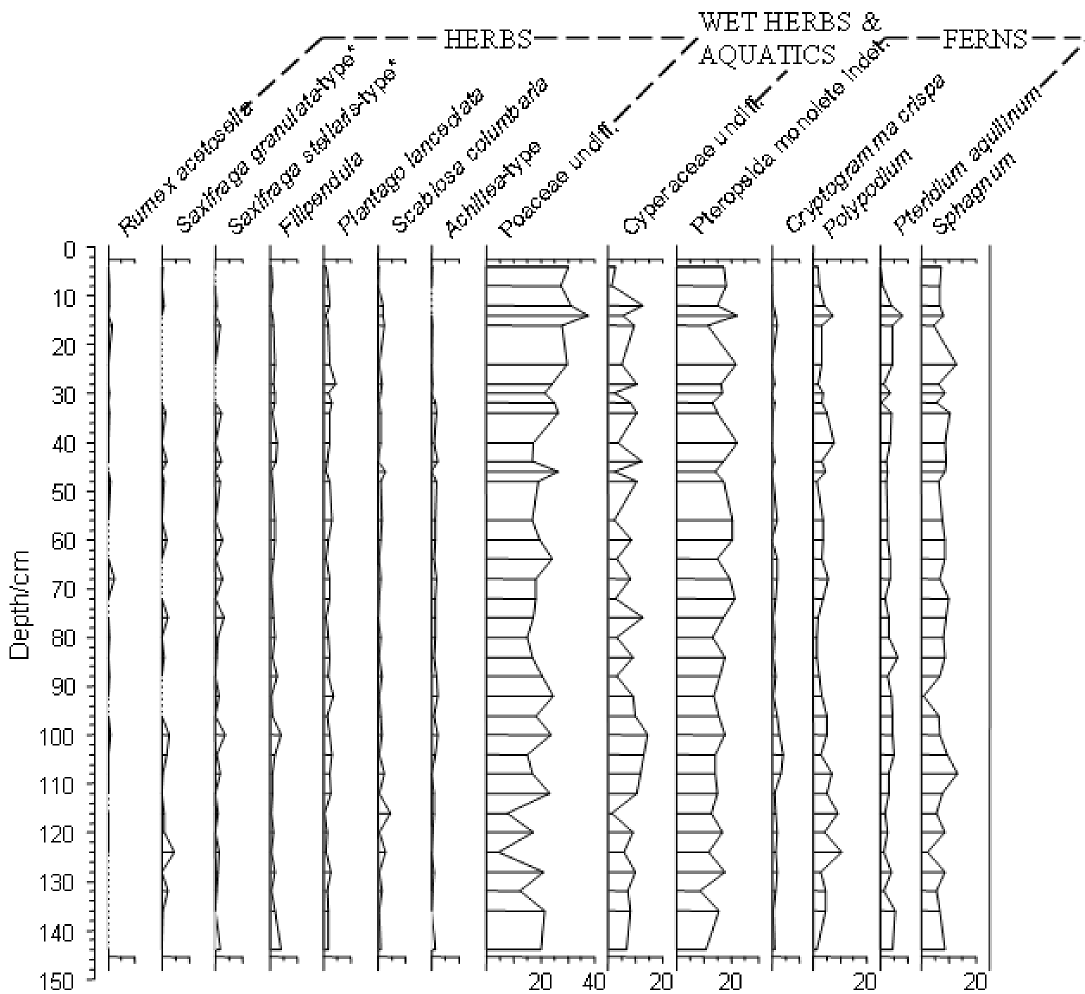



Figure 4.22: LLT pollen percentage diagram showing key non-arboreal pollen and spores (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

*subject to confirmation

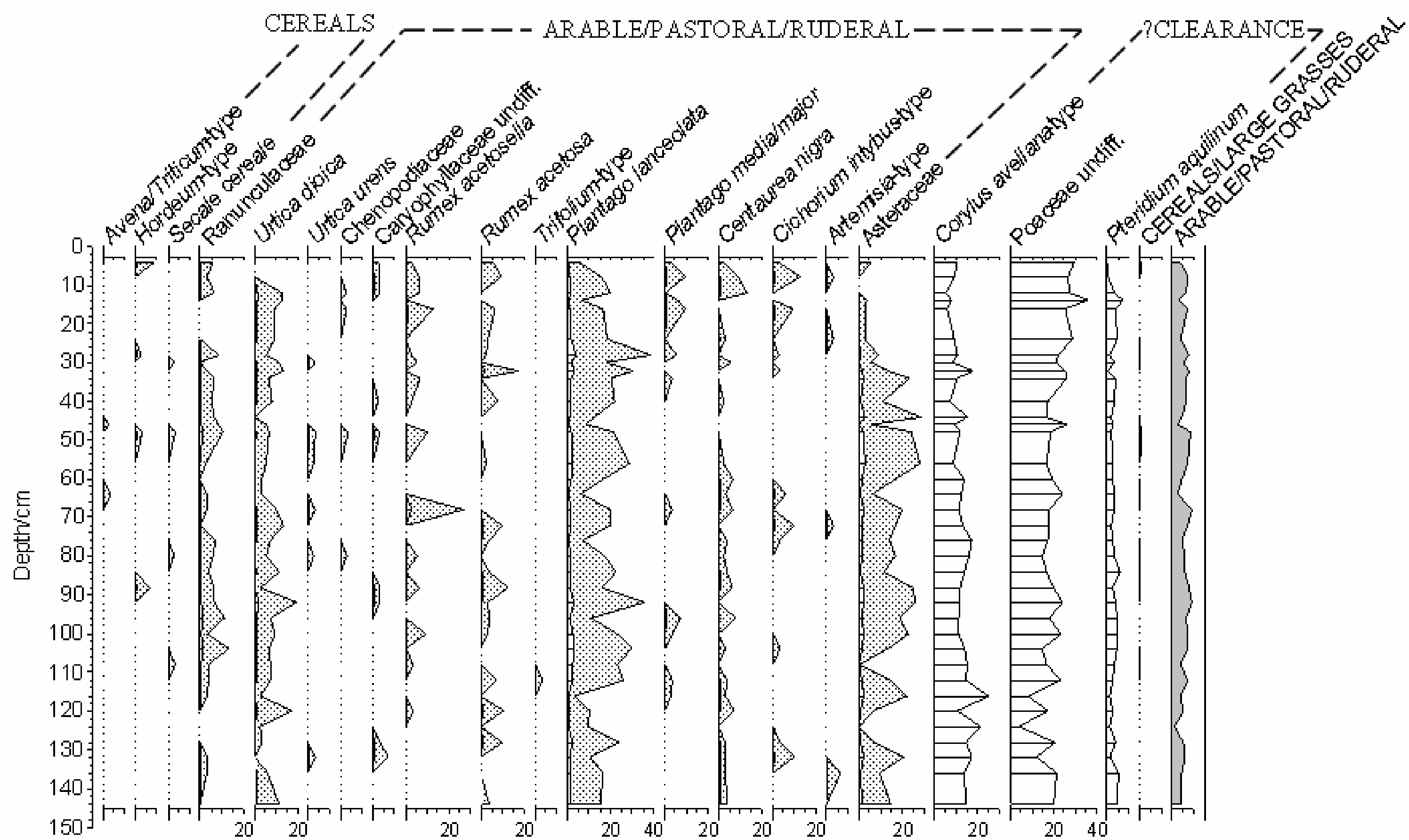



Figure 4.23: LLT pollen percentage diagram showing anthropogenic indicator species. Stippled graphs are exaggerated by a factor of 10. Asteraceae includes all members of this family that are not plotted separately (*e.g. Solidago virgaurea*-type is included, but *Artemisia*-type is not). Nomenclature follows Bennett, 1994.

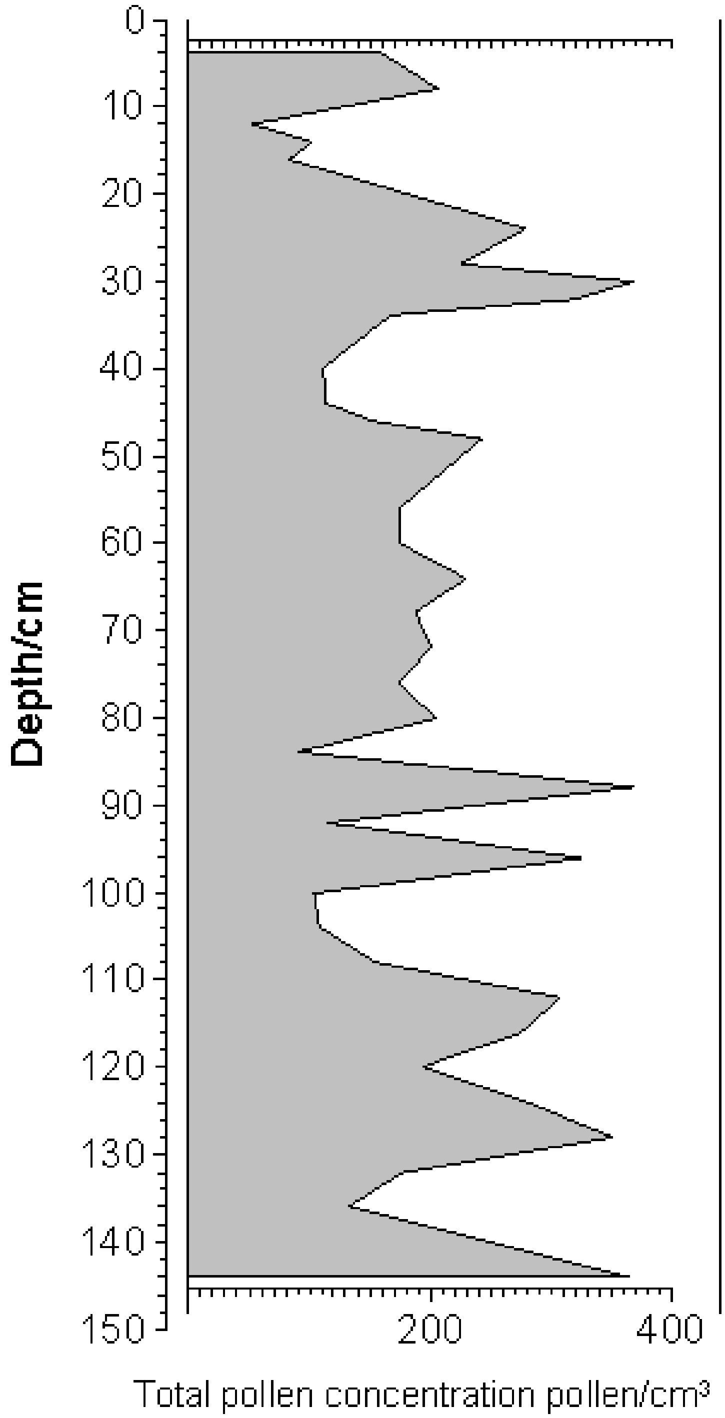



Figure 4.24: LLT total pollen concentration diagram based on the TLP. Scale is $1x10^{-5}$.

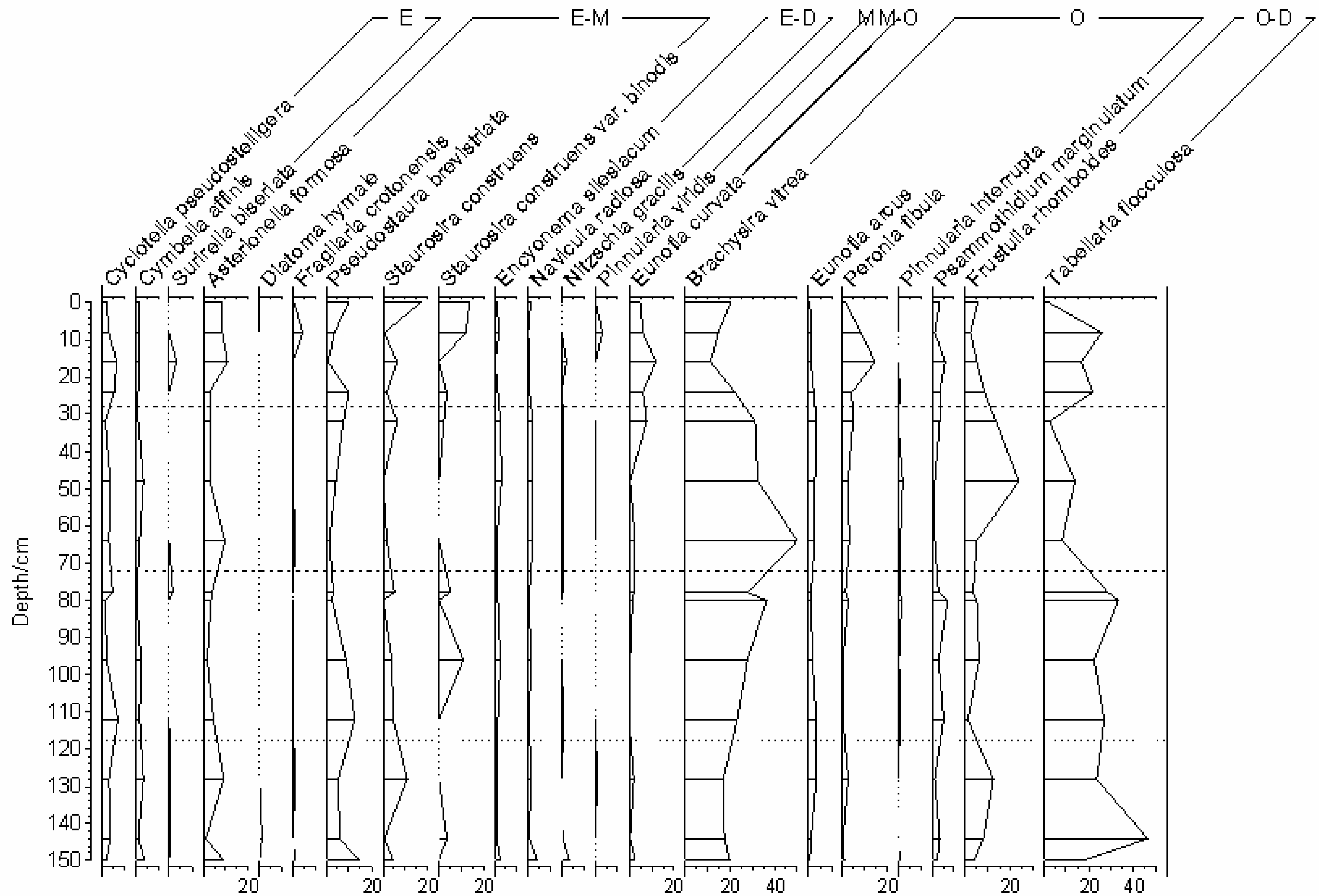
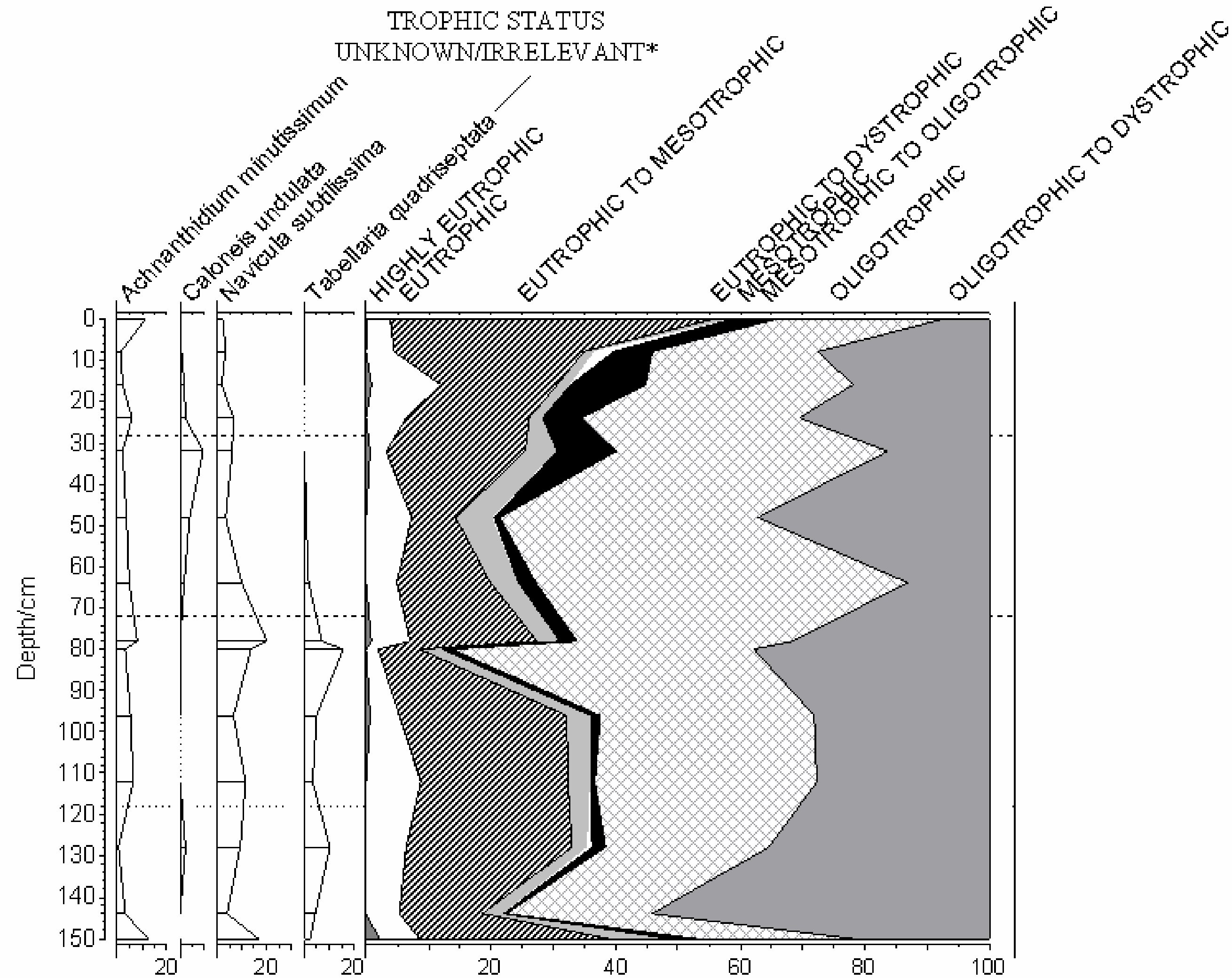



Figure 4.25: LLT diatom percentage diagram showing key trophic indicator species. Group designations are: E – eutrophic; M – mesotrophic; O – oligotrophic, D – dystrophic (E-M – eutrophic to mesotrophic, etc).




*'Irrelevant' (*sensu* Denys, 1991-2) means that nutrient status is not thought to impact on the diatom's distribution significantly.

Figure 4.26: LLT diatom percentage diagram showing key species (present at maximum 2% or more of the TDC) for which trophic information is unknown/irrelevant and cumulative trophic group percentages.

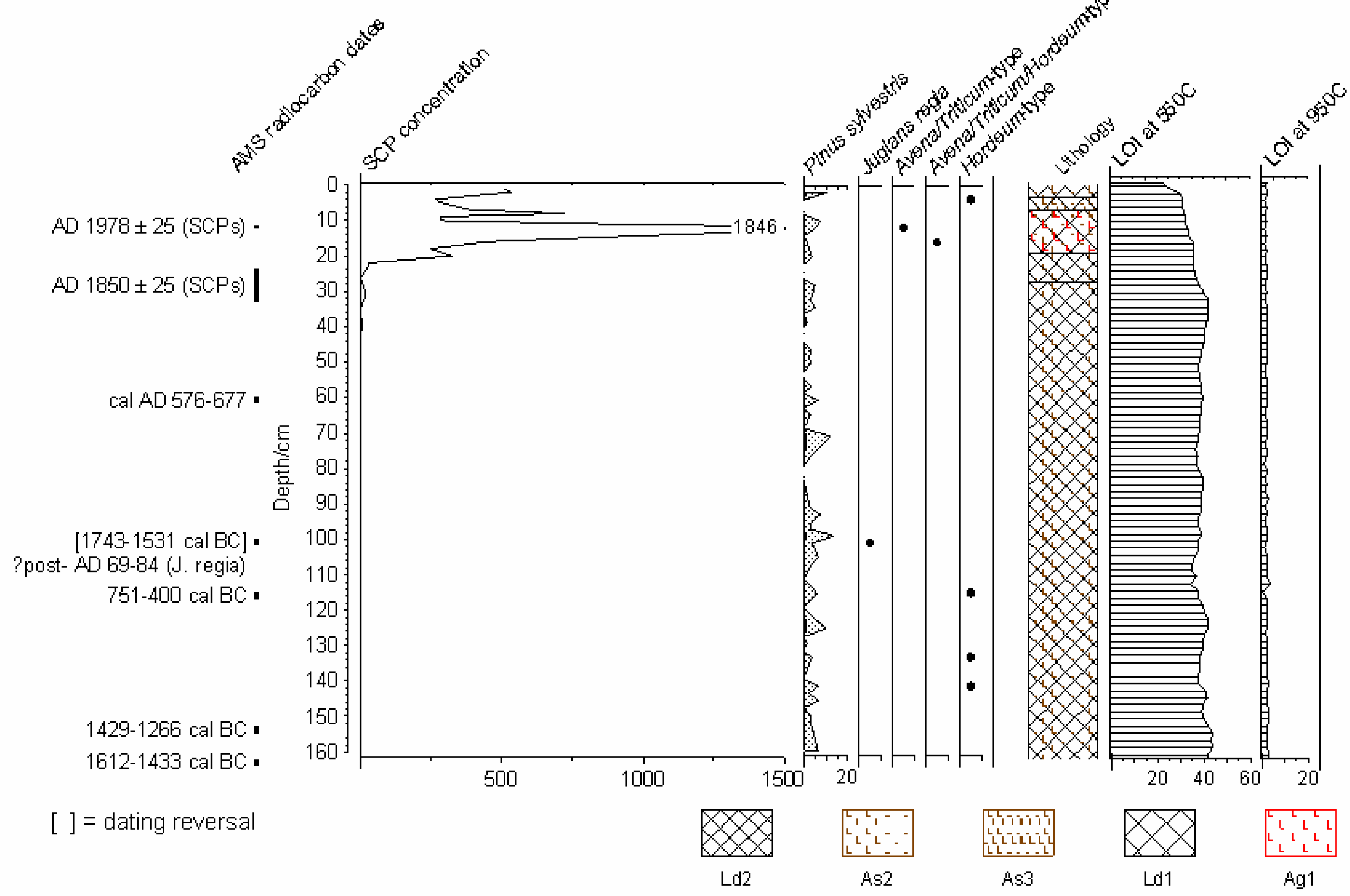



Figure 4.27: LGT age estimation, lithology (see Table 2.1 for components) and LOI. *P. sylvestris* exaggerated by a factor of 10. Nomenclature for pollen types follows Bennett, 1994.

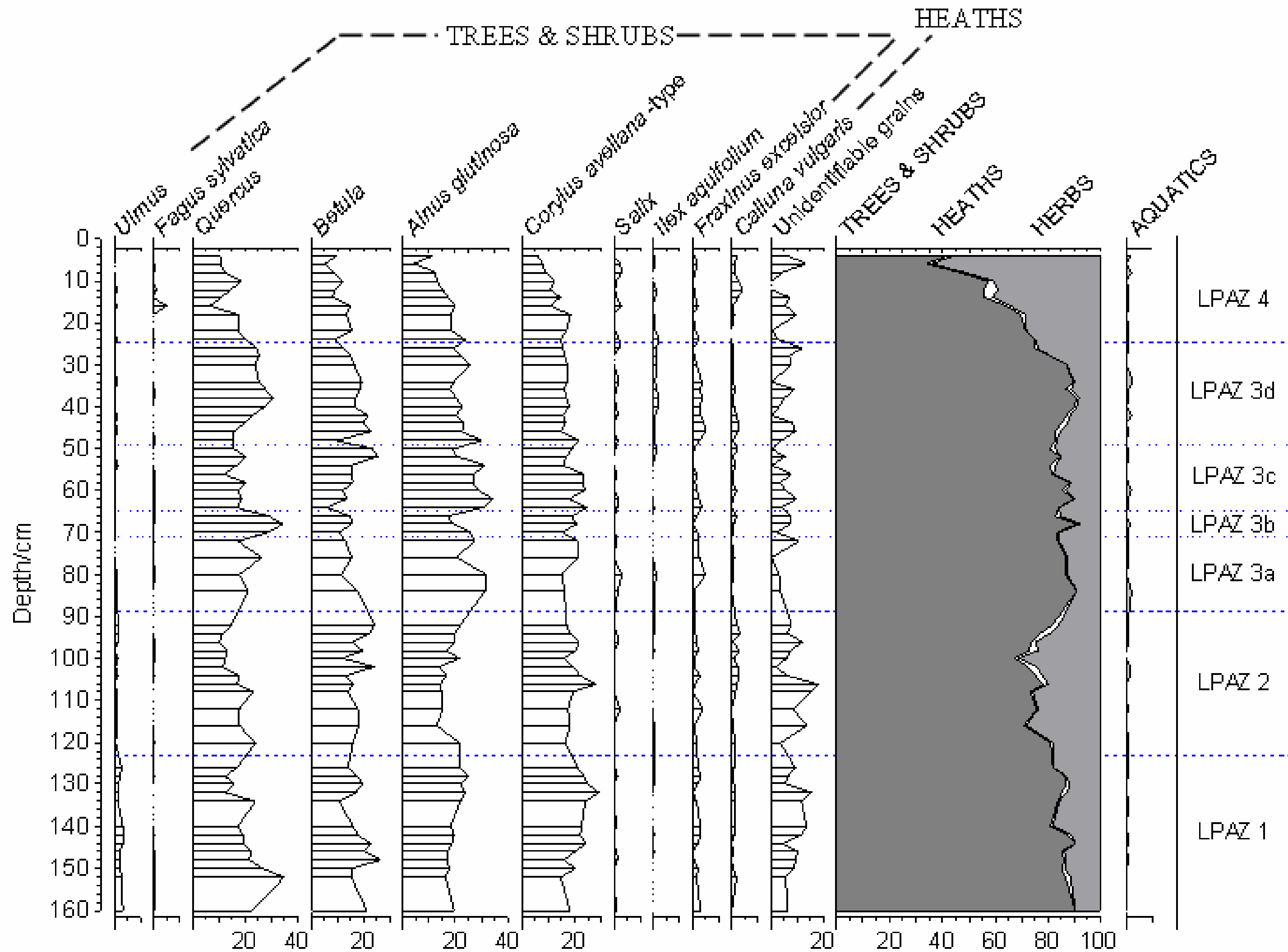



Figure 4.28: LGT pollen percentage diagram showing key arboreal and ericaceous types (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

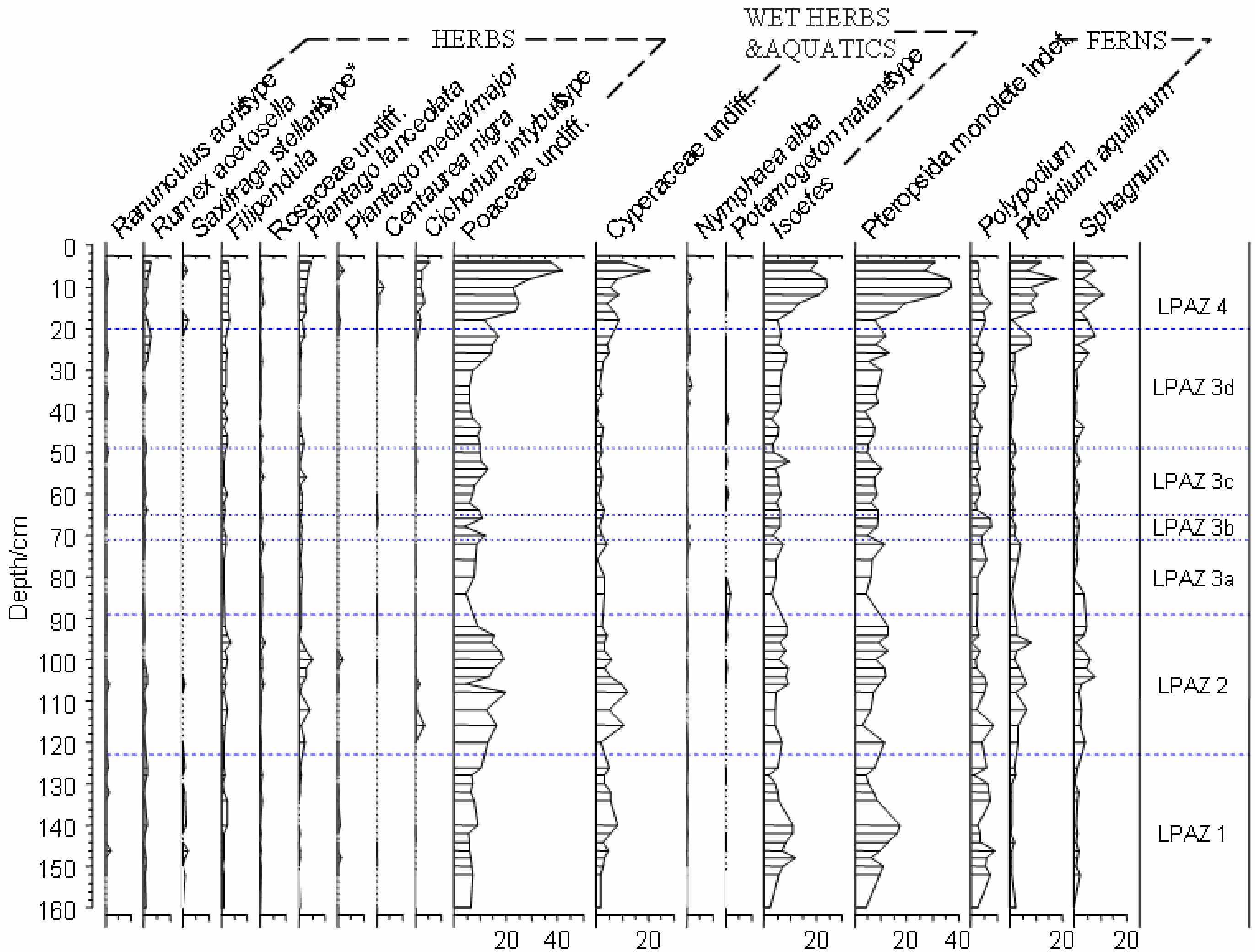



Figure 4.29: LGT pollen percentage diagram showing key non-arboreal pollen and spores (maximum presence 2% of the TLP or greater) and cumulative percentages.

*subject to confirmation

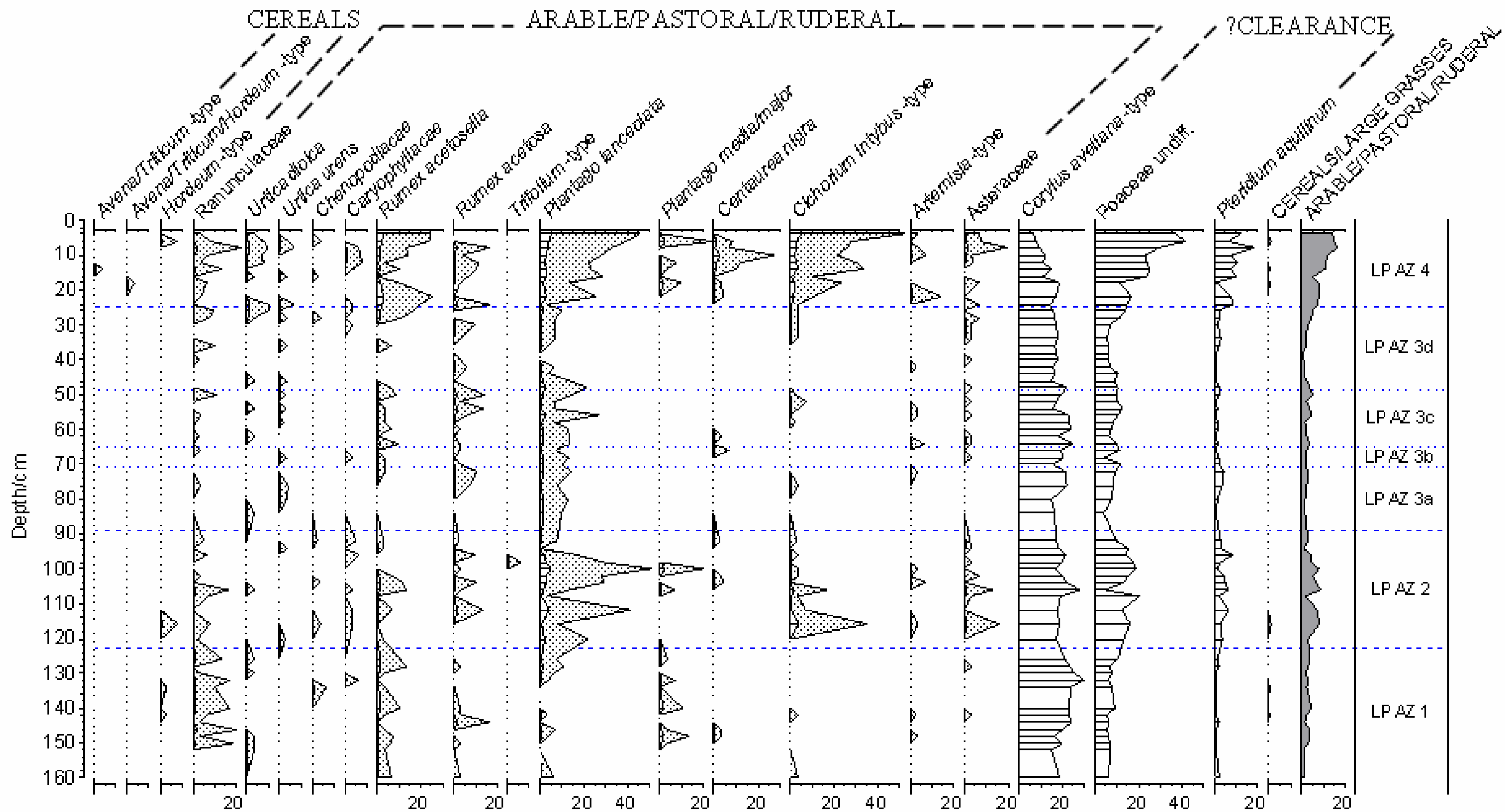



Figure 4.30: LGT pollen percentage diagram showing anthropogenic indicator species. Stippled graphs are exaggerated by a factor of 10. Asteraceae includes all members of this family that are not plotted separately (*e.g. Solidago virgaurea*-type is included, but *Artemisia*-type is not). Nomenclature follows Bennett, 1994.

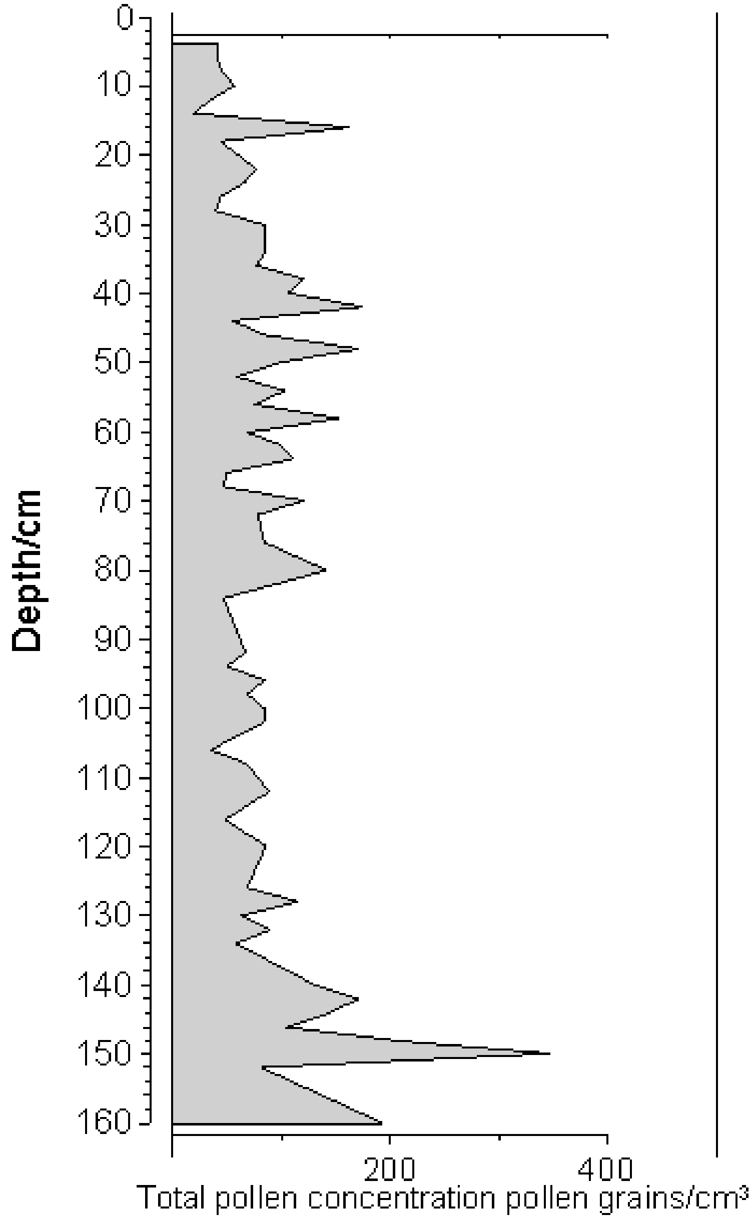



Figure 4.31: LGT total pollen concentration diagram based on the TLP. Scale is $1 \times 10^{-5}$.

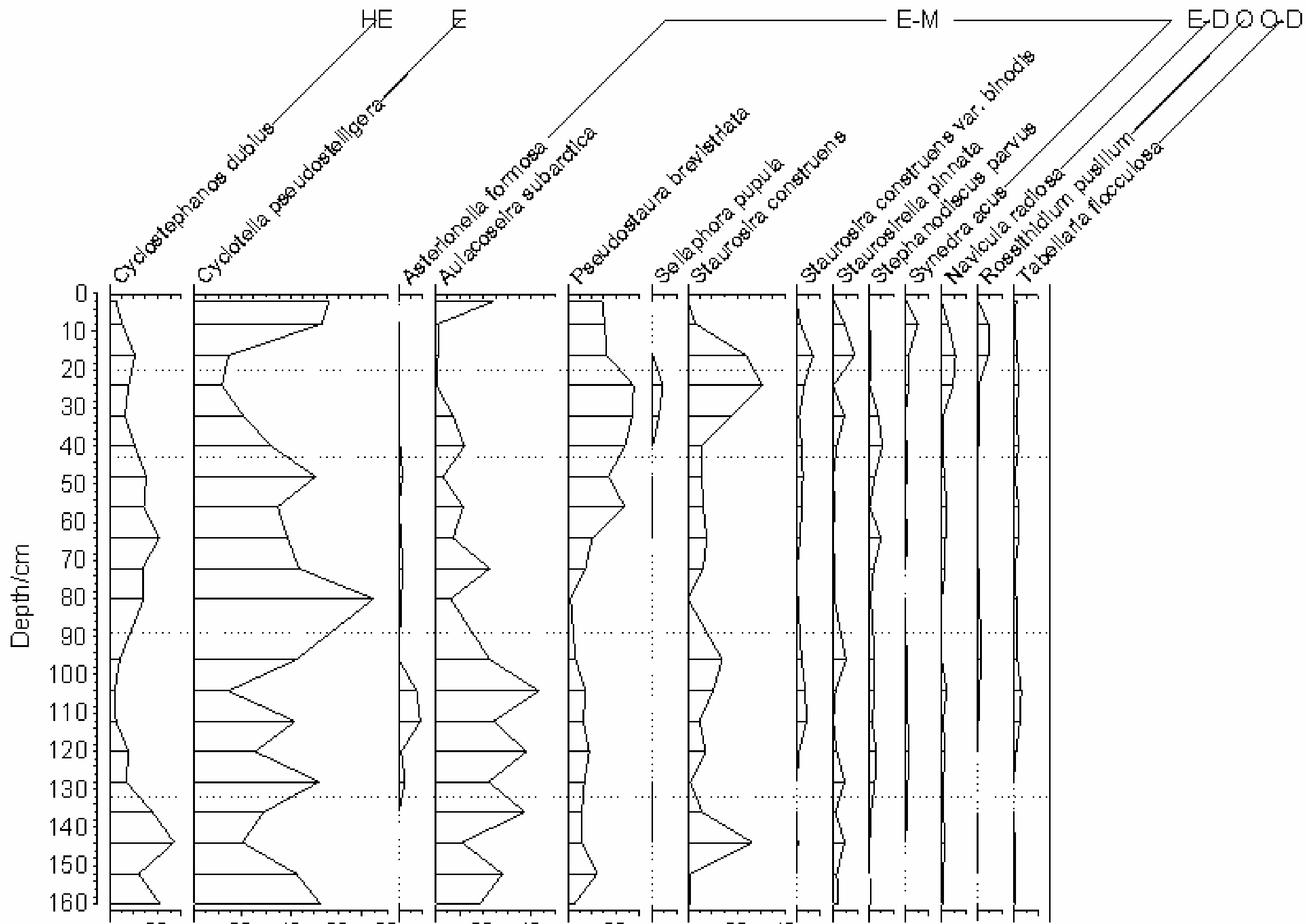
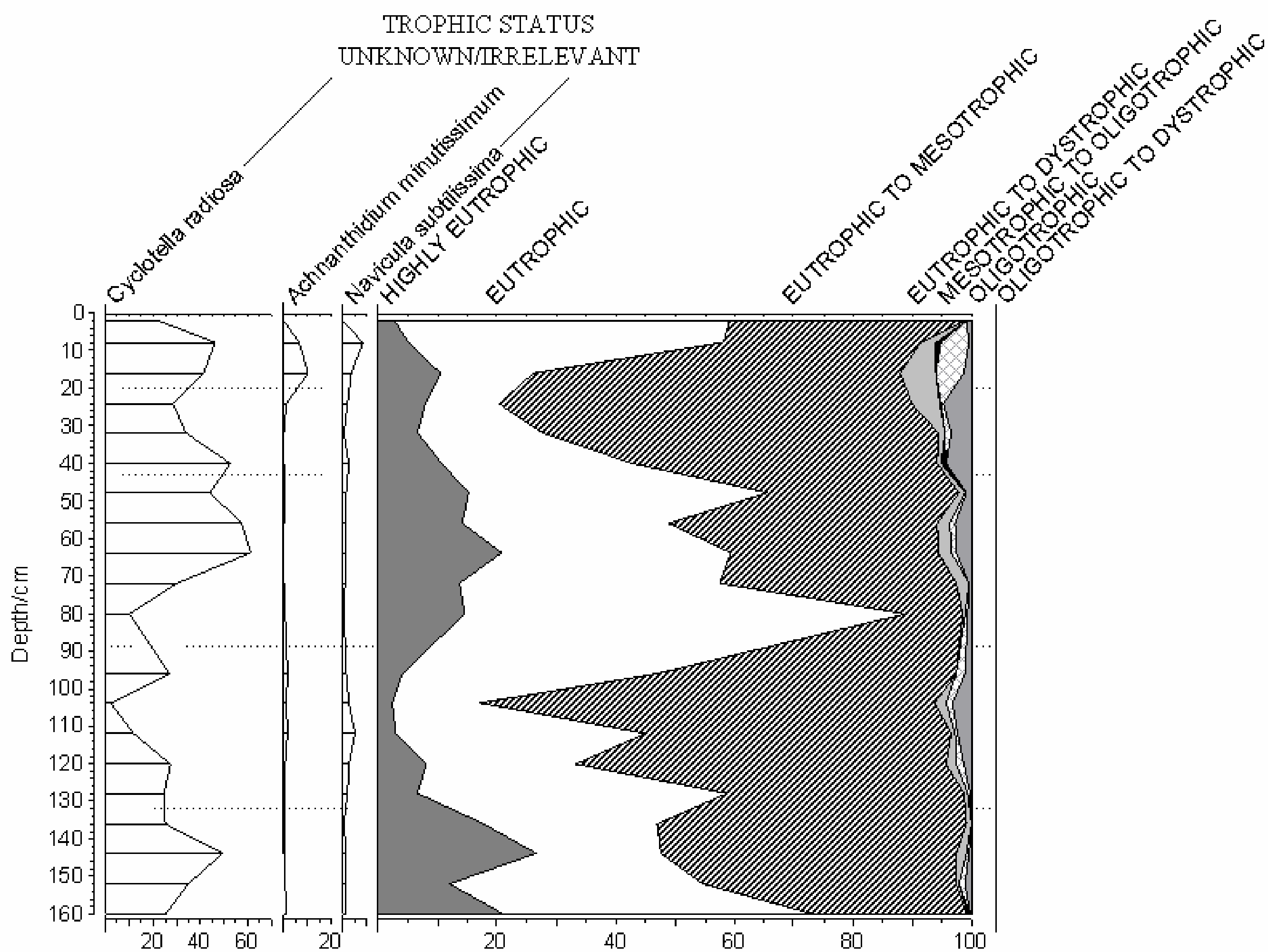



Figure 4.32: LGT diatom percentage diagram showing key trophic indicator species. Group designations are: HE – highly eutrophic; E – eutrophic; M – mesotrophic; O – oligotrophic, D – dystrophic (E-M – eutrophic to mesotrophic, etc).




*'Irrelevant' (*sensu* Denys, 1991-2) means that nutrient status is not thought to impact on the diatom's distribution significantly.

Figure 4.33: LGT diatom percentage diagram showing key species (present at maximum 2% or more of the TDC) for which trophic information is unknown/irrelevant and cumulative trophic group percentages.

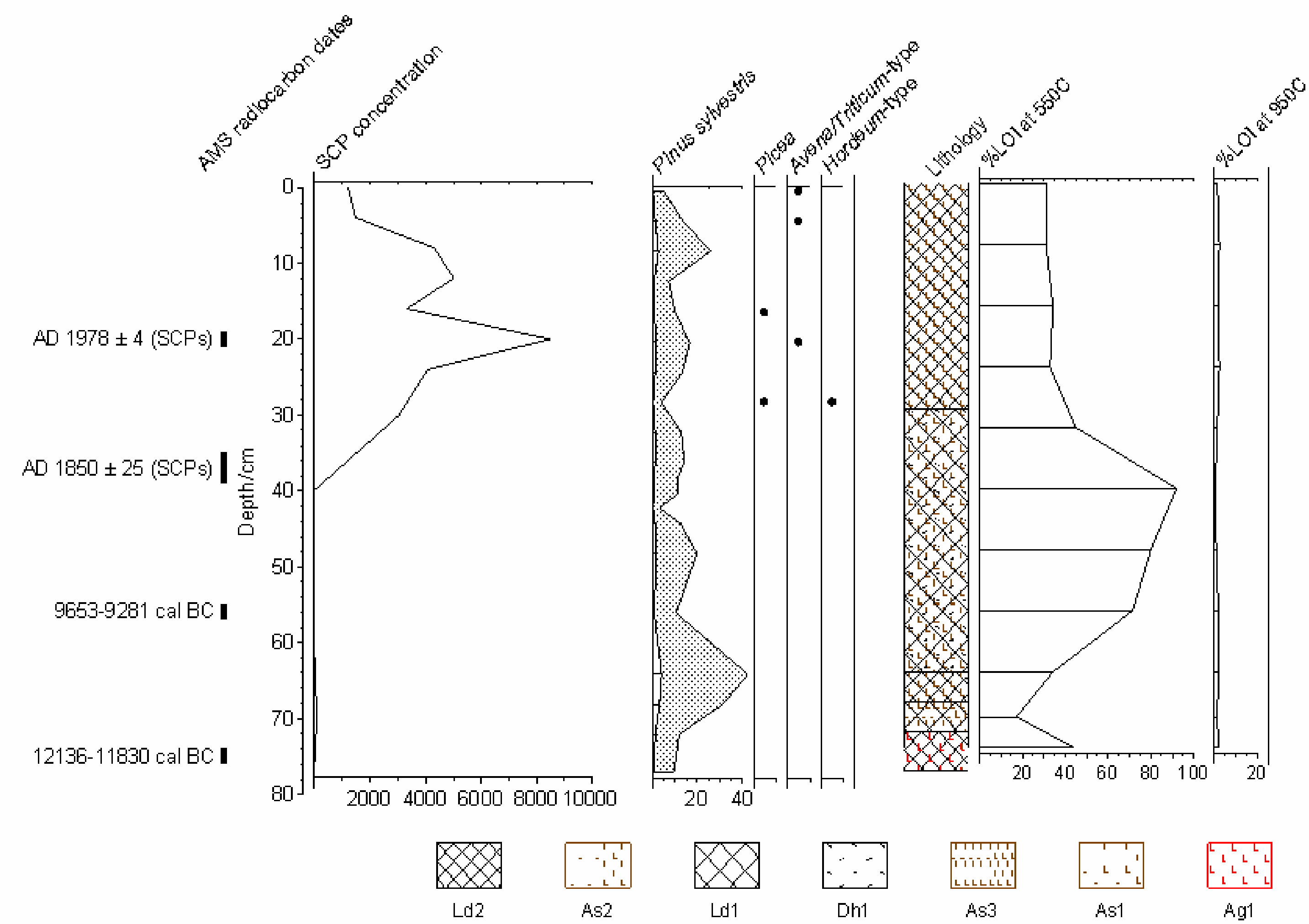



Figure 4.34: TWT age estimation, lithology (see Table 2.1 for components) and LOI. *P. sylvestris* exaggerated by a factor of 10. Nomenclature for pollen types follows Bennett, 1994.

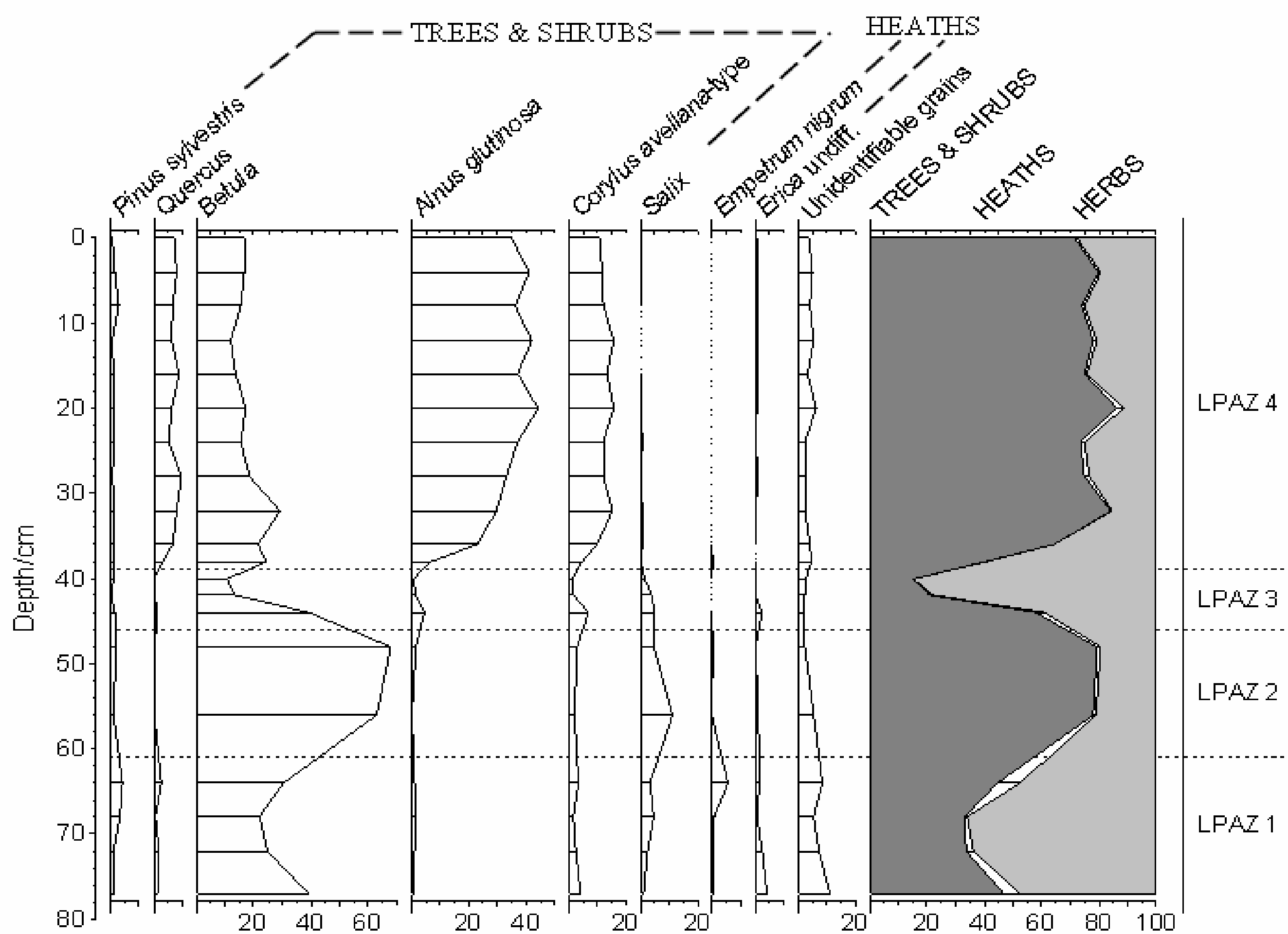



Figure 4.35: TWT pollen percentage diagram showing key arboreal and ericaceous types (maximum presence 2% of the TLP or greater) and cumulative group percentages. Nomenclature follows Bennett, 1994.

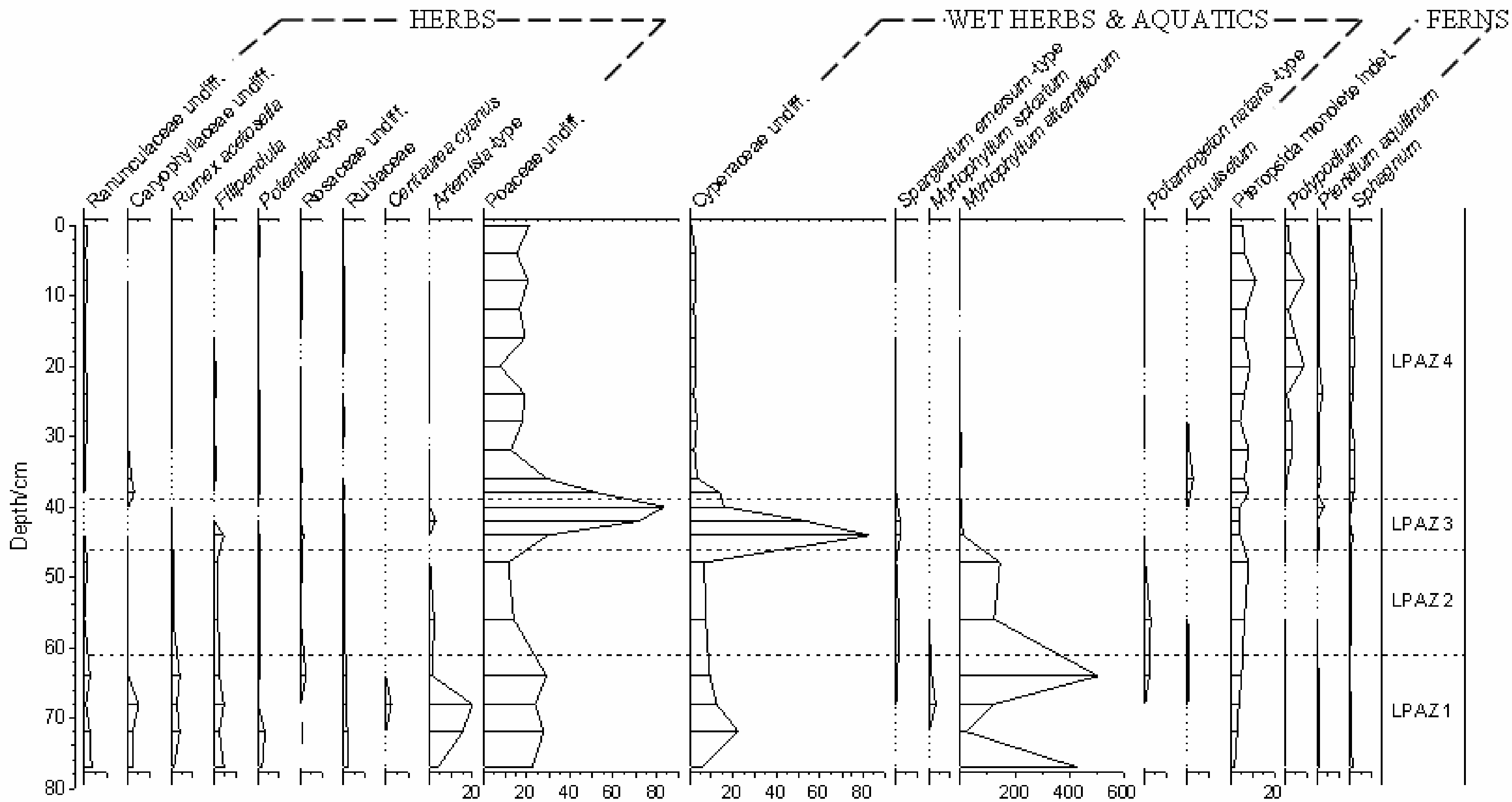



Figure 4.36: TWT pollen percentage diagram showing key non-arboreal pollen and spores (maximum presence 2% of the TLP or greater) and cumulative percentages.

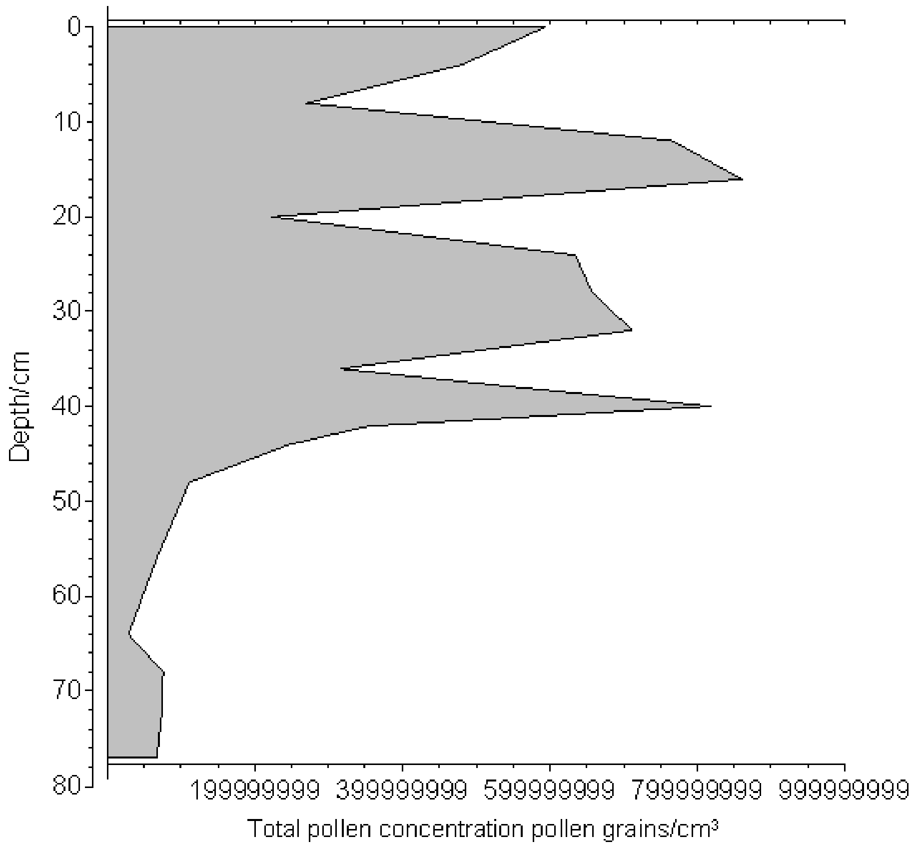



Figure 4.37: TWT total pollen concentration diagram based on the TLP. Scale is $1x10^{-5}$.

# CHAPTER 5: MODELLING AND ANALYSIS

In addition to traditional methods of interpretation, HUMPOL v3 simulation software (Bunting & Middleton, 2005) was employed for visualisation and 'testing' of possible landscape scenarios based on the pollen data from BFT and LGT. These sites were selected for further analysis as they produced useful data for the early medieval period, while the other study sites proved problematic (Chapter 4). Determining the approximate time period to which vegetation 'zones' identified in the pollen diagrams belong was an important step in establishing which pollen data would be most appropriate to utilise in modelling/simulation experiments. The age-depth models for BFT and LGT are explained in Sections 5.2 and 5.3 respectively, after which the various landscape scenarios tested for each site are explained and evaluated. The following section explains the logic for using HUMPOL v3 rather than the LRA (Landscape Reconstruction Algorithm) and details the parameters, values and settings utilised. Site-specific factors such as the lake radius and composition of vegetation communities are detailed below. Simulations have proved a useful tool for visualisation and interpretation of the pollen data presented here, but their application is not without problems and should not be viewed as an alternative to orthodox interrogation of the data. The benefits, limitations and difficulties associated with palynological modelling approaches are discussed in Chapter 6.

### 5.1. Landscape simulation: parameters, settings and choice of software

As explained in Chapter one, HUMPOL is a set of programs that produce expected pollen proportions for selected taxa, for sites located within a landscape defined by the user. In each simulation presented here, pollen proportions were produced for 30 randomly placed lakes; six within each of five simulated 25 by 25 km (625 km$^2$) landscapes. The data were then averaged to provide mean pollen proportions for a lake situated in a landscape of that composition. Pollen loading was simulated at 20 m intervals up to a maximum radius of 5 km from the centre of the site, which was found to be in excess of the estimated relevant source area for pollen (RSAP) at both of the study sites in all simulations (Maps 5.1 and 5.2). Pollen productivity estimates (PPEs) and fall speeds fed into the model are shown in Table 5.1; PPEs vary from one location to another, so the most suitable values available at the time (*i.e.* those acquired from areas with similar climatic and environmental conditions to Northwest England) were selected in consultation with Marie-José Gaillard and Florénce Mazier at Kalmar University. Wind speed was kept at a constant of 3 $ms^{-1}$ in all directions (the default setting in HUMPOL, a convention based on Prentice, 1985), as past wind conditions are unknown (discussed in Section 6.4, Chapter 6). The Prentice-Sugita model for lakes (Sugita, 1993, 1994) was used in preference to the Prentice model for moss polsters and bogs (Parsons & Prentice, 1981; Prentice & Parsons, 1983; Prentice, 1985, 1986, 1988). ERV model 3 was selected rather than ERV 1 or 2, as experimental work suggests that this provides the most accurate simulations of the three (Broström *et al.,* 2004; Nielsen & Sugita, 2005).

The landscape scenarios used for simulations are necessarily simplified relative to a real landscape (Prentice, 1985; Bunting *et al.,* 2008); a limited number of taxa and vegetation communities can be incorporated as the run-time of the model increases dramatically with increasing complexity. A small number of the attempted simulations for both sites failed to run, usually when vegetation communities constituting a small proportion of landscape cover (less than or equal to 5%) were modelled as several large patches (500-1000 m diameter), as opposed to numerous, scattered, smaller patches
(100 m across) or when the total number of taxa was greater than 15. In addition to limitations imposed by the capabilities of the model, the availability of fall speed measurements and suitable PPEs for taxa governs the composition of simulated landscapes to some extent. Values were available for all of the key taxa identified in this study (Table 5.1) with the exception of *Erica*; this taxon was combined with *Calluna vulgaris*-type for BFT simulations as the similarity of the pollen grains should result in comparable fall speeds, but the interchangeability of PPEs for these taxa is uncertain; extensive field survey and palynological work would be required to establish this (*e.g.* Broström *et al.,* 2004; Mazier *et al.,* 2008). Most rare types other than cereals were excluded owing to the unavailability of PPEs and fall speeds; combined, these account for less than 2% of the total land pollen (TLP) in each of the modelled zones, so the vast majority of vegetation types identified in the pollen are accounted for in the simulations. Rare taxa (according to the pollen data) that were modelled with correspondingly low vegetation abundances (*e.g.* 0.1-0.2%) proved problematic and were overrepresented drastically in the simulations. In some cases these taxa were consequently excluded from the simulated communities (*e.g. Secale cereale* at BFT).

The LRA software suite (Sugita, 2007a & b) was also considered for use, but was found to be unsuitable for this project for several reasons. Firstly, the REVEALS stage of the modelling requires pollen data from a large lake, defined as one for which the pollen assemblage does not differ significantly from pollen records of similar sized sites in the region (thus supplying the ‘regional’ pollen signal). With the exception of BYB, a small bog, the sites used in this study are tarns and were selected for their ability to produce local/extralocal pollen records (*sensu* Jacobson & Bradshaw, 1981, equivalent to pollen from within the RSAP, *sensu* Sugita, 1994); as modelling was introduced at a relatively late stage it was impractical to begin work on a large lake in the region within the time-constraints of the project. Considering the large catchment areas of sites with significant inflowing streams (Bonny, 1976; Brown *et al.,* 2007), it might have been possible to establish the regional pollen signal from LLT or BLT if either of these sites had produced a reliable, chronologically secure record. Another solution would have been to incorporate other researchers’ data, but as explained in Chapter 1 there are very few well-dated studies of pollen covering the study period in the Lake District, and no large lakes with suitable data were identified. Sugita found that combining data from numerous small sites could also provide an accurate indication of the regional pollen input (Sugita, 2007a). However, for this to be successful, good chronological control is required and the study period must be represented at each of the sites incorporated to the model. As mentioned previously, pollen records for the early medieval period are thought to be present only at BFT and LGT, which would provide insufficient data for meaningful reconstructions of the regional vegetation.

Table 5.1: PPEs and fall speeds used in HUMPOL (values from [A]Eisenhut, 1961*; [B]Gregory*, 1963; [C]Sugita *et al.*,1999; [D]Nielsen, 2004; [E]Broström *et al.*, 2005) *Cited in Broström *et al.*, 2008.

| **Taxon/pollen type** | **PPE (relative to Poaceae)** | **Fall speed** |
|---|---|---|
| *Alnus glutinosa* | 4.200[C] | 0.021[A] |
| *Betula* | 8.867[C] | 0.024[A] |
| *Calluna* (used for Ericaceae in BFT experiments) | 1.103[D] | 0.038[D] |
| Cerealia | 0.747[D] | 0.060[D] |
| Cichoroideae | 0.244[E] | 0.051[E] |
| *Corylus avellana*-type | 1.400[C] | 0.025[B] |
| Cyperaceae | 1.002[E] | 0.035[C] |
| *Fagus* | 6.667[C] | 0.057[B] |
| *Filipendula* | 2.480[E] | 0.006[E] |
| *Fraxinus* | 0.667[C] | 0.022[A] |
| *Plantago lanceolata* | 0.897[D] | 0.029[D] |
| Poaceae | 1.000[E] | 0.035[C] |
| *Potentilla*-type | 2.475[E] | 0.018[E] |
| *Quercus* | 7.533[C] | 0.035[A] |
| *Ranunculus acris*-type | 3.848[E] | 0.014[D] |
| Rubiaceae | 3.946[E] | 0.019[E] |
| *Rumex acetosa/acetosella* | 1.559[D] | 0.018[D] |
| *Salix* | 1.267[C] | 0.022[B] |
| *Tilia* | 1.267[C] | 0.032[B] |
| *Ulmus* | 0.800[C] | 0.032[B] |

### 5.2. Barfield Tarn: radiocarbon dating and evidence for inwash

As explained briefly in the previous chapter, the reversed radiocarbon dates at 40-42 cm and 73-75 cm from BFT have been rejected in favour of that at 112-114 cm depth. The sequence appears to have good integrity considering the SCP curve and the clear stratification of sediment, pollen and diatom records within the core. Taking the AMS dates individually, at 40 cm depth and more dramatically in the subsequent sample, there is an increase in acidophilous and acidobiontic diatom species (*Eunotia pectinalis var. minor, E. incisa, Tabellaria flocculosa, T. quadriseptata*) concomitant with a reduction in alkaliphilous and circumneutral species (*e.g. Achnanthes minutissimum, Diatoma hymale, Cymbella affiinis, Nitzschia fonticola*) (see Table 4A, Appendix 4 for further information and references for individual species), suggesting a decline in pH at this depth. There is also a peak in *Navicula subtilissima*, thought to indicate increased humicity (Van Dam, 1988), together with an overall rise in oligotrophic to dystrophic taxa. These changes are consistent with the inwash of eroded, acid peat from the catchment, strengthening the case for inclusion of ‘old’, redeposited organics affecting the radiocarbon date. Unfortunately these changes in the diatoms were not fully understood when radiocarbon dating depths were chosen (problems associated with radiocarbon dating of lake sediment are discussed in Chapter 6). The presence of *Secale cereale,* thought to be a Romano-British introduction to the North of England (Dark, 2005) throughout the core also indicates that the uppermost date (which is early- to mid-Romano-British) is highly unlikely to reflect the true age at that depth.

Regarding the second reversed date, at 75 cm there is a yellow clay band, indicating that inorganic material was washed into the tarn due to disturbance/erosion within the catchment area. Arboreal taxa decline at this time (Figure 4.2), suggesting that this might have been caused by exposure of the soil through anthropogenic woodland clearance. The continued presence of arable and grazing indicators demonstrate that farming was being practised in the area

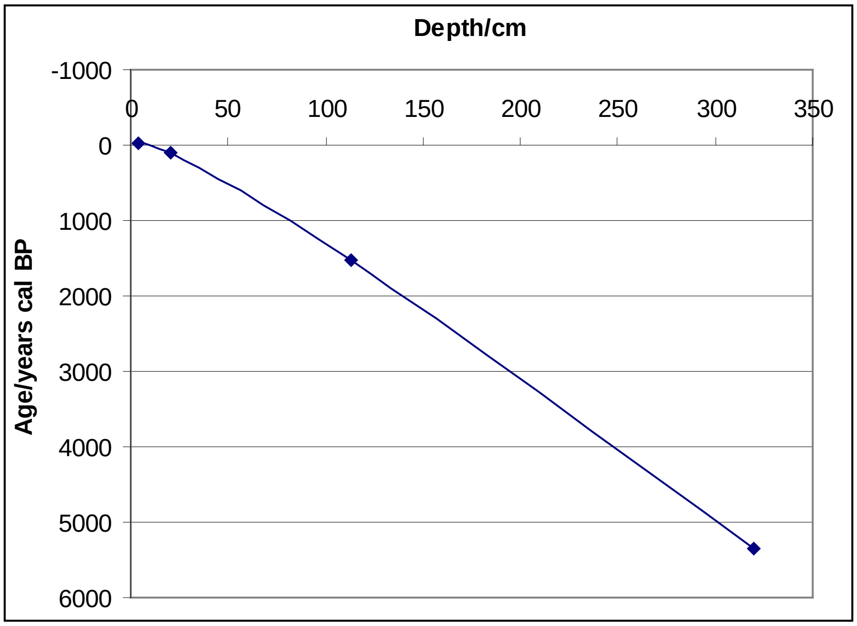



Figure 5.1. Simplified age-depth model for BFT incorporating the radiocarbon date reported by Pennington (1970, 1981). The mid-point of the uncalibrated AMS measurement was plotted at 112-3 cm to comply with the format of the earlier date. The two age estimates near the top of the core are derived from the SCP profile (Figure 4.1).

(Figure 4.4), which can also expose and damage the soil structure through ploughing, overgrazing or trampling by livestock (Limbrey, 1975). As noted in the previous chapter, there is also a substantial spike in *Calluna vulgaris* at 72 cm depth, together with small increases in resilient pollen types (section 4.1.2., LPAZ 3), phenomena which have previously been interpreted as evidence for the incorporation of eroded soils or peat to lake sediment (*cf.* Edwards *et al.,* 2005; Leira *et al.,* 2007). Pollen concentrations decline between 80 and 70 cm depth (Figure 4.5), suggesting poor preservation and/or rapid accumulation of sediment (see Section 5.2), which also supports the conclusion that 'old' pollen was redeposited from the catchment at this time.

The basal AMS date (112-114 cm) falls within the post-Romano-British period and is thought to be an accurate age estimate for the sediment at that depth. There are no indications of inwash at this time and the substantial expansion of heathland taxa throughout this earliest phase is consistent with colder, wetter conditions identified in peat records across the UK in the sixth to seventh centuries AD (*e.g.* Barber, 1981; Blackford & Chambers, 1991; Mauquoy & Barber, 1999; Wimble *et al*., 2000; Hughes *et al.*, 2000; Barber *et al.*, 2003). Comparison with Pennington's age-depth model for BFT (1981: 241) indicates that of the three AMS dates acquired for this project, only that at the base of the core complies with the established chronology for the site. Incorporating the radiocarbon date of 5340 +/- 120 BP (at *c* 320 cm depth) on which her chronology is based suggests good agreement with the age-depth model presented here (Figures 5.1 and 5.2).

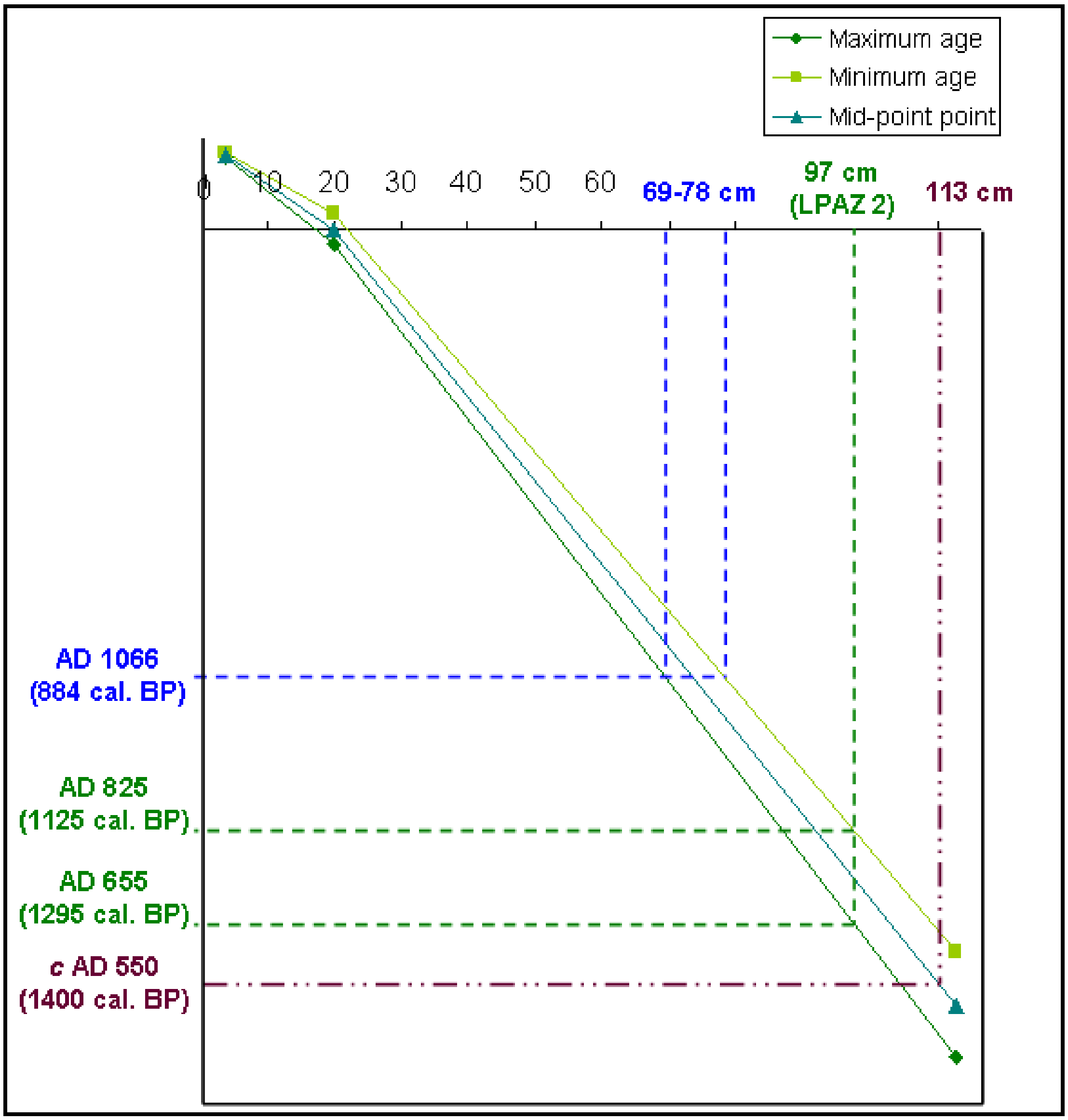



Figure 5.2. Age-depth model for BFT, indicating the depth ranges (2 sigma variation) of important dates/depths. The start of LPAZ 2 (*c* C8th-9th AD) is also indicated. Dates plotted are AD 550 (inferred from expansion of heaths)– post-Roman/early Anglo-Saxon; AD 655-825 – maximum date range for LPAZ 2 boundary, of which the upper; AD 1066 – Norman invasion. The Dark Age/early medieval period falls approximately between AD 410 and 1066.

Logically, the deepest, most recent date must normally be considered the most reliable; 'old' carbon can easily be incorporated to the profile through erosion and redeposition, but for 'young' material to be present substantial mixing or disturbance would be required (*cf.* Pennington, 1981). Although this may be the case for BLT and LLT, it seems unlikely at BFT given the nature of the sedimentary, pollen and diatom records. Another possible source of contamination is root penetration of aquatic plants, but as seen in the sediment description there was very little plant material of any kind in the core, let alone indications of reed disturbance as seen at TWT. The location of the coring site in the deepest part of BFT (7.5 m) should preclude damaging disturbance by aquatic plant growth, unless the tarn was significantly shallower in the past. Further dating evidence would be beneficial to confirm (or overturn) this hypothesis (discussed in Chapter 6), but as this is currently unavailable the basal date will be accepted here to facilitate interpretation of the record.

If a steady rate of accumulation is assumed between the basal radiocarbon estimation and the first occurrence of SCPs (*c* AD 1825-1875 (Rose *et al.*, 1995; Rose & Appleby, 2005)), the post-Romano-British/early medieval period (*c* AD 400-1066) begins at, or just before, the start of the record, ending at approximately 69-78 cm depth depending on whether the maximum or minimum ages are applied (Figure 5.2). The assumption of steady accumulation is questionable as there appear to have been several marked 'inwash' events at BFT (Chapter 4 and Section 5.2). This short-term, rapid accumulation of sediment is problematic in terms of establishing an age-depth model for the site and may be the reason for occasionally dramatic fluctuations in total pollen concentration (Figure 4.5). The dip in concentration from 72-76 cm seems to correspond to a clay inwash layer, but there is not a clear, consistent pattern of correlation with stratigraphy throughout the remainder of the core and absolute pollen values are certainly too variable to be used as a measure of sedimentation rates at BFT (*cf.* Middledorp, 1982, Brush, 1989). It is possible that the higher than average concentrations in LPAZ 2 reflect slower accumulation during this phase, but there is no obvious change in the character of the sediment to support this. 'Pollen influx' is, in any case, a contentious means of measuring sediment accumulation rates because of problems of equifinality; numerous factors affect the quantity of pollen reaching the lake, notably climatic and local environmental conditions affecting pollen productivity and dispersal, and natural or anthropogenic activities that encourage or prevent flowering (*e.g.* grazing, browsing, burning and coppicing) (Groenman van Waateringe, 1993; Nielsen & Odgaard, 2004). In addition, the amount of pollen deposited at a specific point in the lake will be influenced by variation in lake circulation

(Brubaker, 1975; Pennington, 1981), while sedimentary changes might impact upon pollen preservation (*cf.* Havinga, 1984). Deforestation often causes an increase in run-off and sedimentation rates and therefore a decline in pollen per unit sediment, but the resulting increase in overland-/stream-flow might lead to a rise in the levels of redeposited pollen eroded from riverbanks and surface sediments, as well as an overall increase in streamborne pollen where inflows are present (Pennington, 1964, 1979; Bonny, 1978; Nielsen & Odgaard, 2004; Brown *et al.*, 2007). While management practices are likely to affect particular species or vegetation communities, a general amelioration of environmental conditions causing an increase in productivity by many taxa would be difficult to distinguish from a decrease in deposition rates (the issues surrounding variations in pollen productivity are discussed in more detail in Chapter 6 in relation to the use of PPEs in modelling).

Bearing the aforementioned problems in mind, altering the age-depth model on the basis of pollen concentrations is not justified, at least in this case. However, in the absence of further dating evidence, in order to allow for the impact of phases of rapid accumulation in the upper half of the core, the more conservative estimate for the upper limit of the study period has been adopted here, placing the end of the period at *c* 74-8 cm depth. If, as suggested above, the expansion of *Erica* (thought to be *E. tetralix*) signals the 6$^{th}$ century AD climatic downturn, a date of approximately AD 550 can be inferred at *c* 113 cm depth (Figure 4.2 and 5.2). Extrapolation to the base of the core and interpolation between these depths places the post-Romano-British and early medieval periods within LPAZs 1 and 2 (corresponding to LDAZ 1), with the zone boundary falling in approximately the later 8$^{th}$ or early 9$^{th}$ century AD (Figure 5.2). This corresponds with the later Anglo-Saxon period and the time at which permanent Norse settlements were established in England. Cumbria and the Lake District were not part of the Danelaw, but place-names, Nordic pagan imagery on church crosses, ‘meeting’ sites such as the Thingmount near LLT and occasional finds of Viking burials, swords and jewellery strongly support a Norse presence in the region (Section 1.4.3.2).

### 5.2.1. Vegetation and landscape management in the post-Romano-British and Anglo-Saxon periods (*c* AD 430-850)

The pollen data for the early post-Roman period indicate a mixture of open heath and farmland, with arboreal pollen percentages low enough to arise from small patches of woodland such as those seen in the present day landscape (*e.g.* Images 3.1-3.3) and regional[1] pollen inputs. Small quantities of cereal pollen (*Avena/Triticum*-type, *Hordeum*-type, *Secale cereale*) together with herbs associated with agriculture and grazing (*e.g. Urtica dioica, Plantago lanceolata, P. major/media*) indicate arable and pastoral farming within the catchment area at this time. *Calluna* and *Erica* moors might also have been used for rough grazing of sheep, which is common practice in the modern landscape and has been recorded historically in this area (*e.g.* Bailey & Culley, 1805; Van der Post *et al.*, 1997; Dumayne-Peaty & Barber, 1998). The diatom flora is dominated by taxa associated with high to medium nutrient status throughout this early phase, which suggests medium to high levels of phosphorous such as may be caused by agricultural or pastoral waste products being washed into the tarn (*e.g.* animal dung or other fertilisers) or from human settlement in the vicinity (*e.g.* Pennington, 1943; Round, 1961; Evans, 1970).

#### 5.2.1.1. BFT_LPAZ 1 Pollen simulations

Numerous HUMPOL landscape simulations were performed using the pollen data for LPAZ1 at BFT in order to understand better the nature of the pollen record and to test the expected pollen output for different, hypothetical landscapes. In the experimental simulations for this project, different matrices (the dominant vegetation community) and vegetation compositions were tested. The most useful of these, meaning those that produced interesting results, which have a bearing on interpretations of land-use and vegetation cover during the early post-Roman period, are presented here and discussed in the summary of this section. As explained previously (Section 5.1), the number of taxa included in the model is limited by the capabilities of the software and the availability of measurements for PPE and fall speed. Designing the landscape and defining vegetation communities requires interpretation of the pollen data, necessitating decisions about which taxa are significant and which should be excluded. For example, in BFT LPAZ 1 simulations *Tilia* and *Ulmus,* both of which are present at less than 0.5% of the TLP for the zone, were excluded in favour of similarly rare

[1] Those arising from beyond the RSAP, *sensu* Sugita, 1994

herbaceous types likely to be associated with farming. Woodland is represented by the key arboreal species and it was felt that this approach would be more useful in terms of understanding landscape openness and anthropogenic activity. *Secale cereale* was also removed from the model as this species was present at only 0.1% of the TLP; 'Cerealia', which incorporates *Hordeum*-type, *Avena/Triticum*-type and indeterminate *Avena/Triticum/Hordeum*-type grains, was slightly more prevalent and was incorporated to the model.

The first simulation (BFT_LPAZ1_1) was performed using the 'real' (based on counts) pollen proportions in order to gauge the impact of differing production and dispersal properties on the pollen assemblage. Considering the relative PPEs and fall speeds of the grains, it was expected that trees would be overrepresented relative to taxa of open ground, particularly in the case of high pollen-producers such as *Betula* and *Quercus* (Table 5.1). Cerealia was expected to be dramatically underrepresented where only a small area of arable land was modelled, on account of the poor properties of production and dispersal exhibited by cereals (*cf.* Edwards *et al.*, 1986; Edwards & McIntosh, 1988).

For the simulation, taxa were divided into hypothetical communities, retaining the overall percentages for each type insofar as possible. For example, if Poaceae constituted 70% of the TLP, *Quercus* 10%, *Betula* 10% and *Corylus avellana*-type 10%, the communities would consist of grassland (the matrix) and mixed woodland
in the following percentages:

| Community | Percentage landscape cover of community | Percentage vegetation type within community | | | |
|---|---|---|---|---|---|
| | | Poaceae | Quercus | Betula | Corylus |
| Grassland | 70 | 99.91 | 0.03 | 0.03 | 0.03 |
| Mixed woodland | 30 | 0.03 | 33.33 | 33.32 | 33.32 |

Values of 0.03 must be entered rather than zero or the model will not operate. The remaining percentages are then adjusted so that the community total is 100%, hence the slightly peculiar values. BFT_LPAZ1_1 was based around a heathland matrix with patches of pasture/grassland and mixed woodland. Smaller patches of arable land, wet woodland and wet grassland were also plotted (Image 5.1, Tables 5.2 and 5.3). The simulated vegetation communities are necessarily simplified; there is no provision for understorey vegetation in the woodland or for individual trees within grassland, and the intention is to examine the representativity of the simulated pollen assemblage for the key elements in each community rather than to 'reconstruct' the landscape. In this experiment, Cerealia makes up only 10% of the vegetation in arable land.  This is obviously unrealistic, but was necessary in order for the model to run. As the aim was to reconstruct the vegetation based directly on the pollen sum and cereal pollen was very rare (0.2% of the TLP), at first a 100% Cerealia community covering 0.2% of the landscape was fed into HUMPOL.  Despite several attempts at varying the arable patch sizes and reducing the overall number of taxa, the model would not run unless the agricultural community composed 1% or more of the total land cover, for which reason Poaceae (non-cultivated 'grass') makes up almost 50% of the community.

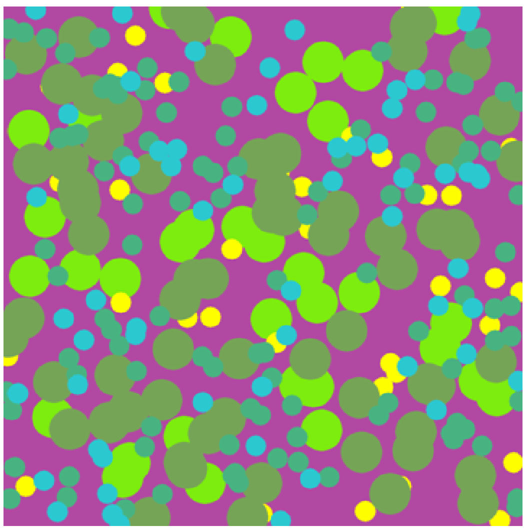


Image 5.1: Example landscape for BFT_LPAZ1_1 (Mosaic)

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Heath | MATRIX (36.1%) | N/A | |
| Pasture/grassland | 14.8% | 1000m | |
| Arable land | 4% | 500m | |
| Mixed woodland | 27.1% | 1000m | |
| Wet woodland | 11.5% | 500m | |
| Wet grassland | 6.5% | 500m | |

Table 5.2: BFT_LPAZ1_1 Community cover and patch sizes

Table 5.3: Community compositions for BFT_LPAZ1_1

| | Alnus | Betula | Cerealia | Cichoroideae | Corylus avellana-type | Cyperaceae | Ericaceae | Filipendula | Plantago lanceolata | Poaceae | Potentilla-type | Quercus | Rubiaceae | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heath | 11.1 | 0.03 | 0.03 | 0.03 | 0.03 | 4.4 | 69.9 | 0.03 | 0.03 | 14.3 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Pasture/ grassland | 0.03 | 0.03 | 0.03 | 8.1 | 0.03 | 0.03 | 0.03 | 0.03 | 4.7 | 70.1 | 10.1 | 0.03 | 4.7 | 2.0 | 0.03 |
| Arable land | 0.03 | 0.03 | 10.0 | 12.5 | 0.03 | 0.03 | 0.03 | 0.03 | 17.5 | 49.7 | 0.03 | 0.03 | 7.5 | 2.5 | 0.03 |
| Mixed woodland | 0.03 | 43.8 | 0.03 | 0.03 | 42.1 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 13.7 | 0.03 | 0.03 | 0.03 |
| Wet woodland | 95.2 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.7 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 28.6 | 0.03 | 18.0 | 0.03 | 53.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |

As expected, the simulation based directly on pollen proportions returned a poor match for the actual pollen data (Figure 5.3). Taxa of open ground and heath were drastically underestimated, particularly Poaceae, Ericaceae and to a lesser extent Cyperaceae. Cichoroideae (*Cichorium intybus*-type) and Cerealia barely registered in the assemblage, whereas tree species (most notably *Alnus glutinosa* and *Betula*) were grossly overestimated by the model. Values for *Corylus avellana*-type were approximately 50% of their 'real' pollen percentages, while the proportion of *Quercus* was too high. This pattern largely follows the predicted outcome of the scenario, although the scale of difference between the modelled vegetation abundances and simulated pollen percentages (and presumably, therefore, between past vegetation cover and fossil pollen data) is more difficult to estimate without the application of numerical modelling (discussed further in Chapter 6). The results of BFT_LPAZ1_1 clearly demonstrate the need for careful consideration of the different pollen production and dispersal properties of taxa when interpreting palynological data, as well as highlighting the poor representation of herbaceous and ericaceous taxa relative to tree species in pollen assemblages.

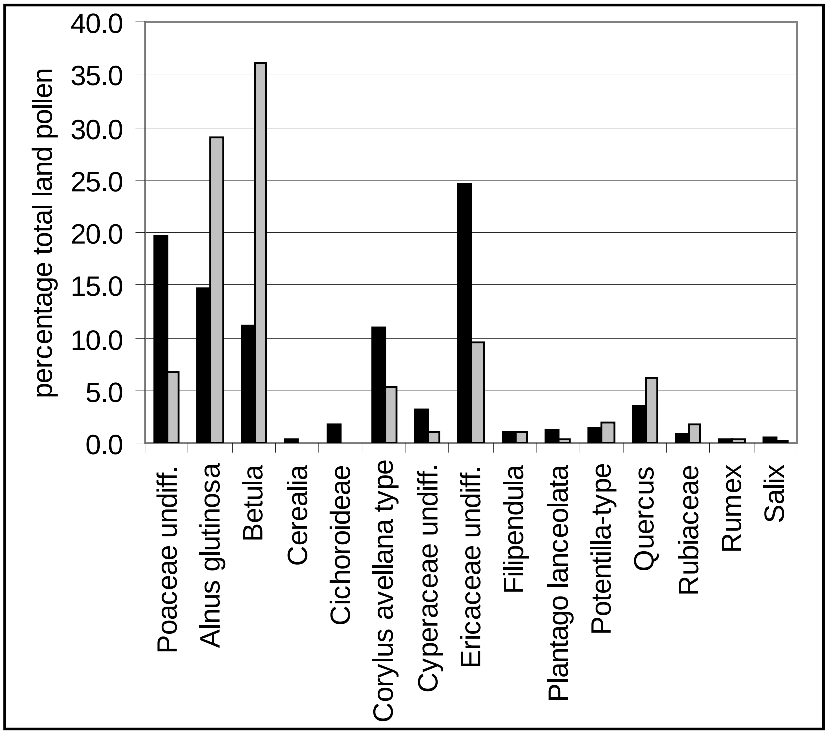



Figure 5.3. Real (black) and simulated (grey) pollen proportions (simulation BFT_LPAZ1_1).

In addition to the simulated pollen data, Polsim v3 {Sugita, 2002} estimates the RSAP for the site based on the nature and distribution of simulated vegetation communities and the size of the sampling basin. The radius used for BFT (based on the mean average as the site is not circular) was 100 m, for which BFT_LPAZ1_1 estimated a source area of 2800 m (Figure 5.4), meaning that for a site the size of BFT in a landscape like that in the scenario, the non-regional (*i.e.* local and extralocal) component of the pollen assemblage could be explained almost entirely in relation to the vegetation within a 2.8 km radius of the site.

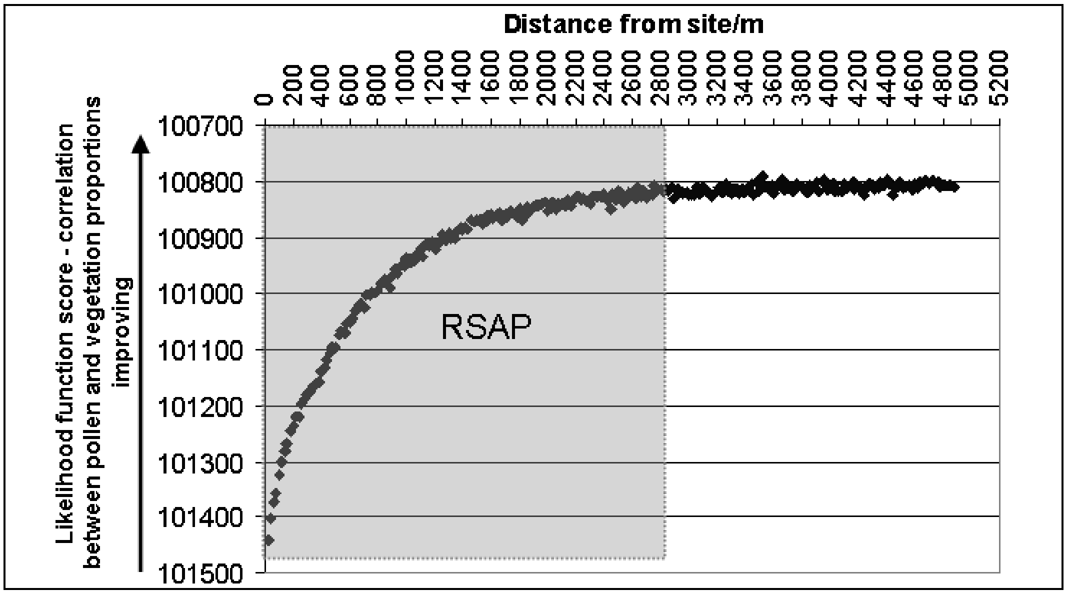


Figure 5.4: Likelihood function scores with increasing distance from the lake edge, showing predicted radius of RSAP for BFT_LPAZ1_1.

The percentage cover and compositions of vegetation communities were adjusted for subsequent simulations on the basis of the results from BFT_LPAZ1_1. The stark differences between the simulated data for BFT_LPAZ1_1 and the real pollen proportions indicate that the vegetation patterns in this scenario are very unlikely to match those in the early post-Roman/Anglo-Saxon landscape. Because of this, many adjustments were required in terms of the compositions, percentage cover and patch sizes of communities to move from the landscape in BFT_LPAZ1_1 to that in BFT_LPAZ1_2 (presented below). The intermediate simulations are not presented here as they either produced data that were a poor match for the counted pollen values (as in BFT_LPAZ1_1), or were so similar to BFT_LPAZ1_2 in both their composition and simulated pollen outputs that describing their outputs would add little to the discussion.

Experiment BFT_LPAZ1_2 produced the best fit for the data without altering the matrix from heathland. In this simulation grassland and arable communities were combined to produce a ‘mixed farmland’ category; this was intended to represent the combination of small-scale agricultural plots and larger grazed areas that might be expected to occur around individual farmsteads or small settlements (Image 5.2, Table 5.4 & 5.5). This is probably a more realistic scenario for the period than relatively large, discrete patches of arable and pastoral land as modelled in BFT_LPAZ1_1. The maximum patch size for the mixed woodland community was reduced to reflect its diminished total land cover. In addition, significant changes were made to the composition of this vegetation type; both *Betula* and to a lesser extent *Quercus* percentages were reduced, while the proportion of *Corylus avellana*-type was almost doubled (Tables 5.3 and 5.6). Wet woodland was also adjusted, with the percentage of *Alnus* being decreased to allow for higher *Salix* values. Wet grassland patches were made smaller, based partly on a reduction in land cover, but also on the supposition that this community was likely to be confined to relatively small areas at the lake margins or within wetter parts of heathland. A substantial increase (calculated according to the percentage within a community and the percentage total land cover of that community) was made to the modelled abundances of Cichoroideae and Cerealia, both of which were dramatically underrepresented in the first simulation. BFT_LPAZ1_2 produced simulated pollen values much closer to the real data than BFT_LPAZ1_1, although open ground indicators and to a lesser extent, trees associated with wet woodland, are overrepresented by the simulated pollen data in this experiment (Figure 5.5). The model estimated an RSAP of 2200 m for this landscape (Figure 5.6), significantly smaller than for the previous simulation.

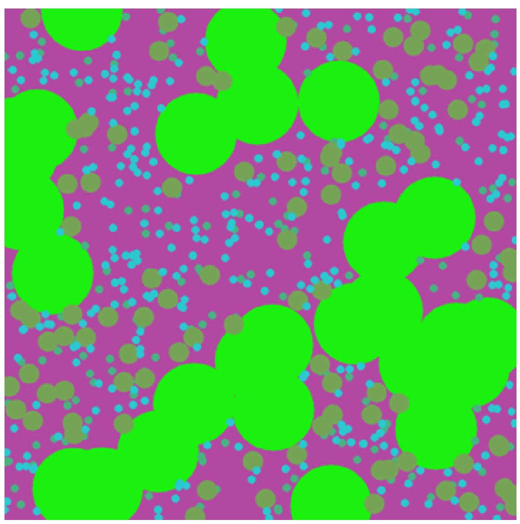


Image 5.2: Example landscape for BFT_LPAZ1_2 (Mosaic)

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Heath | MATRIX (41.5%) | N/A | |
| Mixed farmland | 39% | 2000m | |
| Wet woodland | 3% | 200m | |
| Mixed woodland | 11% | 500m | |
| Wet grassland | 5.5% | 200m | |

Table 5.4: BFT LPAZ 1_2 Community cover and patch sizes.

Table 5.5. Community compositions for BFT LPAZ1_2

| | Alnus | Betula | Cerealia | Cichoroideae | Corylus avellana-type | Cyperaceae | Ericaceae | Filipendula | Plantago lanceolata | Poaceae | Potentilla-type | Quercus | Rubiaceae | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heath | 3.0 | 0.03 | 0.03 | 0.03 | 0.03 | 3.0 | 85.0 | 0.03 | 0.03 | 8.67 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Mixed farmland | 0.03 | 0.03 | 4.0 | 40.56 | 0.03 | 0.03 | 0.03 | 0.03 | 5.0 | 48.0 | 1.0 | 0.03 | 0.5 | 0.7 | 0.03 |
| Wet woodland | 80.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 19.61 |
| Mixed woodland | 0.03 | 11.0 | 0.03 | 0.03 | 80.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 8.64 | 0.03 | 0.03 | 0.03 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 40.0 | 0.03 | 7.0 | 0.03 | 52.64 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |

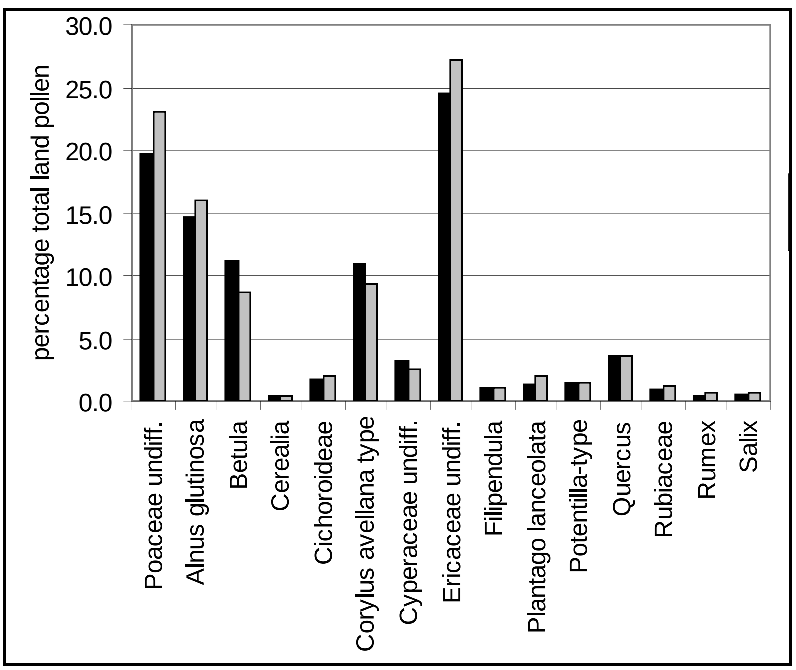



Figure 5.5: Real (black) and simulated (grey) pollen proportions (simulation BFT_LPAZ1_2).

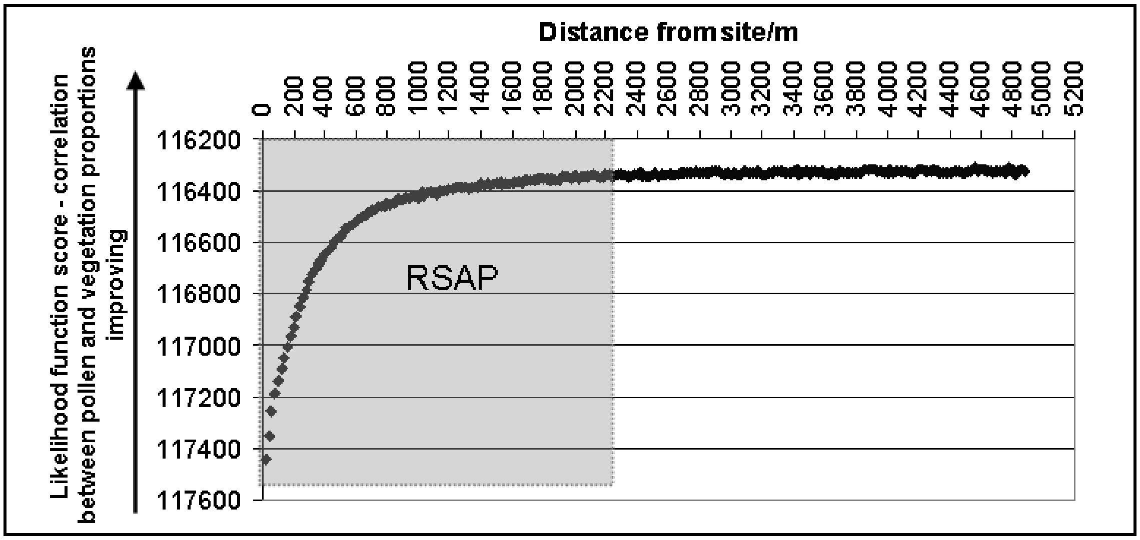



Figure 5.6: Likelihood function scores with increasing distance from the lake edge, showing predicted radius of RSAP for BFT_LPAZ1_2.

The data produced by BFT_LPAZ1_2 suggest that a landscape such as that envisaged in this scenario might produce a pollen signal similar to that seen in the early post-Romano-British to Anglo Saxon phase at BFT. Owing to the close match between the real and simulated pollen percentages in this experiment, in most of the subsequent simulations the community compositions were not altered substantially. In simulation BFT_LPAZ1_3 the matrix vegetation was changed from heathland to mixed farmland. This did not alter the relative proportions of heath and agricultural/pastoral substantially, but spread the farmland community throughout the landscape more evenly, while concentrating heathland into patches measuring up to 2 km in diameter (Image 5.3, Tables 5.6 and 5.7). Interestingly, BFT_LPAZ1_3 produced an estimated RSAP larger than any other recorded for BFT with a radius of 3200 m (Figure 5.7). *Betula* was found to be underrepresented in the simulated pollen proportions, whereas those for Poaceae, *Plantago lanceolata* and other taxa of the mixed farmland category were too high (Figure

5.8), but the overall agreement between real and experimental data is good for this scenario.

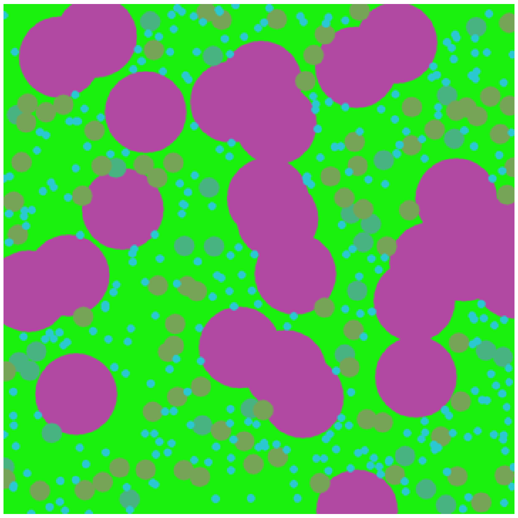


Image 5.3: Example landscape for BFT_LPAZ1_3 (Mosaic).

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Mixed farmland | MATRIX (43%) | N/A | |
| Heath | 39% | 2000m | |
| Wet woodland | 3.5% | 500m | |
| Mixed woodland | 9% | 500m | |
| Wet grassland | 5.5% | 200m | |

Table 5.6: BFT_LPAZ1_3 Community cover and patch sizes.

Table 5.7: Community compositions for BFT_LPAZ1_3.

| | Alnus | Betula | Cerealia | Cichoroideae | Corylus avellana-type | Cyperaceae | Ericaceae | Filipendula | Plantago lanceolata | Poaceae | Potentilla-type | Quercus | Rubiaceae | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mixed farmland | 0.03 | 0.03 | 4.5 | 35.0 | 0.03 | 0.03 | 0.03 | 0.03 | 7.0 | 51.06 | 1.0 | 0.03 | 0.5 | 0.7 | 0.03 |
| Heath | 2.0 | 0.03 | 0.03 | 0.03 | 0.03 | 3.0 | 85.0 | 0.03 | 0.03 | 9.67 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Wet woodland | 90.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 9.61 |
| Mixed woodland | 0.03 | 9.0 | 0.03 | 0.03 | 82.64 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 8.0 | 0.03 | 0.03 | 0.03 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 40.0 | 0.03 | 7.0 | 0.03 | 52.64 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |

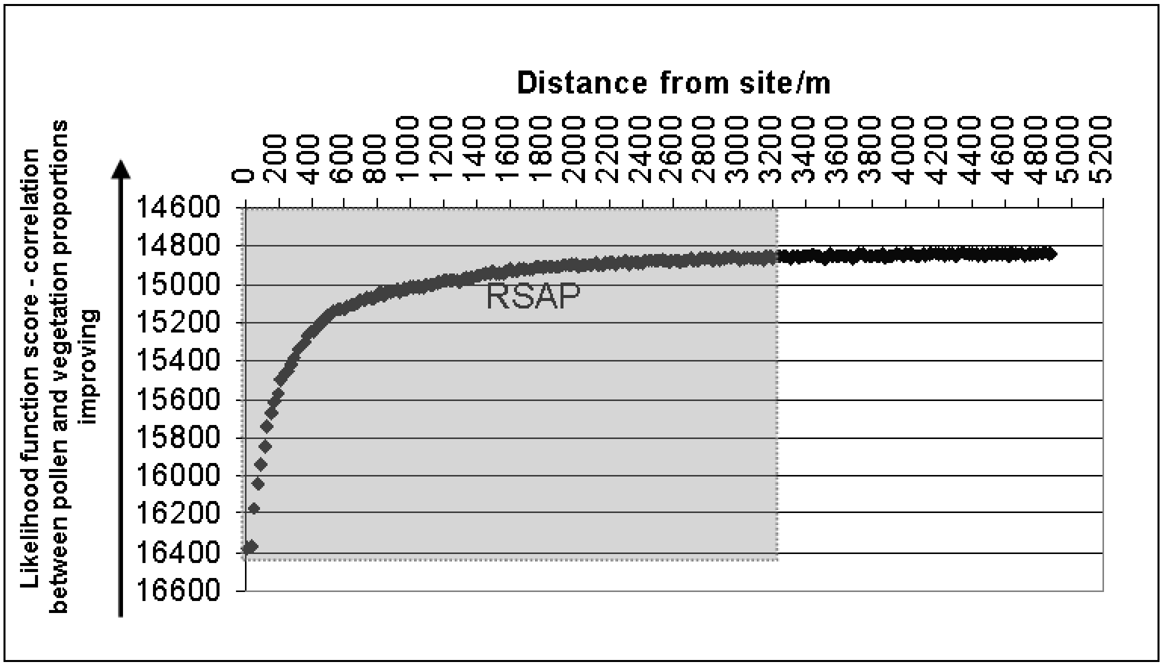



Figure 5.7: Likelihood function scores with increasing distance from the lake edge, showing predicted radius of RSAP for BFT_LPAZ1_3.

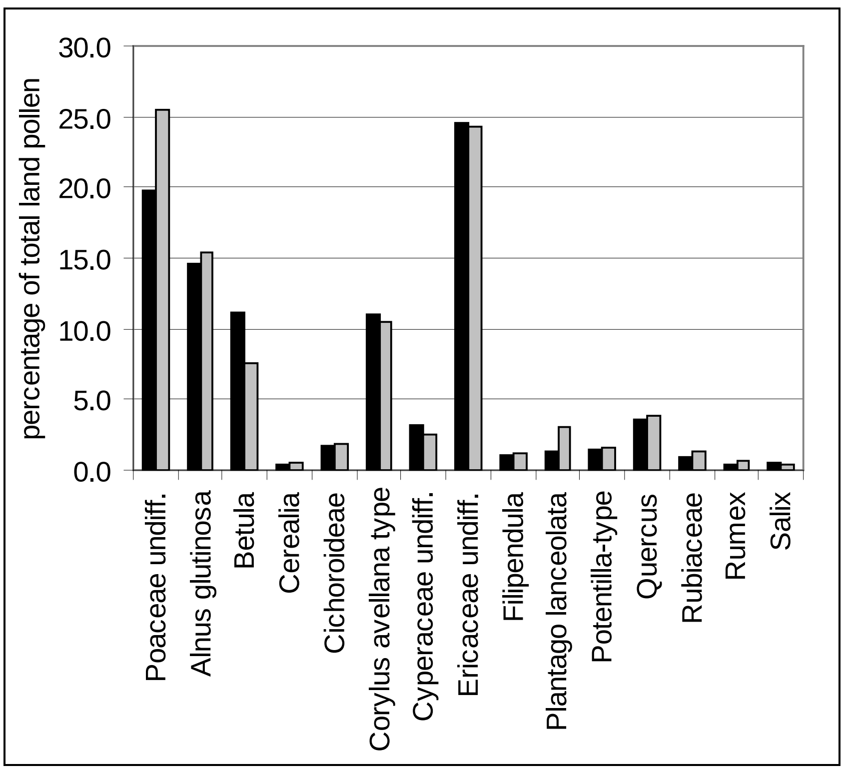



Figure 5.8: Real (black) and simulated (grey) pollen proportions (simulation BFT_LPAZ1_3).

In the final simulation presented for LPAZ 1 (BFT_LPAZ1_4), the matrix vegetation was changed to a ‘rough grazing/ grassland’ community (Image 5.4, Tables 5.8 and 5.9), which was intended to reflect more accurately the type of vegetation seen in much of the Lake District today. Arable land was plotted as a separate community in small patches of 100 m diameter. An important difference between this scenario and BFT_LPAZ1_1 (on a heathland matrix) is that the cultivated patches are scattered throughout a *grazed* landscape; this is a similar situation to that embodied by the ‘mixed farmland’ community in BFT_LPAZ1_2 and 3.

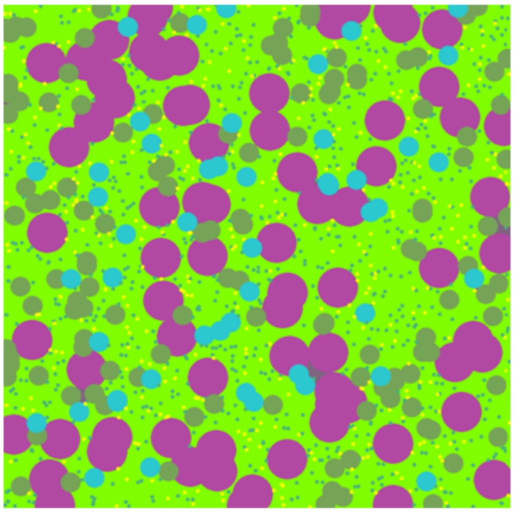


Image 5.4: Example landscape for BFT_LPAZ1_4 (Mosaic)

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Rough grazing/ grassland | MATRIX (47%) | N/A | |
| Heath | 30% | 1000m | |
| Mixed woodland | 13% | 500m | |
| Wet grassland | 5.5% | 500m | |
| Wet woodland | 3% | 100m | |
| Arable land | 1.5% | 100m | |

Table 5.8: BFT_LPAZ1_4 Community cover and patch sizes

Table 5.9: Community compositions for BFT_LPAZ1_4

| | Alnus | Betula | Cerealia | Cichoroideae | Corylus avellana-type | Cyperaceae | Ericaceae | Filipendula | Plantago lanceolata | Poaceae | Potentilla-type | Quercus | Rubiaceae | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rough grazing | 0.03 | 0.03 | 0.03 | 27.79 | 0.03 | 3.0 | 22.0 | 0.03 | 4.0 | 40.8 | 1.0 | 0.03 | 0.7 | 0.5 | 0.03 |
| Heath | 3.0 | 0.03 | 0.03 | 0.03 | 0.03 | 10.0 | 76.67 | 0.03 | 0.03 | 10.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Mixed woodland | 0.03 | 12.0 | 0.03 | 0.03 | 79.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 8.64 | 0.03 | 0.03 | 0.03 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 20.0 | 0.03 | 7.0 | 0.03 | 72.64 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Wet woodland | 85.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 14.61 |
| Arable | 0.03 | 0.03 | 72.4 | 10.0 | 0.03 | 0.03 | 0.03 | 0.03 | 3.0 | 13.73 | 0.03 | 0.03 | 0.3 | 0.3 | 0.03 |

Rough grazing land was modelled as a relatively dry habitat with 22% Ericaceae and just 3% Cyperaceae, which was given more weight in the heathland and wet grassland patches dispersed throughout the landscape.  The composition of mixed woodland was altered slightly (with *Betula* becoming more important) and the percentage of woodland cover was increased slightly owing to its underrepresentation in simulations intermediate between BFT_LPAZ1_3 and 4.  This experiment produced pollen data that match the real data relatively closely; Cerealia is underrepresented and tree values are slightly high, but most taxa display similar pollen percentages in both the real and simulated data assemblage (Figure 5.9)  Interestingly, although the overall modelled abundance of Ericaceae was higher than in the previous simulations (owing to a strong presence in both of the most dominant habitats), the simulated pollen values for Ericaceous pollen are lower than those in BFT_LPAZ1_2 and 3. BFTT_LPAZ1_4 had an estimated RSAP of 2200 m (Figure 5.10).

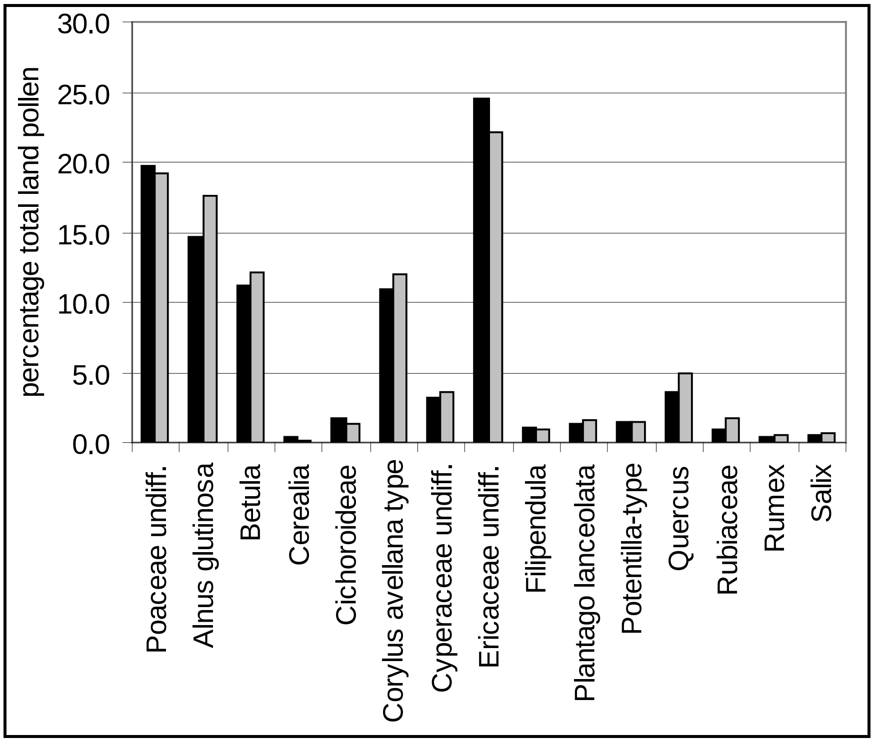



Figure 5.9: Real (black) and simulated (grey) pollen proportions (simulation BFT_LPAZ1_4).

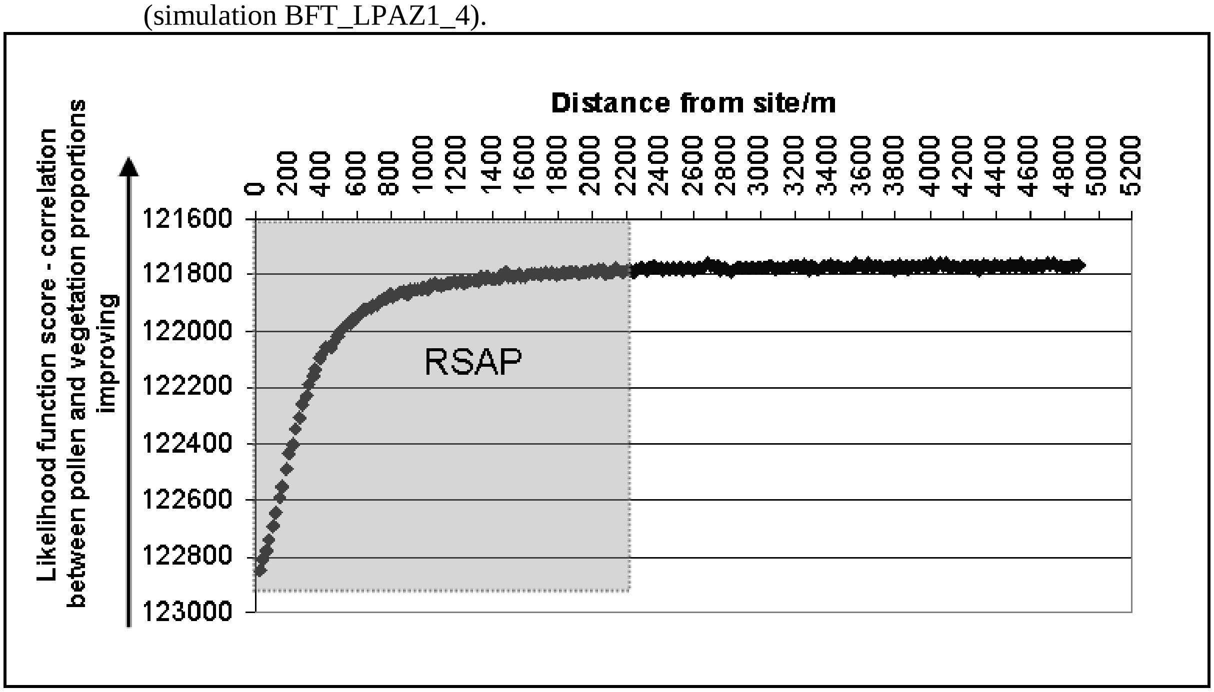



Figure 5.10: Likelihood function scores with increasing distance from the lake edge, showing predicted radius of RSAP for BFT_LPAZ1_4

The simulations performed for the early post-Romano-British phase at BFT support the interpretation of an open landscape with substantial areas of heath and grazed/farmed land and a small amount of agricultural land. With the exception of BFT_LPAZ1_1, all of the scenarios presented here simulated pollen proportions similar to the real palynological data for this period, the implication being that the pollen assemblage for LPAZ 1 at BFT could have been produced by the vegetation patterns in any one of the three models (or a combination of these). The simulations that most accurately mirrored the real data for the period (*i.e.* those with no taxa dramatically misrepresented) were those based on a heath-dominated landscape with large patches of mixed farmland and on a 'rough grazing' matrix (BFT_LPAZ1_2 and BFT_LPAZ1_4 respectively). Both of these scenarios allow for the dispersal of agricultural land within larger areas of pasture, which is probably a better model for early medieval farming in the area than discrete patches of agricultural and pastoral land scattered across the landscape; it seems likely that cultivation would have been concentrated around individual farmsteads or at the periphery of settlements rather than in the large fields favoured by modern, commercial agriculture. This is discussed further in relation to archaeology in Chapter 6, incorporating interpretations of the later Anglo-Saxon and Norse periods at BFT and considering the patterns observed in other palynological studies from the region.

### 5.2.2. Vegetation and landscape management in the later Anglo-Saxon and Norse periods (*c* AD 850-1100)

The later part of the study period at BFT is characterised by a marked reduction in heathland taxa, while trees and shrubs appear to expand. Agricultural, pastoral and ruderal indicators are no more prevalent than in the previous phase. The pollen data could be interpreted as the expansion of woodland onto former heath, with notable increases in *A. glutinosa*, *Betula* and to a lesser extent, *Corylus avellana*-type, although the dramatic loss of *Erica* and *Calluna vulgaris* might also result from overgrazing (*cf.* Bardgett *et al.*, 1995; Pakeman *et al.*, 2003). The continued, low-level presence of anthropogenic indicators suggests that agriculture was practised on a small scale, similar to that in the preceding post-Roman to mid-Anglo-Saxon period. The diatom flora continues to be dominated by species of high to medium nutrient status, possibly owing to the dung of grazing animals washing into the tarn or effluent from human settlement nearby (*cf.* Pennington, 1943; Round, 1961; Evans, 1970).

#### 5.2.2.1. BFT_LPAZ 2 Pollen simulations

As the general character of the landscape appears to have been established successfully in the modelling experiments for LPAZ 1, fewer simulations were required for LPAZ 2. The 'rough grazing' matrix and communities used in BFT_LPAZ1_4 were retained as the basis for landscape scenarios in this period.  To reflect changes in the pollen assemblage, the extent of the heathland community was reduced substantially and the percentage cover of wet woodland was increased.  Slight changes were made to the arable and rough grazing compositions in accordance with developments in the pollen diagrams, but these were essentially minor adjustments and patch sizes were retained from BFT_LPAZ1_4.

The best match for the real data was provided by BFT_LPAZ2_1, which is presented below. Intermediate simulations wherein mixed woodland cover was increased in accordance with the pollen curves produced simulated percentages that overrepresented tree species compared to the real data.  The small increase in woodland cover shown in scenario BFT_LPAZ2_1 (Image 5.5 and Table 5.10), together with slight adjustments to the composition of mixed woodland (Table 5.11) was sufficient to reproduce the changes in *Betula* and *Corylus avellana*-type observed in the pollen diagram (Figures 4.2 and 5.11).

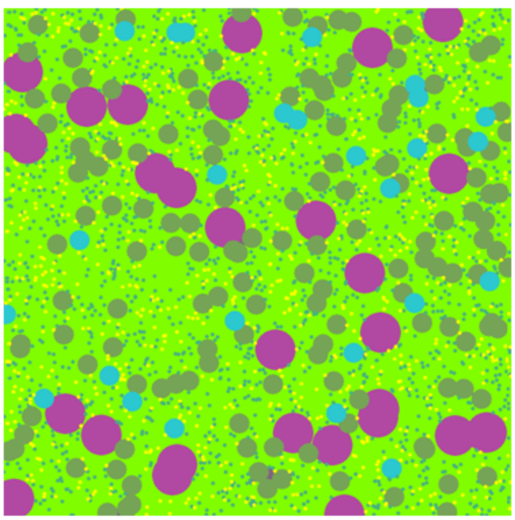


Image 5.5: Example landscape for BFT_LPAZ2_1 (Mosaic).

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Rough grazing/ grassland | MATRIX (57.5%) | N/A | |
| Heath | 13% | 1000m | |
| Mixed woodland | 17% | 500m | |
| Wet grassland | 3% | 500m | |
| Wet woodland | 6% | 100m | |
| Arable land | 3.5% | 100m | |

Table 5.10: BFT_LPAZ2_1 Community cover and patch sizes.

Table 5.11: Community compositions for BFT_LPAZ2_1.

| | Alnus | Betula | Cerealia | Cichoroideae | Corylus avellana-type | Cyperaceae | Ericaceae | Filipendula | Plantago lanceolata | Poaceae | Potentilla-type | Quercus | Rubiaceae | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rough grazing | 0.03 | 0.03 | 0.03 | 28.8 | 0.03 | 3.0 | 19.0 | 0.03 | 3.5 | 43.79 | 0.9 | 0.03 | 0.3 | 0.5 | 0.03 |
| Heath | 2.0 | 0.03 | 0.03 | 0.03 | 0.03 | 7.0 | 79.67 | 0.03 | 0.03 | 11.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Mixed woodland | 0.03 | 18.0 | 0.03 | 0.03 | 73.14 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 8.5 | 0.03 | 0.03 | 0.03 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 18.0 | 0.03 | 9.0 | 0.03 | 72.64 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Wet woodland | 88.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 11.61 |
| Agriculture | 0.03 | 0.03 | 73.4 | 10.3 | 0.03 | 0.03 | 0.03 | 0.03 | 2.0 | 13.63 | 0.03 | 0.03 | 0.2 | 0.2 | 0.03 |

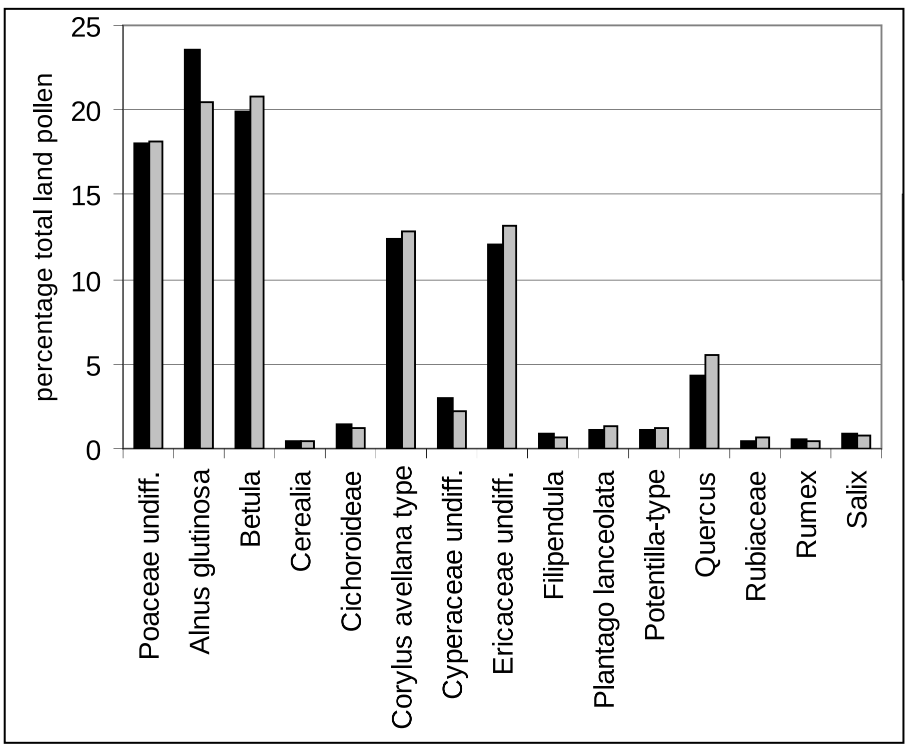



Figure 5.11. Real (black) and simulated (grey) pollen proportions (simulation BFT_LPAZ2_1).

Wet woodland was somewhat underrepresented in this experiment (*e.g. A. glutinosa*, Figure 5.11), perhaps indicating that this community was more widespread than it is in the example landscape. However, the fact that *Alnus* is a common component of streamborne pollen makes interpretation of pollen data for this species difficult (*cf.* Bonny, 1978; Pennington, 1979); a rise in alder pollen might result from an increase in the contribution of inflows to the pollen assemblage relative to airborne pollen, as opposed to changing vegetation patterns in the wider landscape. This problem is discussed further in relation to the limitations of modelling in Chapter 6 (Section 6.4). The RSAP for BFT_LPAZ2_1 was 1800 m (Figure 5.12).

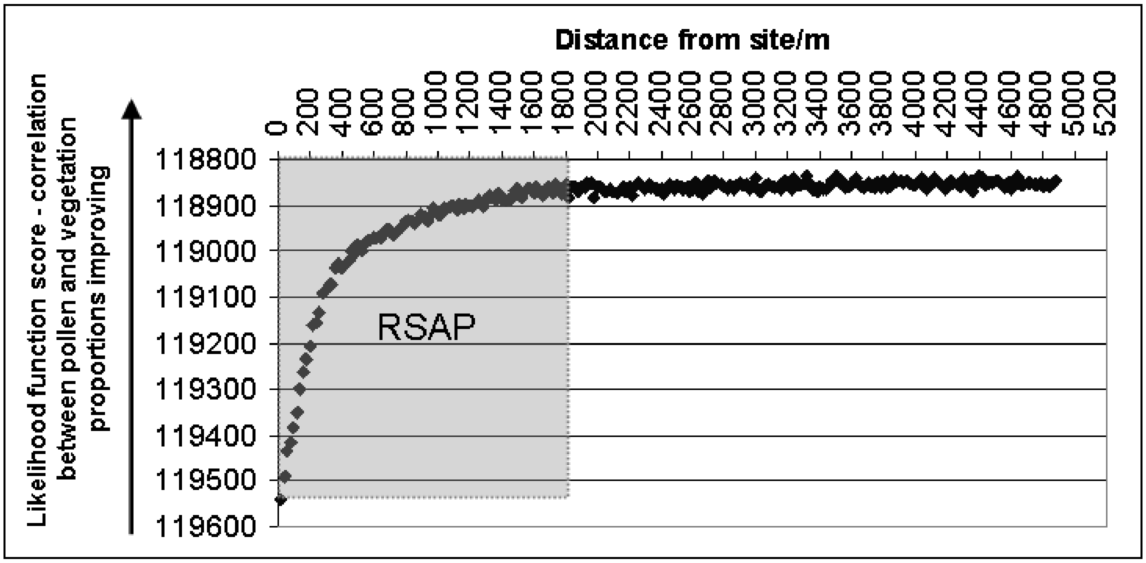



Figure 5.12: Likelihood function scores with increasing distance from the lake edge, showing predicted radius of RSAP for BFT_LPAZ2_1.

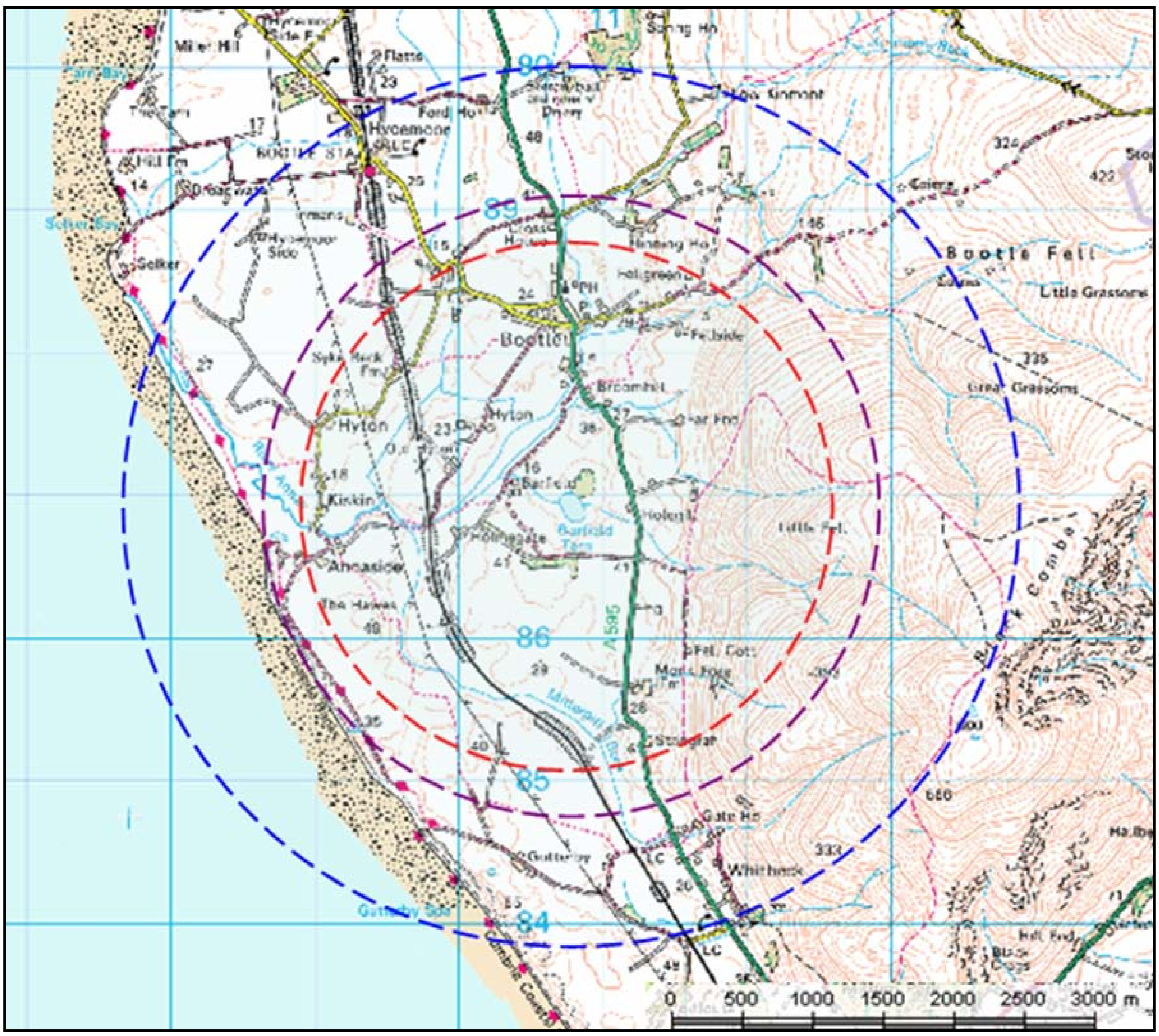
The most compelling observation noted during the modelling attempts for BFT_LPAZ2 concerns the extent of 'rough grazing' or pasture and agricultural land. As noted previously, the pollen diagram for this period suggests little change in terms of farming activity; cereals remain rare and Poaceae actually declines. There are no notable changes in other anthropogenic indicators, apart from a slight increase in *Urtica dioica* and *Rumex* spp. and sporadic occurrences of the arable weed *Centaurea cyanus*. However, in order to attain values similar to the real pollen percentages grazing/grassland taxa in the simulations, it was necessary to increase the coverage of the rough grazing community substantially (by 22.3% relative to the percentage cover in BFT_LPAZ1_4). It was also necessary to increase the extent of the arable community, which was more than doubled in this scenario; as Cerealia was underestimated in BFT_LPAZ1_4 this might not signify. However, the presence of poorly dispersed taxa of open and cultivated ground (Cerealia and *Cichorium intybus*-type) suggests that the vegetation communities from which these are derived were probably located within the RSAP of the tarn, as these types are unlikely to contribute to the 'regional' pollen derived from outside of this area. This conclusion is to some extent supported by Hellman *et al.*'s (2009a) experimental simulation work (also using HUMPOL), in which they assessed the sensitivity of simulated pollen data to indicators of 'landscape openness'. Their data suggest that increasing openness leads to better representation of well-dispersed indicator species such as *Rumex* and *Plantago lanceolata,* but that plants with low pollen productivity and high fall speeds such as Cichoroideae are underrepresented unless 'landscape openness' exceeds 90% (Hellman *et al.*, 2009a).

The simulation data suggest that despite changes in the pollen curves indicative of marked woodland regeneration (the average percentage for *Betula* is more than double that in the previous zone (Figure 4.2)) and a slight *reduction* in herbaceous taxa (Figure 4.3), it is possible to explain the pollen assemblage for the later Anglo-Saxon/Norse period in terms of a relatively minor expansion of woodland (by 31% (compared to previous values), but still constituting only 17% of land cover) and an almost equivalent increase in open ground indicators (by 22.3%, to account for over half of the simulated land cover). Bearing this in mind, it could be argued that the pollen diagram is exaggerating the expansion of woodland at this time, while failing to reflect simultaneous increases in the extent of rough grazed land. If this is the case, an increase in the rough grazed community relative to a decline in heaths would tend to support the hypothesis that grazing contributed to (or caused) the decline in heathland.

Another interesting point to note is that the extent of the estimated RSAP for simulation BFT_LPAZ2_1 (1.8 km, Figure 5.12) is smaller than any of the RSAP values in simulations for the earlier phase and significantly smaller than the maximum predicted radius of 3200 m (for BFT_LPAZ1_3, Figure 5.7).

Assuming the estimations are accurate at least in the direction and approximate scale of change, this reduction in the radius of the RSAP has a large impact on the land surface area represented by the pollen sample; a radius of 2.2 km gives a source area of around 15 km$^2$, while for a 1.8 km radius the source area is reduced to *c* 10 km$^2$. Even more dramatically, a radius of 3.2 km equates to a pollen source area of 32 km$^2$, more than triple the extent of the smallest RSAP (Map 5.1). The potential for drastic increases or decreases in the RSAP is clearly problematic when attempting to interpret vegetation patterns from pollen data, not least because for a given site, the nature of the vegetation seems to influence the size of the RSAP through time more than any other factor (Calcote, 1995; Koff *et al.*, 2000; Bunting *et al.*, 2004; Nielsen & Sugita, 2005). Although the relationship between RSAP and vegetation is complicated, an increase in landscape openness seems to increase the source area for pollen, while a rise in arboreal taxa around the site will reduce the RSAP (*e.g.* Jacobson & Bradshaw, 1981; Koff *et al.*, 2000). In this case, the decrease in source area noted for BFT_LPAZ2_1 might be reflecting the increase in mixed and wet woodland communities within the modelled landscape.

The RSAP estimates simulated by HUMPOL are substantially larger than the several hundred metres indicated by Jacobson and Bradshaw's model (1981) as the radius from within which local and extralocal pollen is derived in small lakes. They suggest that for a lake of 200 m diameter (*i.e.* BFT), the extralocal component constitutes approximately 50% of the pollen sum, while local and regional pollen account for 20% and 30% of the assemblage respectively. Unfortunately, owing to the lack of a well-dated 'regional' pollen assemblage for comparison with the data from BFT, localised developments cannot be easily distinguished from regional changes using numerical models (*cf.* Sugita, 2007a & b). The patterns identified at BFT are discussed in relation to data from other pollen sites in the region in the Chapter 6.




Map 5.1. BFT RSAPs from simulations. The blue circle represents the largest simulated RSAP (3.2 km), the red circle shows the smallest (1.8 km) and the purple circle shows the mean average for the site (2.2 km).

### 5.3. Loughrigg Tarn: age-depth modelling

The age-depth model for LGT is far less contentious than that for BFT (Figures 5.13 and 5.14) and the site produced a substantially longer record in terms of the time period covered by the data. The pollen concentrations for this site show slightly less variation and are lower on average than those for BFT (Figure 4.31). The only episode of inwash identified relates to the reversed radiocarbon date at 100-102 cm depth, at which time *Tabellaria flocculosa* and *T. quadriseptata* expand. As noted for BFT, increases in these species may stem from acidification, perhaps owing to the inwash of eroded soils or peat (see Table 4A, Appendix 4). These changes in the diatom flora coincide with increases in many of the pollen types associated with grazing or disturbance, together with a marked decline in *Quercus* (Figures 4.28-4.30), which suggests clearance of oak woodland at this time. These changes occur in LPAZ 2, which is characterised by increases in herbaceous taxa at the expense of trees, together with the expansion of Poaceae, *Plantago lanceolata* and *Pteridium aquilinum*, from which it can be inferred that tree cover was removed to facilitate pastoral farming. Removing the tree cover exposes the landscape to erosion, which is likely to result in 'old' organic material being washed in from the catchment, particularly where the cleared land is subject to grazing and trampling by livestock. The age-depth model based on interpolation between radiocarbon dates and SCPs places this clearance phase in the late Bronze/early Iron Age, although as mentioned in Chapter 4, the single grain of *Juglans regia* at 100 cm suggests a *terminus post quem* (*TPQ*) of Romano-British date at that depth. This grain has been dismissed as a product of contamination; considering the AMS dates above and below this point, accumulation would need to be remarkably slow in the later prehistoric period, after which an unprecedented increase in the rate of sediment accumulation would be required for even an *early* Romano-British date to be accepted (Figure 5.13).

Fortunately, the radiocarbon date at 60-62 cm depth falls within post-Romano-British-to-'early Anglo-Saxon' times, providing a secure marker for the earlier part of the study period. Interpolation between this date and the start of the SCP curve (*c* AD 1850 ± 25 years) enables the early medieval period to be defined with reasonable confidence for LGT, ending with the inception of the 'middle' medieval period (*c* 11th century AD) at approximately 50 cm depth, which means the Anglo-Saxon and Norse periods are confined entirely to LPAZ 3c (Figures 4.28-4.30). Allowing for the 2 sigma age ranges of the radiocarbon dates, the age-depth model (excluding the *TPQ* for *J. regia*) places the beginning of the Romano-British period in LPAZ 3a and the Roman withdrawal from Britain somewhere between the start of LPAZ 3b and the transition to LPAZ 3c (Figure 5.14). As explained in Chapter 4, the pollen assemblage in LPAZ 3 indicates woodland regeneration and a decline in farming (*i.e.* in the Romano-British and early- to mid-medieval periods). However, a dramatic expansion of diatoms associated with high nutrient status at this time (LDAZ 3) suggests an increased input of organics/phosphorous from the catchment, which would accord with animal dung or other nutrient-rich material washing into the tarn. Interestingly, the diatom assemblage would tend to support an *intensification* of grazing at this time rather than abandonment of farmed land. Specifically arable weeds were not found at any stage of LGT's history, and cereal pollen, which is present in later prehistoric and post-medieval/modern times, is absent from the early historic pollen record. In light of this it seems unlikely that crops were being cultivated in the tarn's catchment area in either the Romano-British or early medieval periods.

Pollen simulation experiments were carried out in order to aid interpretation of landscape and vegetation changes in the post-Roman to mid-medieval periods. Data used for modelling were divided according to the pollen subzones; based on the age-depth model (Figure 5.14) these have been interpreted as late- to post-Romano-British and early Anglo-Saxon (*c* AD 300-630) (LPAZ 3b) and later Anglo-Saxon to Norse (*c* AD 630-1066) (LPAZ 3c - for simulations only pollen data below a depth of 50 cm (estimated date of *c* 11$^{th}$ century AD) was used).

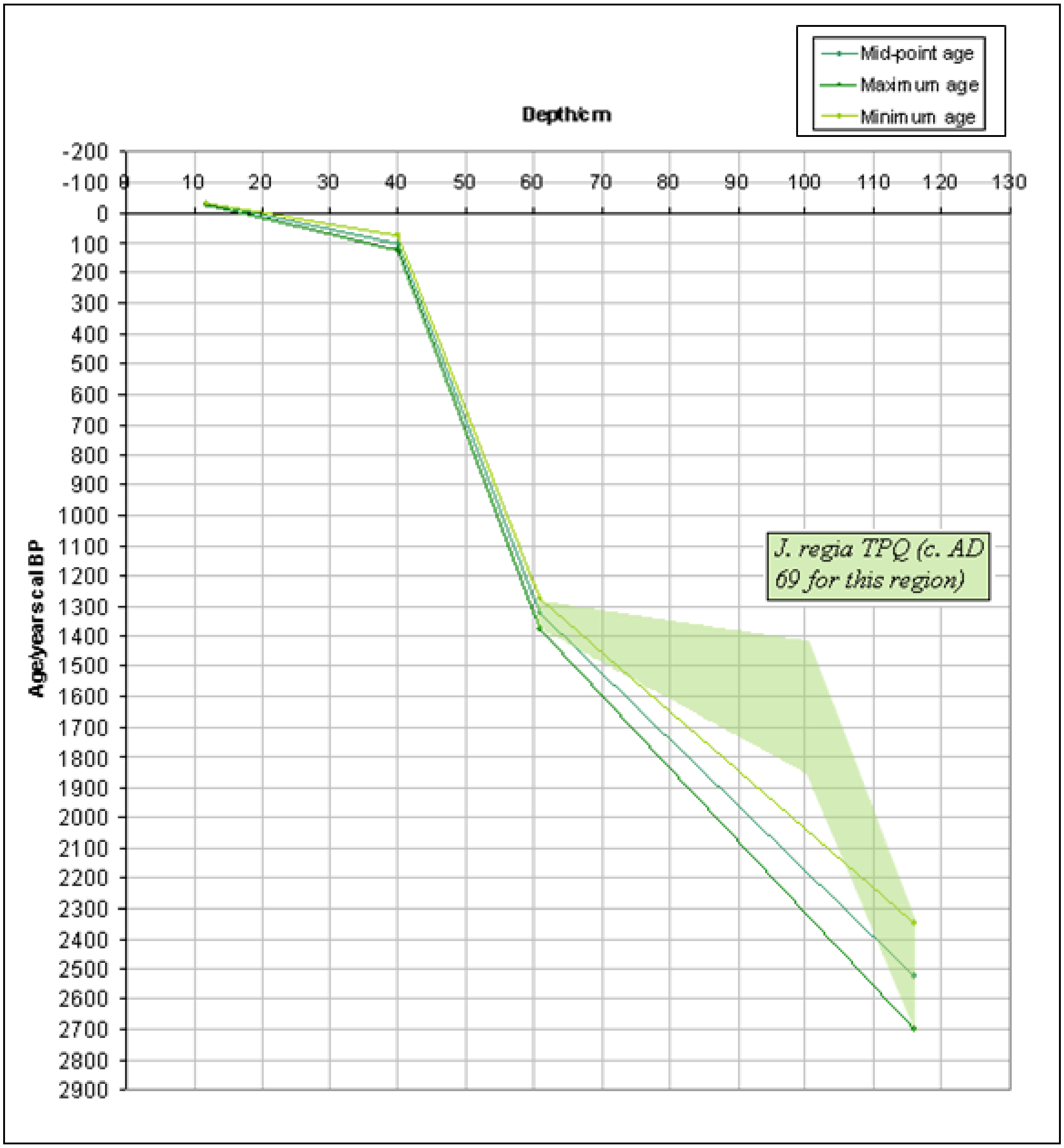



Figure 5.13: Age-depth model for LGT for the later prehistoric period onwards. The alternative model incorporating the TPQ for *J. regia* is indicated by the green shaded area. The full age-depth model incorporating AMS dates for the bottom of the core can be found in Appendix 5 (Figure 5A) and fits well with the model in which the *J. regia* date is excluded.

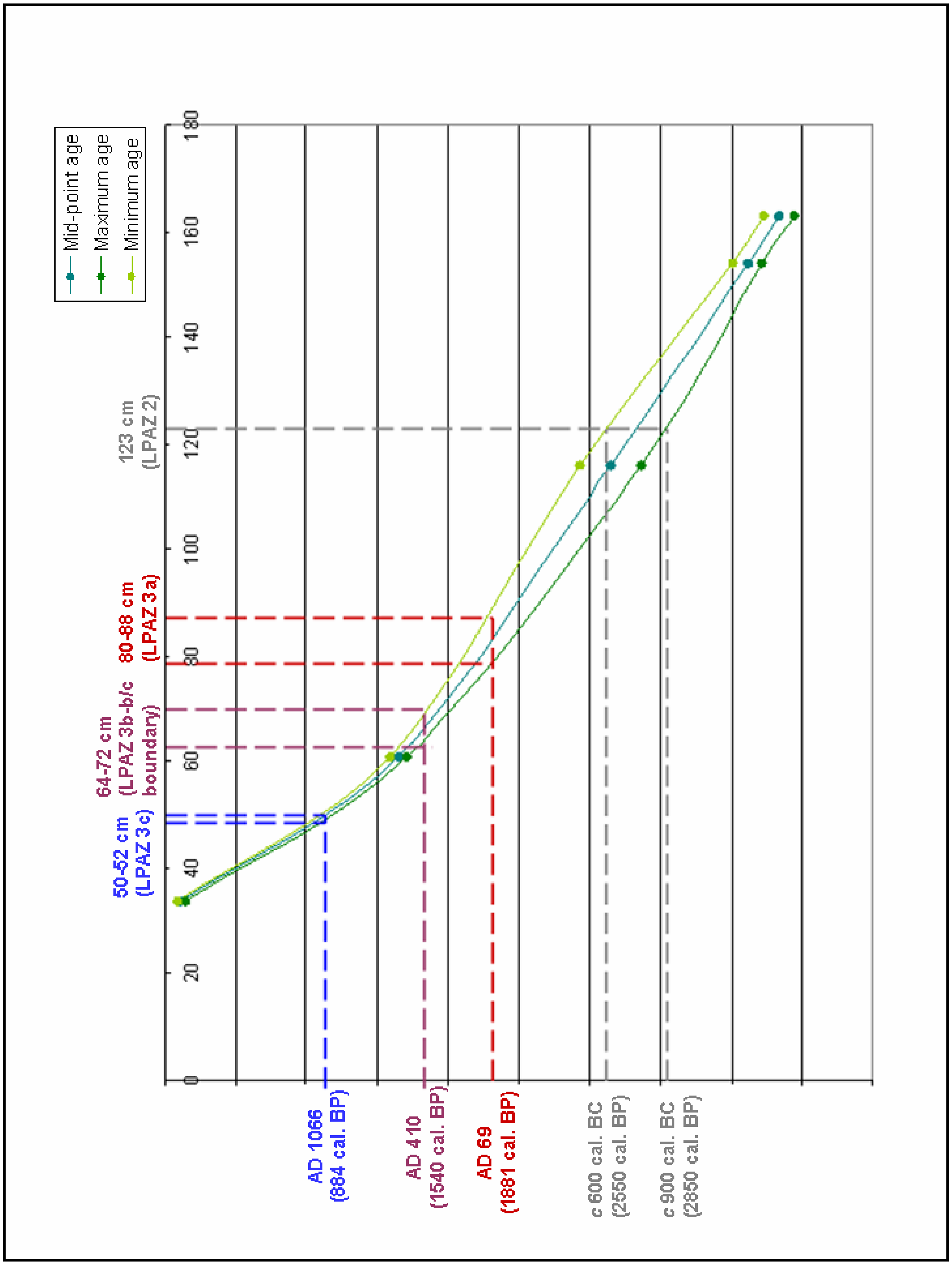



Figure 5.14. LGT Age-depth model indicating the depth ranges (2 sigma variation) of important dates relating to the study period. The start of the late Bronze/early Iron Age pastoral clearance (LPAZ 2) is also indicated. Dates plotted are AD 69 – earliest date for Roman invasion in Northwest England; AD 410 – Roman withdrawal from Britain; AD 1066 – Norman invasion. The Dark Age/early medieval period falls approximately between AD 410 and 1066. Horizontal gridlines are placed every 400 years cal. BP.

### 5.3.1. Vegetation and landscape management in the late- to post-Romano-British and early Anglo-Saxon periods (*c* AD 300-630)

The pollen data for LGT indicate a very different landscape to that at BFT; heathland species are virtually absent throughout the profile and the pollen assemblage is dominated heavily by woodland taxa. LPAZ 3b is defined by a dramatic expansion of oak, which corresponds to a temporary decline in herbaceous taxa, particularly Poaceae. The brevity of this change and the limited number of taxa affected (the main change is in *Quercus*) prevented a full zonal boundary (as opposed to a subzone) from being placed here, but the change is significant and comes after an increase in *Corylus avellana*-type at the end of LPAZ 3a. This might reflect the spread of colonising hazel onto abandoned pastoral land (supported by the decline in grazing and open ground taxa that begins in LPAZ 3a), followed by the development of mixed oak woodland. This scenario complies with traditional theories regarding the socio-cultural deterioration of the 'Dark Ages' as discussed in Chapter 1. Interestingly, the age-depth model for LGT indicates that this 'decline' began earlier, in the late Iron Age, continuing throughout the Romano-British and early- to middle-medieval periods (Figures 5.14 and 4.28-4.30). This phenomenon has been noted at other sites in the region and is discussed in Chapter 6.

As mentioned in the previous section, the diatom assemblage coinciding with LPAZ 3 (LDAZ 3) is dominated by taxa associated with high nutrient status; the prevalence of highly eutrophic diatoms (*e.g. Cyclostephanos dubius*) is indicative of an increase in total phosphorous, which is sustained until the early part of LPAZ 3d and suggests an intensification of grazing or similar activity close to the tarn. There are numerous possible explanations for the apparent disparity in the records, some of which are explored here. Firstly, it is possible that the differences relate to scale; diatoms are likely to reflect changes in the immediate catchment area of the tarn, while the source area for pollen may be substantially larger. The pollen record from LGT is likely to sense changes at a broader scale than the diatom record, in this case, woodland regeneration outside of the tarn's catchment for inwash of phosphorous/organics. However, owing to its small size and enclosed nature (Section 3.6), Loughrigg Tarn's pollen record ought to provide a good indication of local/extralocal vegetation patterns (see Section 1.5.1.5); although changes in the wider landscape will also influence the pollen data, significant developments in the vicinity of the tarn should be reflected in the composition of the pollen assemblage.

Alternatively, it is possible that a 'wood pasture' habitat existed around the tarn (as is found in parts of the New Forest), in which case eutrophication might result from the accumulation of dung of either wild or domesticated animals around the tarn. This interpretation is to some extent supported by evidence for an earlier episode of enrichment in the Bronze Age (LDAZ 1 and LPAZ 1), at which time a limited number of pastoral indicators are present and arboreal taxa constitute in excess of 80% of the TLP (Figures 4.28-4.30). As has often been lamented (*e.g.* Buckland, 1984; Behre, 2007), distinguishing natural openings in woodland grazed by wild animals from small clearings (natural or anthropogenic) grazed by livestock is notoriously difficult palynologically (Section 1.5.2.2). It could perhaps be argued that the scale of the impact on nutrient status at LGT is sufficient to indicate a relatively large number of grazers in the area (*i.e.* a herd), particularly as the phase of 'clearance' identified in the late Bronze to late Iron Ages (LPAZ 2) seems to coincide with a *decline* in eutrophic and highly eutrophic diatoms (Figures 4.32 and 4.33). It seems unlikely that wild herbivores grazing in the catchment would have a greater impact on the tarn's chemistry than anthropogenic clearance associated with pastoral and possibly arable (*Hordeum*-type pollen was found in LPAZ 2) farming.

The factors affecting pollen production and dispersal also require consideration; it is possible that the pollen signal is not reflecting the openness of the landscape successfully, perhaps owing to the suppression of grass (and other herb) pollen values as a direct result of grazing. This phenomenon has been identified in experimental work in the Netherlands, where grass pollen percentages were seen to rise dramatically when tree cover was first removed, but to decline almost to pre-clearance levels under continuous grazing, giving a false impression of woodland regeneration (Groenman van Waateringe, 1993). The perpetual presence of pastoral and ruderal taxa throughout the early medieval period, notably *Plantago lanceolata*, *Rumex* spp. and rather more sporadically, *Urtica* spp. might support this hypothesis, though as explained in Chapter one these species are found in many open habitats and are not conclusive evidence for anthropogenic activity.

As the examples above demonstrate, interpretation of pollen data is made difficult by the problem of equifinality; numerous landscape scenarios might produce pollen signals that are essentially indistinguishable, at least without additional information from other environmental proxies (such as diatoms). HUMPOL v3 simulations were carried out to understand better the likely extent and composition of vegetation communities at this time and are presented below.

### 5.3.1.1. LGT LPAZ 3b pollen simulations

As in the case of BFT, some of the attempted simulations for LGT_LPAZ3B failed to run; this was resolved by reducing the number of taxa through removal of rare types. Only the most useful simulation results (meaning those that are thought to have a bearing on interpretation of the pollen data) are presented here, the majority of which were based on a mixed woodland matrix with patches of grazing/grassland, wet woodland, wet grassland and heath. There was no definitive evidence for cereal cultivation in the pollen record, so arable land was not incorporated in any of the scenarios.  As for the BFT experiments, the first simulation (LGT_LPAZ3B_1 (Image 5.6. Tables 5.13 and 5.14)) was based on direct translation of the pollen percentages into proportions of vegetation cover and was predictably unsuccessful at reproducing the real pollen proportions.  The majority of open-ground taxa were underrepresented, with the exception of *Ranunculus acris*-type ('Ranunculus'), for which the simulated values far exceeded those based on the pollen data (Figure 5.15).  *R. acris*-type is problematic as an open-ground indicator because it includes '*Ranunculus* undiff.', which encompasses species  such as the aquatics *R. lingua* (greater spearwort) and *R. aquatilus* (water crowfoot) (according to Bennett, 1994).  As these taxa may have been growing within or at the margins of LGT and *R. acris* itself might be found around the edges of the site, changes in the percentage of this pollen type are difficult to interpret, although they are perhaps more meaningful when considered in association with percentages of other open-ground taxa and wet grassland types respectively.

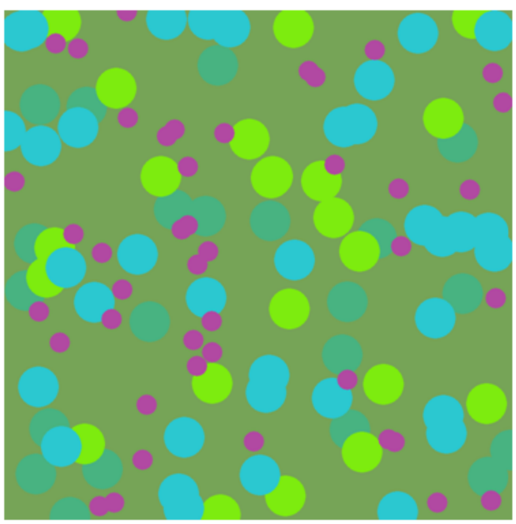


Image 5.6: Example landscape for LGT_LPAZ3B_1 (Mosaic).

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Mixed woodland | MATRIX (60%) | N/A | |
| Wet woodland | 10% | 1000m | |
| Grazing/ grassland | 10% | 1000m | |
| Wet grassland | 15% | 1000m | |
| Heathland | 5% | 500m | |

Table 5.12: LGT_LPAZ3B_1 Community cover and patch sizes.

Table 5:13: Community compositions for LGT_LPAZ3B_1.

| | Alnus | Betula | Calluna vulgaris | Cichoroideae | Corylus avellana-type | Cyperaceae | Filipendula | Fraxinus | Plantago lanceolata | Poaceae | Quercus | Ranunculus acris-type | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mixed woodland | 0.03 | 20.0 | 0.03 | 0.03 | 25.0 | 0.03 | 0.03 | 5.0 | 0.03 | 0.03 | 49.7 | 0.03 | 0.03 | 0.03 |
| Wet woodland | 69.4 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 30.0 |
| Grazing/ grassland | 0.03 | 0.03 | 0.03 | 5.0 | 0.03 | 0.03 | 0.03 | 0.03 | 10.0 | 74.7 3 | 0.03 | 5.0 | 5.0 | 0.03 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 39.7 | 20.0 | 0.03 | 0.03 | 30.0 | 0.03 | 10.0 | 0.03 | 0.03 |
| Heathland | 5.0 | 0.03 | 49.7 | 0.03 | 0.03 | 20.0 | 0.03 | 0.03 | 0.03 | 25.0 | 0.03 | 0.03 | 0.03 | 0.03 |

*Quercus* was dramatically overrepresented, while the estimated value for *Betula* was more than double the mean pollen percentage recorded for the period. *Corylus avellana*-type, *Alnus glutinosa* and *Fraxinus excelsior* produced simulated percentages much lower than the real values and *Calluna vulgaris* was found to be slightly underrepresented. As in the case of BFT_LPAZ1_1, this demonstrates the potential impact of pollen productivity and differences in grain morphology on the degree to which taxa, and consequently habitats, are represented in the pollen assemblage. The RSAP for LGT_LPAZ3B_1 was 2800 m, which was based on a basin radius of 150 m (the average for the tarn) (Figure 5.16).

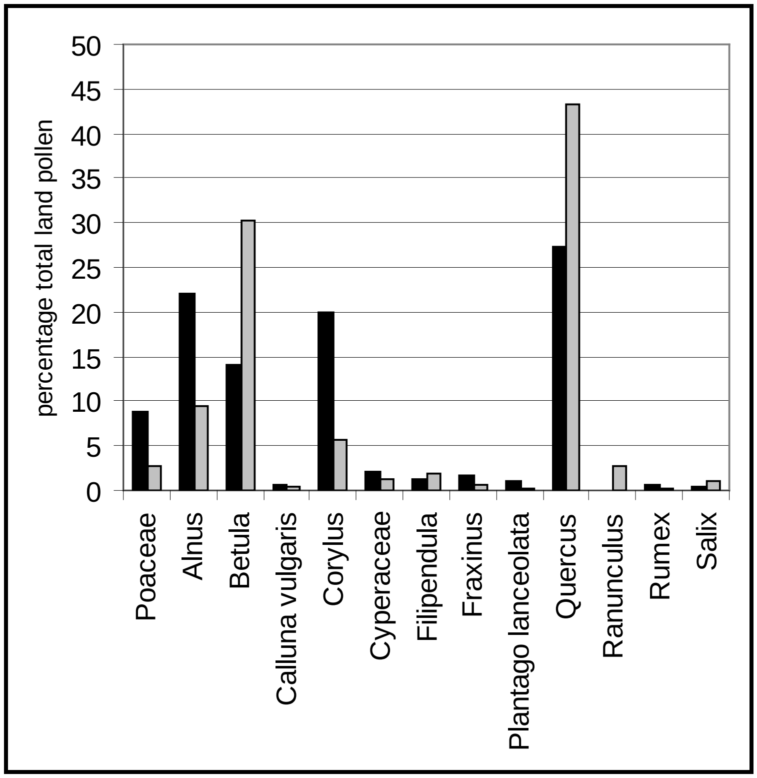



Figure 5.15: Real (black) and simulated (grey) pollen proportions (simulation LPAZ_LGT3B_1).

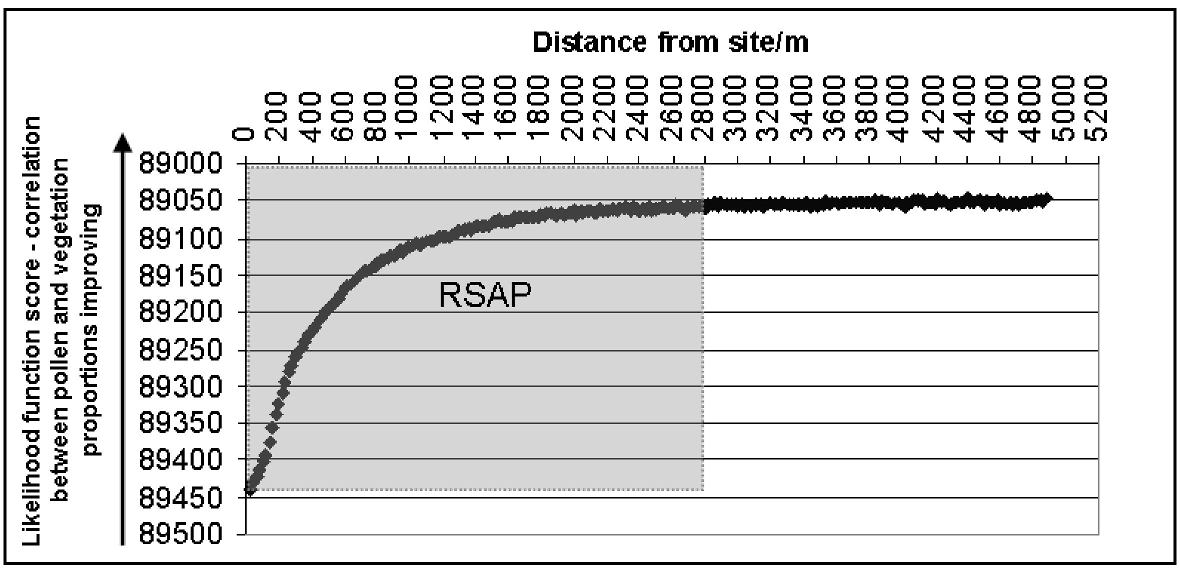



Figure 5.16: Likelihood function scores with increasing distance from the lake edge, showing predicted radius of RSAP for LPAZ_LGT3B_1.

The composition of the simulated landscape was altered based on the results of LGT_LPAZ3B_1, which entailed a reduction in the percentage of mixed woodland and more than doubling the percentage cover of grazing/grassland. The first simulation to reproduce the real pollen data successfully was LGT_LPAZ3B_2. The increased proportion of open ground – mostly grazing/grassland, but also heath – is immediately obvious on comparison of the Mosaic images and associated tables from this and LGT_LPAZ3B_1 (Images 5.6 and 5.7 and Tables 5.12 and 5.14 respectively). Community compositions were also adjusted, most dramatically in the case of mixed woodland where *Quercus* and *Betula* were reduced substantially in favour of *Corylus avellana*-type and *F. excelsior* (Table 5.15). The simulated pollen data for woodland species were brought much closer to the real values by these changes, suggesting that the landscape modelled in this example could more easily have produced the observed pollen data for LPAZ 3c than that in the previous example. However, percentages of arboreal pollen were still too high in LPAZ3B_2 simulations relative to the real data, while Poaceae and other open ground taxa continued to be underestimated by the model (Figure 5.17).

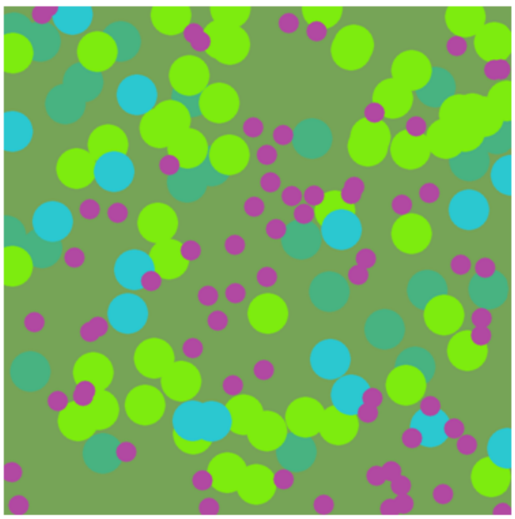


Image 5.7: Example landscape for LGT_LPAZ3B_2 (Mosaic).

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Mixed woodland | MATRIX (52%) | N/A | |
| Wet woodland | 11% | 1000m | |
| Grazing/ grassland | 22% | 1000m | |
| Wet grassland | 7% | 1000m | |
| Heathland | 8% | 500m | |

Table 5.14: LGT_LPAZ3B_2 community cover and patch sizes.

Table 5.15: Community compositions for LGT_LPAZ3B_2.

| | Alnus | Betula | Calluna vulgaris | Corylus avellana-type | Cyperaceae | Filipendula | Fraxinus | Plantago lanceolata | Poaceae | Quercus | Ranunculus acris-type | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mixed woodland | 0.03 | 7.0 | 0.03 | 60.23 | 0.03 | 0.03 | 9.5 | 0.03 | 0.03 | 23.0 | 0.03 | 0.03 | 0.03 |
| Wet woodland | 94.67 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 5.0 |
| Grazing/ grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 11.0 | 85.03 | 0.03 | 0.2 | 3.5 | 0.03 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 52.5 | 12.3 | 0.03 | 0.03 | 34.73 | 0.03 | 0.2 | 0.03 | 0.03 |
| Heathland | 0.5 | 0.03 | 51.0 | 0.03 | 17.5 | 0.03 | 0.03 | 0.03 | 30.73 | 0.03 | 0.03 | 0.03 | 0.03 |

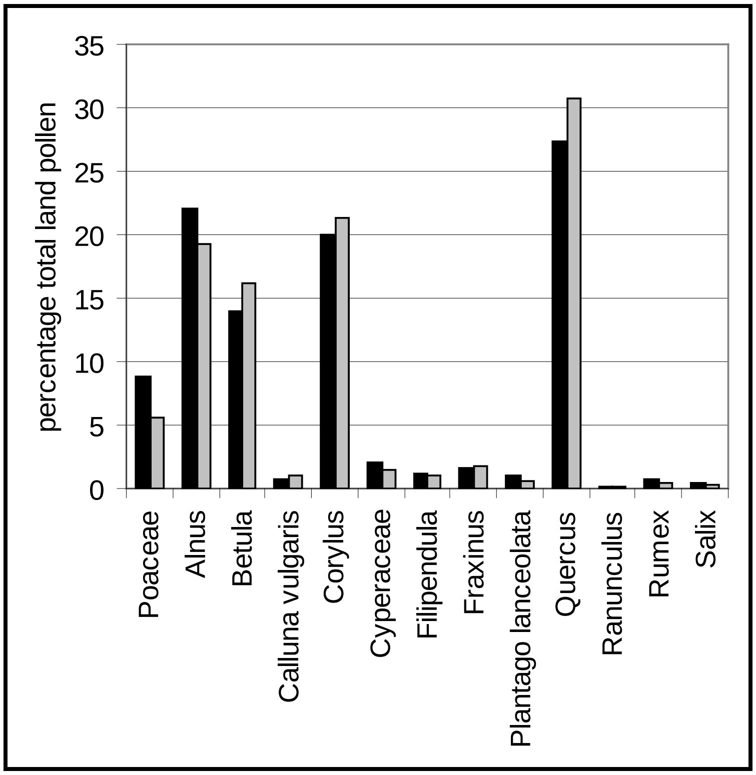



Figure 5.17: Real (black) and simulated (grey) pollen proportions (simulation LGT_LPAZ3B_2).

Experiment LGT_LPAZ3B_2 returned the same RSAP as the previous simulation (Figure 5.18), which implies that in the modelled landscape at least, the increase in 'landscape openness' resulting from the reduction in mixed woodland was not sufficient to alter the size of the catchment area represented by the pollen assemblage.

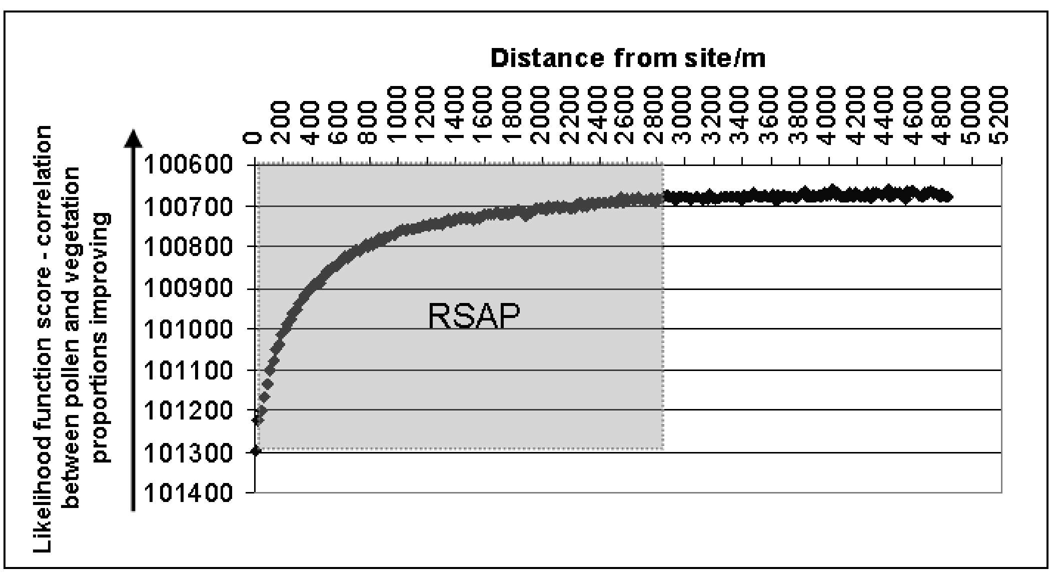



Figure 5.18: Likelihood function scores with increasing distance from the lake edge, showing predicted radius of RSAP for LGT_LPAZ3B_2.

The most successful simulation based on a mixed woodland matrix was LGT_LPAZ3B_3. The percentage woodland cover was reduced further than in the previous simulation, while the extent of grassland was increased. Minor adjustments were made to some of the communities (Tables 5.16 and 5.17, Image 5.8) and *R. acris*-type was excluded in favour of *Fagus*; both are very rare in terms of average pollen percentages in LPAZ 3c and despite several attempts at adjusting other aspects of the modelled landscape, Polsim (the last program to be used within a HUMPOL simulation) failed to run with both of these types incorporated. It was therefore necessary to exclude *R.* acris-type in order to accommodate *Fagus*. The main reason for this decision was the fact that species within *R. acris*-type are found in a wide range of habitats (*cf.* Bennett, 1994) and are consequently of limited use in the interpretation of land cover/land-use patterns. Also, it was hoped that including *Fagus* in the simulations would give a better idea of the importance of beech in mixed woodland than could be gained from the pollen data alone. *Fagus* has a high PPE, but produces large, heavy grains that are unlikely to travel far from the source (Table 5.1), which suggests that it will be well-represented when the trees are local to the sampling basin, but less likely to be detected at a regional level (unless also present locally).

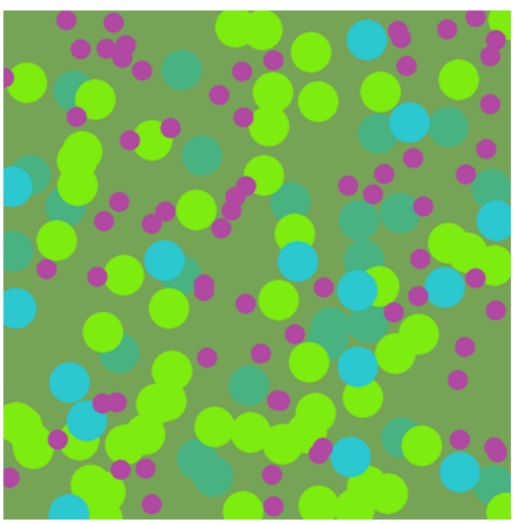


Image 5.8: Example landscape for LGT_LPAZ3B_3 (Mosaic).

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Mixed woodland | MATRIX (51%) | N/A | |
| Wet woodland | 11% | 1000m | |
| Grazing/ grassland | 23% | 1000m | |
| Wet grassland | 7% | 1000m | |
| Heathland | 8% | 500m | |

Table 5.16: LGT_LPAZ3B_3 community cover and patch sizes.

LGT_LPAZ3B_3 provides a much closer match for the real data than previous simulations, with the only significant differences being the overrepresentation of *Alnus glutinosa* and underestimation of wetland herbs (*Filipendula* and Cyperaceae) (Figure 5.19). Although LGT only has very small inflows, it is possible that the streamborne pollen contributed by these is boosting levels of *Alnus* in the pollen sum (*cf.* Bonny, 1978; Pennington, 1979). In addition, alder is likely to grow around the margins of the tarn, in which case it will be a significant contributor to locally derived pollen. The lake margins and streambanks are also likely habitats for wetland herbs, which are in any case relatively insignificant with regard to the overall interpretations of land-use.

Table 5.17 Community compositions for LGT_LPAZ3B_3

| | Alnus | Betula | Calluna vulgaris | Corylus avellana-type | Cyperaceae | Fagus | Filipendula | Fraxinus | Plantago lanceolata | Poaceae | Quercus | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mixed woodland | 0.03 | 6.6 | 0.03 | 61.0 | 0.03 | 0.66 | 0.03 | 9.5 | 0.03 | 0.03 | 22.0 | 0.03 | 0.03 |
| Wet woodland | 94.67 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 5.0 |
| Grazing/ grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 11.0 | 85.03 | 0.03 | 3.5 | 0.03 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 52.67 | 0.03 | 12.3 | 0.03 | 0.03 | 34.73 | 0.03 | 0.03 | 0.03 |
| Heathland | 1.0 | 0.03 | 50.0 | 0.03 | 18.0 | 0.03 | 0.03 | 0.03 | 0.03 | 30.73 | 0.03 | 0.03 | 0.03 |

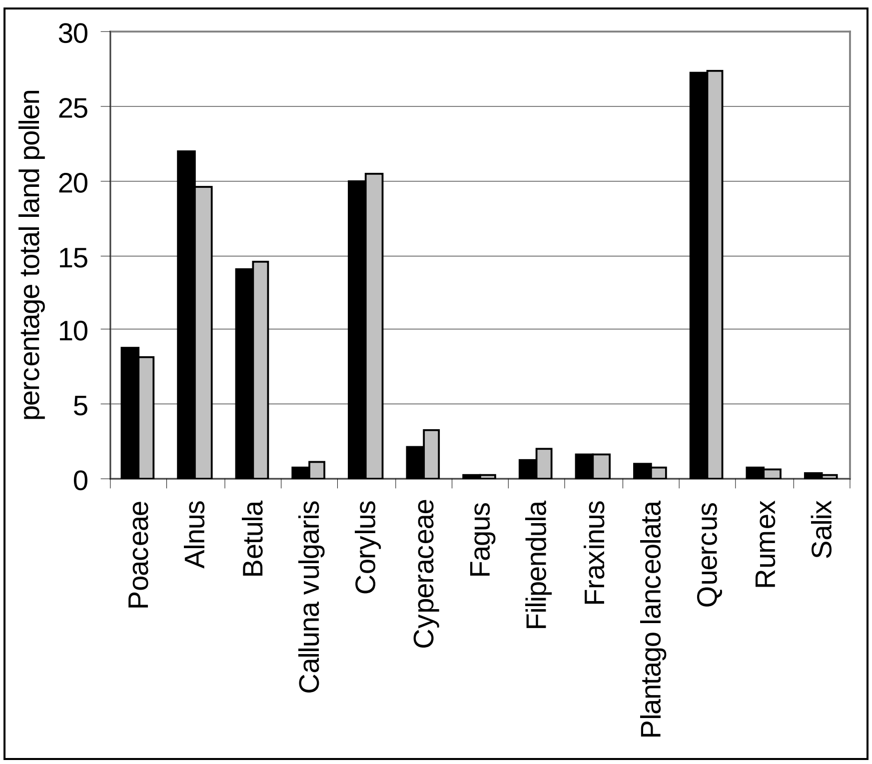



Figure 5.19. Real (black) and simulated (grey) pollen proportions (simulation LGT_LPAZ3B_3).

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The estimated RSAP for this landscape scenario was substantially larger than that in the simulations for less open landscapes, with a value of approximately 3400 m (Figure 5.20).

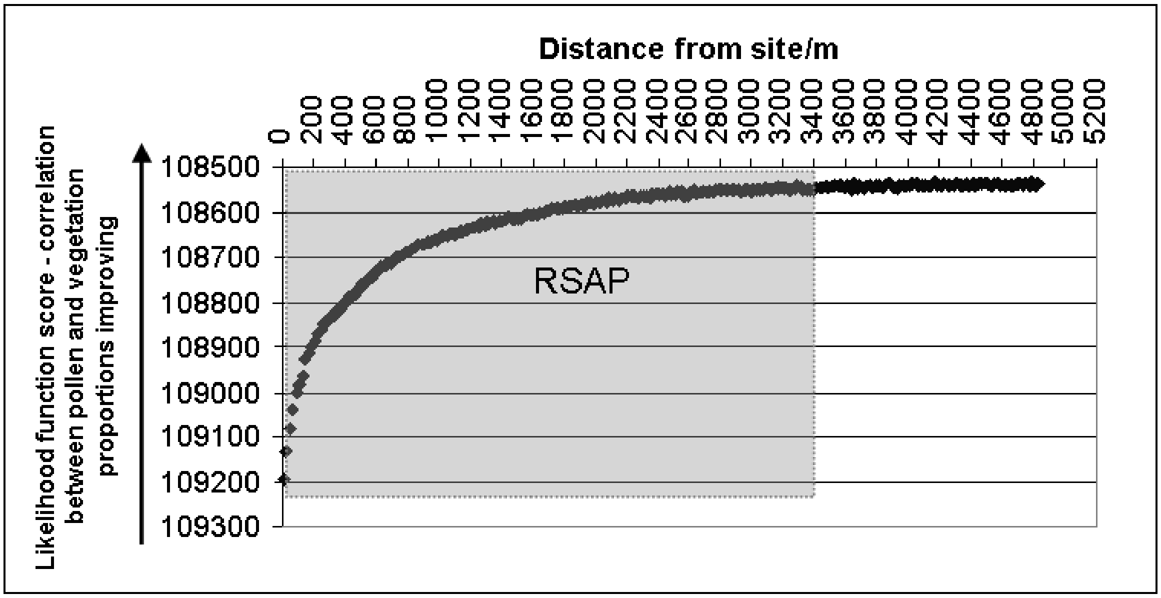



Figure 5.20: Likelihood function scores with increasing distance from lake edge, showing predicted radius of RSAP for LGT_LPAZ3B_3.

The examples presented here suggest that the landscape around LGT was significantly more open than indicated by the pollen data. In addition to a greater percentage cover of grazing/grassland throughout the landscape, the modelling data suggest that *Corylus avellana*-type was a far more substantial component of woodland than it appears to be based on the pollen diagram alone; this may indicate the presence of scrub woodland or of more open woodland in general, perhaps dominated by oak or ash (*cf.* Clapham *et al.*, 1962). There are some important issues associated with species representation and PPEs relating to this interpretation; trees are thought to produce more pollen when situated in open woodland or at the edges of forests, presumably because the increased light levels enhance growth and enable them to flower more frequently (Aaby, 1986; Nielsen & Odgaard, 2004). Consequently, the PPE for a species and hence its contribution to the pollen sum will vary depending on whereabouts it is situated in the landscape. Simulation data have been found to be strongly affected by changing the PPE values used (Nielsen, 2004), suggesting that changes in pollen productivity could cause significant over- or underrepresentation of taxa and therefore communities. This problem is not confined to interpretations based on modelling and is discussed further in Chapter 6 (Section 6.4).

### 5.3.2. Vegetation and landscape management in the Anglo-Saxon and Norse periods (*c* AD 630-1066 AD)

During the later part of the study period there is a marked decline in *Quercus* and an expansion of *Alnus glutinosa*, as well as a small, but noteworthy increase in taxa of open ground, particularly those associated with grazing and disturbance (Figure 4.30). These types remain rare and are found somewhat sporadically, yet the increase from the previous zone might indicate an intensification of pastoral activity in the area. This interpretation would be difficult to justify on the basis of open-ground herbs alone (*cf.* Buckland & Edwards, 1997; Behre, 2007), but the decline in oak woodland also points to clearance at this time. Perhaps more importantly, the diatom flora evince further signs of eutrophication; there is a rise in taxa associated with high nutrient status and a peak in the highly eutrophic species *Cyclostephanos dubius* just at the start of LPAZ 3c (Figure 4.32), which would comply with dung from grazing animals washing into the tarn. The increase in *A. glutinosa* suggests the onset of wetter, colder conditions, perhaps as a result of the sixth to seventh century AD climatic deterioration (see Section 1.2.5), although as mentioned previously, alder is likely to be overrepresented on account of the likelihood that it grows alongside the small inflows feeding into LGT and around the tarn itself. The simulations below were based on the pollen data from the start of LPAZ 3C (65 cm) to 50 cm depth, which is thought to be approximately the start of the middle medieval period (approximately the 11$^{th}$-12$^{th}$ centuries AD onwards (Figure 5.14)).

#### 5.3.2.1. LGT_LPAZ 3c Pollen simulations

Simulation LGT_LPAZ3C_1 was produced by retaining the mixed woodland matrix and approximate community compositions of LGT_LPAZ3B_3 and simply decreasing mixed woodland in favour of wet woodland (Image 5.9, Tables 5.18 and 5.19). This gave the best match for the data of all the attempted simulations (Figure 5.21), but is a relatively unlikely scenario; *A. glutinosa* favours wet areas and is more likely to be found in the river valleys and around the fringes of the lake, yet much of the land around LGT slopes steeply and presumably drains well. Bearing this in mind, it seems improbable that wet woodland could have spread across a substantial part of the landscape around the site (as envisaged in LGT_LPAZ3C_1).

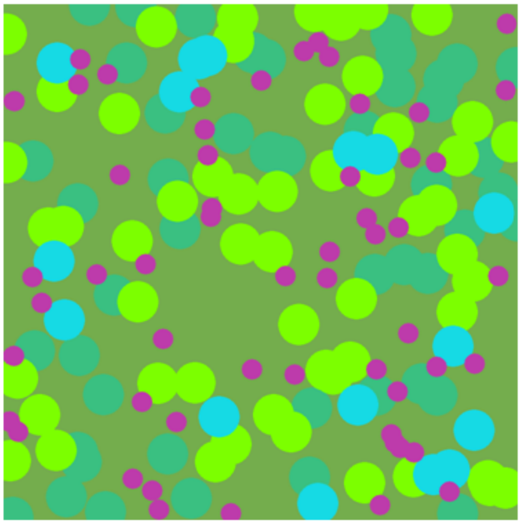


Image 5.9: Example landscape for LGT_LPAZ3C_1 (Mosaic)

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Mixed woodland | MATRIX (43.5%) | N/A | |
| Wet woodland | 20% | 1000m | |
| Grazing/ grassland | 23% | 1000m | |
| Wet grassland | 7% | 1000m | |
| Heathland | 6.5% | 500m | |

Table 5.18: Community cover and patch sizes for LGT_LPAZ3C_1

Table 5.19: Community compositions for LGT_LPAZ3C_1

| | Alnus | Betula | Calluna vulgaris | Corylus avellana-type | Cyperaceae | Fagus | Filipendula | Fraxinus | Plantago lanceolata | Poaceae | Quercus | Rumex acetosa/ acetosella | Salix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mixed woodland | 0.03 | 5.0 | 0.03 | 70.0 | 0.03 | 1.0 | 0.03 | 10.0 | 0.03 | 0.03 | 13.76 | 0.03 | 0.03 |
| Wet woodland | 92.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 7.67 |
| Grazing/ grassland | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 10.5 | 85.2 | 0.03 | 4.0 | 0.03 |
| Wet grassland | 0.03 | 0.03 | 0.03 | 0.03 | 52.5 | 0.03 | 12.0 | 0.03 | 0.03 | 35.2 | 0.03 | 0.03 | 0.03 |
| Heathland | 5.73 | 0.03 | 48.0 | 0.03 | 21.0 | 0.03 | 0.03 | 0.03 | 0.03 | 25.0 | 0.03 | 0.03 | 0.03 |

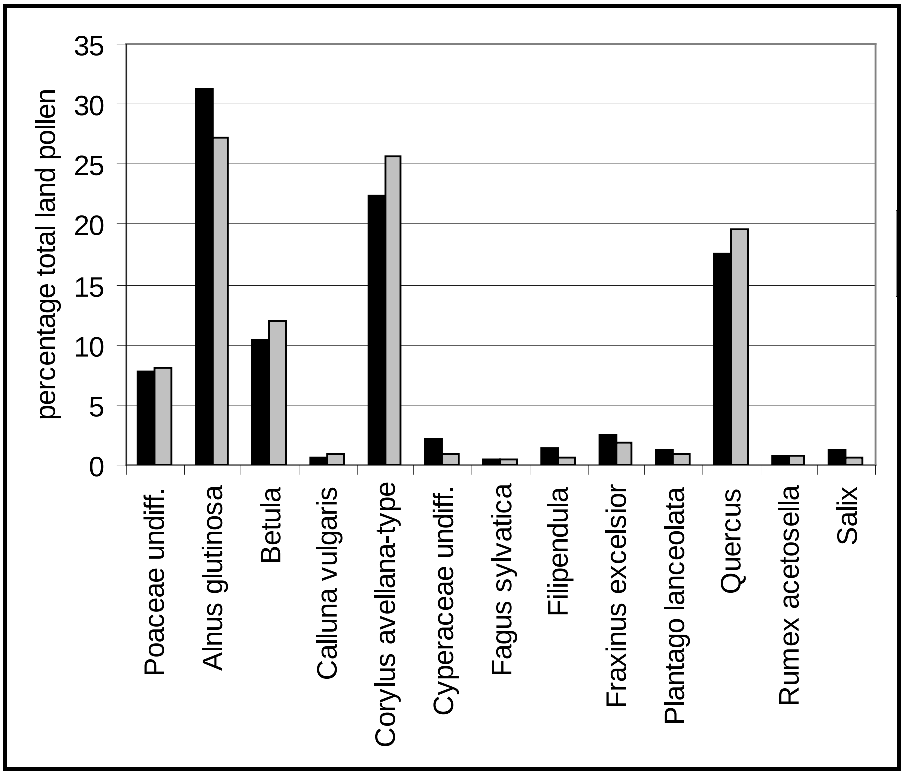



Figure 5.21. Real (black) and simulated (grey) pollen proportions (simulation LGT_LPAZ3C_1).

The simulated source area for LGT_LPAZ3C_1 was 4200 m (Figure 5.22). This is larger than any of the simulations for LPAZ 3b.

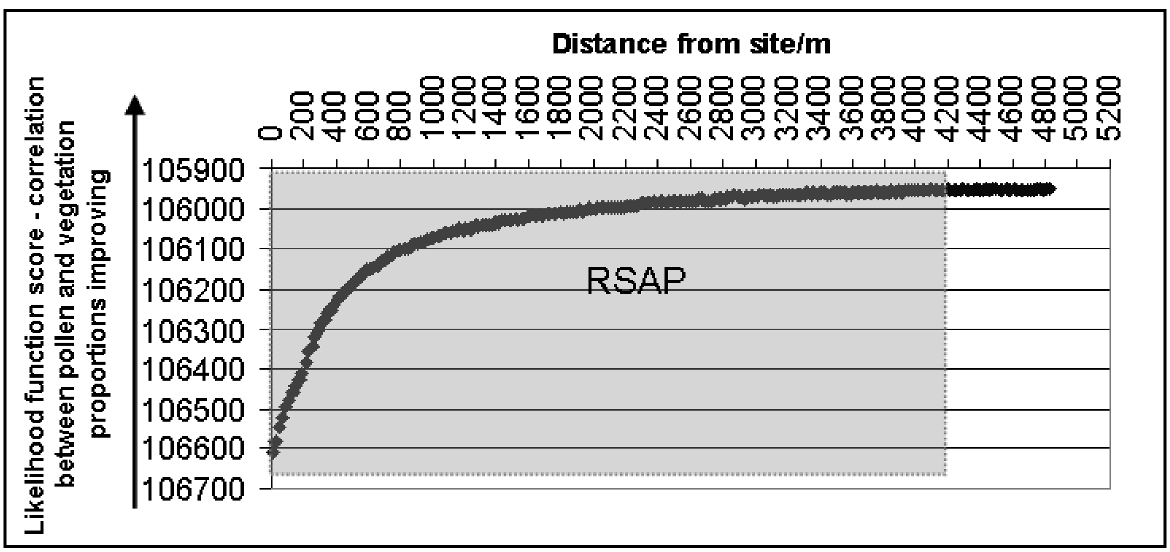



Figure 5.22: Likelihood function scores with increasing distance from lake edge, showing predicted RSAP for LGT_LPAZ3C_1.

Two further experiments for the later Anglo-Saxon and Norse periods are presented below; although the pollen data simulated by these do not match the real data as well as those for LGT_LPAZ3C_1, the results are interesting and highlight some problems with the interpretation of real and simulated pollen data. Experiment LGT_LPAZ3C_2 was based on

LGT_LPAZ3B_3, but with the percentage cover of grassland and mixed woodland reversed so that grazed land formed the matrix (Image 5.10, Table 5.20). This simulation greatly overestimated Poaceae and other open-ground taxa as might be expected, while underestimating mixed woodland species (especially *Corylus avellana*-type).

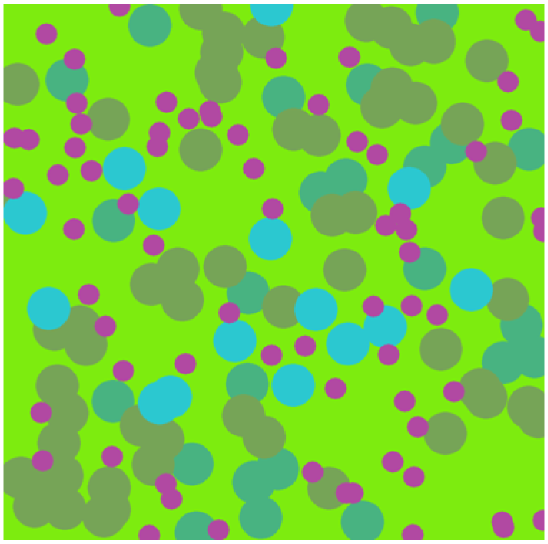


Image 5.10: Example landscape for LGT_LPAZ3C_2 (Mosaic).

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Grazing/ grassland | MATRIX (51%) | N/A | |
| Wet woodland | 11% | 1000m | |
| Mixed woodland | 23% | 1000m | |
| Wet grassland | 7% | 1000m | |
| Heathland | 8% | 500m | |

Table 5.20: LGT_LPAZ3C_2 Community cover and patch sizes (see Table 5.17 for compositions)

Although the grazing matrix did not produce a good fit for the real pollen data, there are intriguing differences between the simulated pollen proportions from LGT_LPAZ3B_3 and LGT_LPAZ3C_2, affecting taxa that were altered neither in terms of community composition nor percentage land cover. *A. glutinosa, Salix* and *Calluna vulgaris* all increase, the former by almost 10% (Figure 5.23). Presumably this is owing to a decrease in species with high PPEs and low fall speeds (*e.g. Betula* and *Quercus*) in favour of herbaceous types with lower PPEs and poorer dispersal properties. This supports previous research emphasising the importance of vegetation distribution (*e.g.* as discrete patches or as the matrix in this example) in determining pollen percentages (*e.g.* Sugita, 1994; Calcote, 1995; Bunting, 2002; Nielsen & Sugita, 2005). Although it cannot be claimed that the modelled pollen data for this experiment match the 'real' pollen percentages well, LGT_LPAZ3C_2 serves to demonstrate the potential impact of landscape clearance on the overall composition of the pollen assemblage. Following on from this, the apparent increase in *A. glutinosa* during this period might to some extent result from changes in the wider landscape or the relative contributions of local, extralocal and regional pollen to the assemblage, rather than a dramatic expansion of wet woodland cover. This is to supported by the RSAP for this landscape, which was found to be larger than that for LGT_LPAZ3B_3 at approximately 3800 m (Figure 5.24).

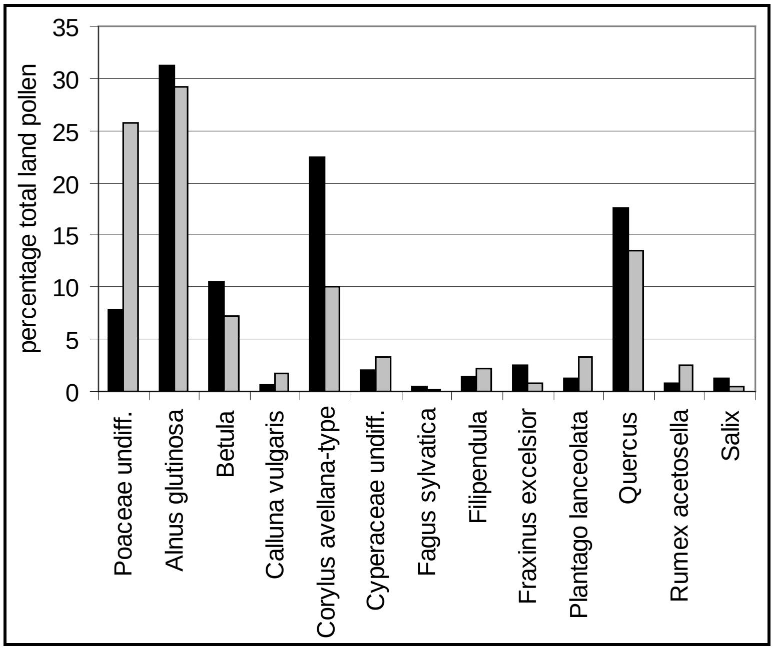



Figure 5.23: Real (black) and simulated (grey) pollen proportions (simulation LGT_LPAZ3C_2).

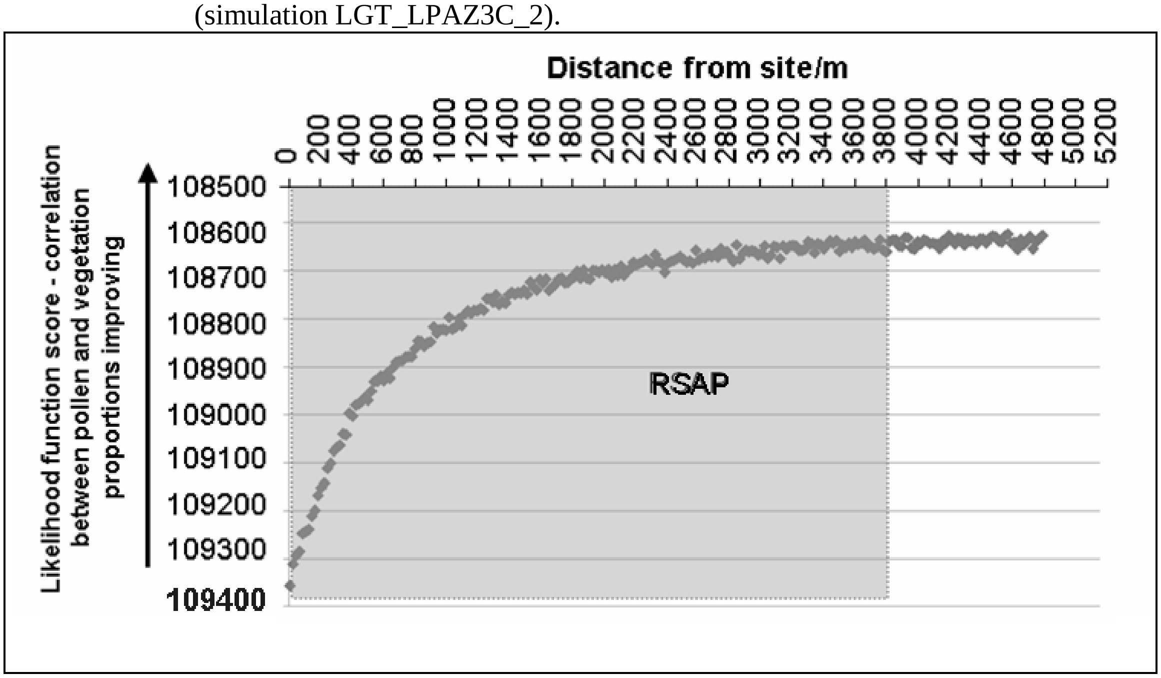



Figure 5.24: Likelihood function scores with increasing distance from lake edge, showing predicted RSAP for LGT_LPAZ3C_2.

The final experiment present for LGT (LGT_LPAZ3C_3) was based on LGT_LPAZ3B_3 as in the previous simulation, but retaining the mixed woodland matrix and all community compositions. In this scenario, the effect of increasing the percentage landscape cover of grazing/grassland from 23 to 30% was tested (Image 5.11, Table 5.21). This was expected to cause an increase in open-ground indicators and a decrease in woodland taxa, as the percentage of mixed woodland in the matrix was reduced to compensate for the rise in grassland. However, on examination of the pollen data simulated by LGT_LPAZ3B_3 and LGT_LPAZ3C_3 (Figure 5.25), it is evident that the changes in landscape cover have no discernible impact on the simulated proportions of *Corylus avellana*-type or *Fagus* and cause a slight *increase* in *Quercus* and *Betula*. Poaceae and other grazing/grassland taxa increase to become overrepresented relative to the real data, while in comparison to LGT_LPAZ3B_3, wet grassland and wet woodland species decline (Figure 5.25). The RSAP for LGT_LPAZ3C_3 is slightly larger than that for LGT_LPAZ3B_3 at 3750 m (Figures 5.20 and 5.26). As in the previous example, this simulation did not provide a good match for the real pollen percentage data relating to the later Anglo-Saxon/Norse period, but demonstrates the complexity of the relationship between pollen assemblages and contemporary vegetation patterns.

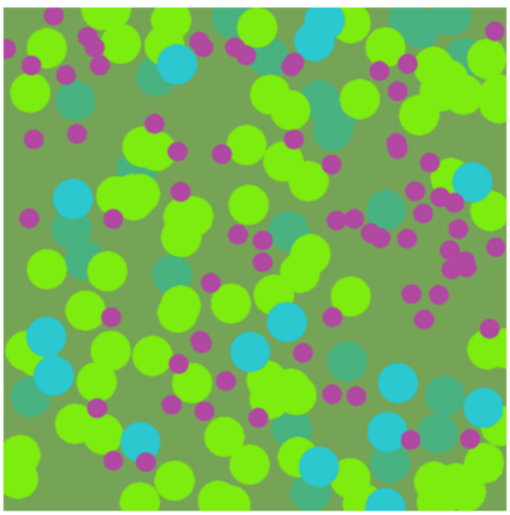


Image 5.11: Examples land for LGT_LPAZ3C_3 (Mosaic).

| Community | Landscape cover | Maximum patch size | Colour |
|---|---|---|---|
| Mixed woodland | MATRIX (44%) | N/A | |
| Wet woodland | 11% | 1000m | |
| Grazing/ grassland | 30% | 1000m | |
| Wet grassland | 7% | 1000m | |
| Heathland | 8% | 500m | |

Table 5.21: LGT_LPAZ3C_3 community cover and patch sizes. See Table 5.17 for compositions.

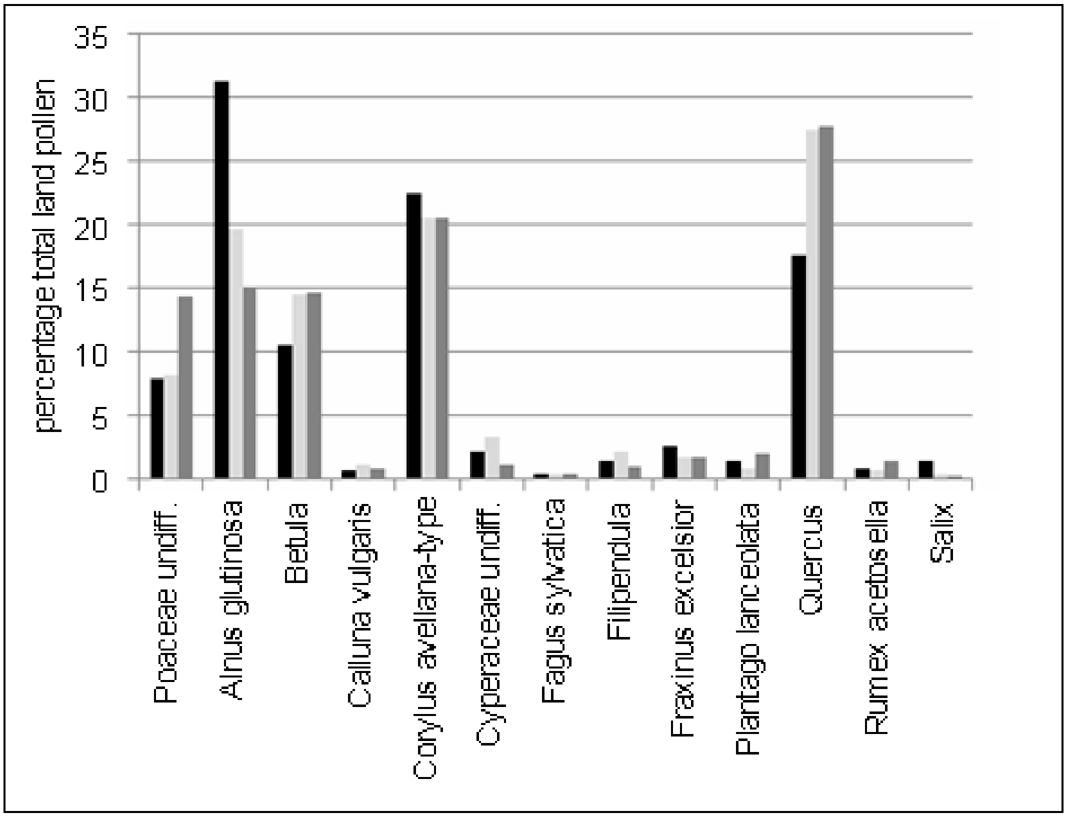



Figure 5.25: Real (black) and simulated pollen proportions for LGT_LPAZ3B_3 (light grey) and LGT_LPAZ3C_3 (dark grey).

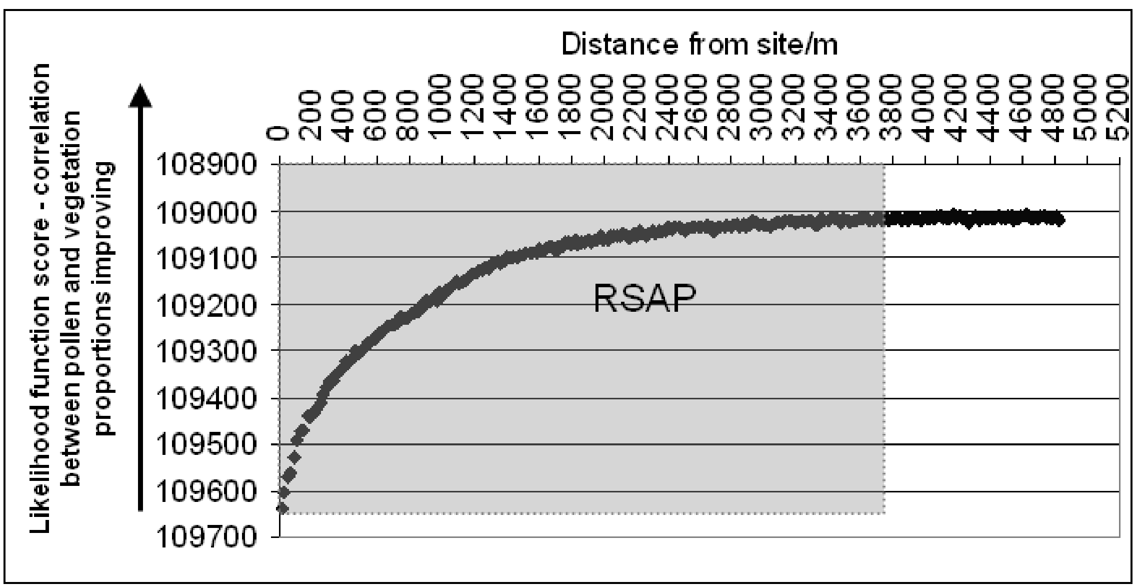
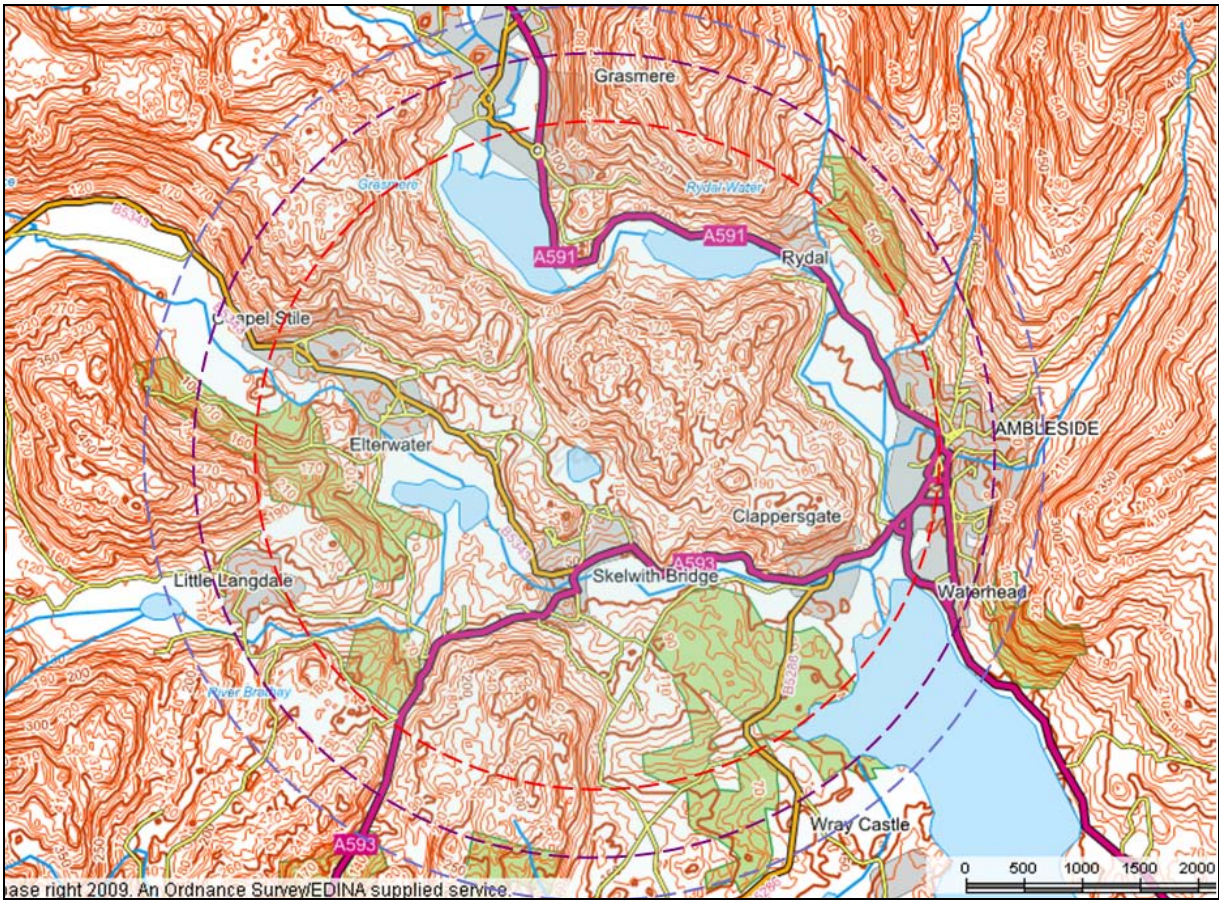



Figure 5.26: Likelihood function scores with increasing distance from edge of lake, showing predicted RSAP for LGT_LPAZ3C_3

The three scenarios presented in this section highlight the problems posed by equifinality of processes when interpreting pollen data and demonstrate the usefulness of models and simulations as a means of testing different landscape scenarios. The results discussed above also highlight the importance of giving careful consideration to the meaning of simulated data and the ecological likelihood of conjectured landscape changes.

According to Jacobson & Bradshaw's model (1981: 82), a tarn of 300 m diameter (*i.e.* 150 m radius, which is the average for LGT) would be expected to receive approximately 15-20% of its pollen from 'local' sources within 20 m of the site, 25-30% from 'extralocal' vegetation located within a few hundred metres of the lake and the remainder (*c* 50%) from 'regional' sources, which encompass any inputs from beyond the extralocal area. The simulation data presented here suggest that in the scenarios tested, the extralocal pollen, which together with the local component could be equated with pollen from within Sugita's RSAP (*e.g.* 1994, 2007a & b), is likely to be derived from within a radius of several kilometres of the site, which represents a significantly larger source area than suggested by Jacobson & Bradshaw's model (1981). If the HUMPOL simulations are reasonably accurate in their estimation of source area, the implication is that even 'small' lakes without inflows have a relatively large source area, within which the vegetation makes a relatively significant contribution. In addition, the composition and distribution of vegetation communities has been found to be highly influential on the RSAP, meaning that the source area for local and extralocal pollen, in addition to the percentage of pollen received from these and regional 'background' sources, may vary considerably in relation to changes in the surrounding vegetation (Sugita, 1994; Calcote, 1995; Jackson & Kearsley, 1998; Koff *et al.*, 2000; Parshall & Calcote, 2001; Bunting *et al.*, 2004; Nielsen & Sugita, 2005; Hellman *et al.*, 2009a).



Map 5.2: LGT RSAPs from simulations. The blue circle represents the largest simulated RSAP (4.2 km), the red circle shows the smallest (2.8 km) and the purple circle shows the mean average for the site (*c* 3.5 km).

# CHAPTER 6: DISCUSSION

The overarching aim of this study has been to establish the extent and nature of human impact on the landscape during the early medieval period, focusing on analysis of proxy data (pollen and diatoms) from small tarns in the Lake District and Cumbria. As explained in Chapter 1, the relative dearth of archaeological and documentary evidence relating to post-Romano-British, pre-Norman Cumbria, in addition to wider problems of understanding regarding 'Dark Age' history, have in the past led to the assumption that the early medieval period was a time of cultural decline, abandonment of farmland and consequently woodland regeneration. Early palynological studies in Northwest England, for which radiocarbon dates were often unavailable or imprecise, tended to equate agricultural activity with Roman settlement, periods of woodland expansion with the early 'Dark Ages', subdued agriculture with Anglo-Saxon farmers and pastoral clearances with Norse settlers (*e.g.* Pearsall & Pennington, 1947; Smith, 1959; Franks & Pennington, 1961; Oldfield, 1963, 1969; Pennington, 1965, 1970; Dickinson, 1975). The question of whether or not these assumptions can be justified is discussed below, drawing on the pollen and diatom data accumulated in the course of this study and the relatively small body of palaeoecological research that sheds light on the early medieval landscape history of the region.

As demonstrated in Chapters 4 and 5, Barfield Tarn in the southwest of the region and Loughrigg Tarn in the central Lake District produced good pollen and diatom records for the study period. The chronology for Loughrigg Tarn is relatively secure, while that for Barfield Tarn would benefit from further dating evidence (Figures 5.2 and 5.14 in the preceding chapter). The early medieval palaeoecological records from the two tarns are discussed and compared below, with reference to the scant Dark Age archaeological remains discovered to date. The potential for pollen simulation work to aid identification of areas within which as yet unidentified sites are likely to exist, is also considered. This is followed by a synthesis of all available (to the author's knowledge) palynological data relating to the study period.

The HUMPOL experiments carried out for this project proved interesting and were used to 'test' the simulated pollen outputs of landscape scenarios against the actual fossil pollen data. A brief discussion of the key benefits and limitations of pollen modelling and some points arising from the simulation data presented in the previous chapter can be found in Section 6.4.

Unfortunately, as explained in Chapter 4 the remaining study sites (Blelham Tarn, Burney Tarn and neighbouring Burney Bog, Little Langdale Tarn and Tewet Tarn) proved problematic owing to truncation, compression and disturbance of the sediments. The pollen and diatom records from these sites are not discussed in detail here, but the problems associated with palaeoecological work on lake sediments, the difficulties encountered in terms of radiocarbon dating and the valuable lessons learnt in the course of this project are expounded in Section 6.

### 6.1. Summary of early medieval Barfield Tarn

The pollen and associated simulation results for Barfield Tarn indicate an open landscape with only small patches of mixed and wet woodland throughout the study period. The HUMPOL simulations that reproduced the real pollen data most successfully were based on dominant communities of heathland and grassland/pasture or a mixture of 'rough grazing' and heath throughout the post-Romano-British and Anglo-Saxon phases. The extent of heathland was much reduced during the later Anglo-Saxon and/or Norse period, probably as a direct result of livestock grazing, which has been identified as an important factor in the depletion or destruction of heather moorland communities in the UK (*e.g.* Bardgett *et al.*, 1995; Pakeman *et al.*, 2003). Arboreal taxa are seen to increase substantially in the pollen diagram at this time (especially birch and alder), a change that would normally be attributed to the expansion of woodland. However, HUMPOL experiments presented in the previous chapter suggest that the increase in tree pollen can be explained by a far smaller increase in woodland than that implied by the pollen curves. Furthermore, in order to achieve simulated values similar to real pollen percentages it was necessary to increase the extent of 'rough grazed' land, despite a slight decline in herbaceous pollen compared to levels in the earlier post-Romano-British period. The implication of these findings is that changes in the pollen record for the Anglo-Saxon/Norse phase at Barfield Tarn could be explained by a slight expansion of woodland and an *increase* in grazing within the landscape, resulting in loss of heathland habitats in favour of rough grazed land. Models are by no means complex enough to mirror accurately the processes affecting the composition of a pollen assemblage in the real world, and numerous scenarios may produce similar outputs owing to problems of equifinality. Nonetheless, the data produced give a better indication of the impact of differential pollen production and dispersal properties of taxa on the pollen assemblage, and the interaction between these as the vegetation changes, than can be gleaned from examining the pollen data qualitatively (discussed further in Section 6.4).

Although large-scale farming is not supported by the pollen data, the continued openness of the landscape together with the perpetual presence of pastoral/ruderal indicator species implies that grazing was an important management practice in the region and complies with Pennington's suggestion that later prehistoric clearances in the vicinity of Barfield Tarn were large-scale and permanent (Pennington, 1970). Woodland regeneration has been shown to occur within 15-25 years of the exclusion of grazing animals in the De Imbos nature reserve in the Netherlands (Groenman van Waateringe, 1986), while in the New Forest in southern England, colonising tree species were found to be established after just six years (Putman *et al.*, 1989). The same study identified significant differences in the flora present within grazed and ungrazed habitats at the end of the 22 years for which plots were monitored, although additional enclosure experiments in the Forest indicate that 'regenerated' woodland may be substantially different in composition from the original woodland (Grant & Edwards, 2008).

Occurrences of cereal pollen, although rare and inconsistent in terms of classification (*e.g. Avena/Triticum*-type, *Hordeum*-type), together with occasional grains of the arable indicator *Centaurea cyanus,* indicate that crops were being grown within the catchment area of the tarn. The HUMPOL scenarios tested in Chapter 5 suggest that this is consistent with small-scale, mixed farming, such as might be expected in association with family farms or small settlements. As explained in Chapter 1, much of what has been claimed about the scale and nature of early medieval farming practices in this region is based on little evidence, but the combination of pollen and simulation data for the early post-Roman period supports the presence of small-scale agricultural plots within an open, grazed landscape rather than extensive areas of cultivated land.

Unfortunately, as the collected pollen and diatom records for Barfield Tarn do not cover the Iron Age and Romano-British periods and earlier work at the site has focused on Mesolithic/Neolithic and Bronze Age vegetation change, it has not been possible to establish whether anthropogenic activity was reduced, increased or unchanged at the start of the early medieval period. However, there is no positive evidence for abandonment of farmland or for woodland regeneration in the earlier post-Romano-British phase at Barfield Tarn and as explained above, the later part of the study period seems to be characterised by an intensification of grazing in the landscape.

As noted in Chapter 3, to the author's knowledge no 'Dark Age' sites have been identified in the vicinity of Barfield Tarn and only one Romano-British artefact – a Roman statuette (NMR: SD 18 NW14) – is recorded from within a 2 km radius of the site (E.H.NMR, 15/03/2009). The evidence presented here indicates that low-level mixed farming was underway in the vicinity of the tarn during the early medieval period, which implies that there must have been settlements in the area. These may have been small and dispersed throughout the landscape, but must have been of sufficient size and population to have a visible impact on the vegetation and hence the pollen record. The most likely location for settlement is probably Bootle, which lies within the RSAP of the tarn even at the lowest estimated range (Map 5.1) and was certainly established by AD 1087 when it was recorded in the Domesday Book. Another intriguing prospect is the site of extensive later prehistoric and medieval remains on Bootle Fell, at Great Grassoms (Table 3.1); although this lies just beyond the range of the RSAP for Barfield Tarn in most of the HUMPOL simulations, 'regional' vegetation from outside of the RSAP also contributes to the pollen assemblage in varying proportions. It is also possible that pollen from this area would be carried to the site by run-off from the fells, a factor that is not accounted for by the modelling approach used here. Barfield Farm itself lies on the site of older buildings; these are thought to be post-medieval, but the earliest date at which the site was occupied is currently unknown. Finally, there are numerous enclosures and earthworks of 'unknown' date in the surrounding area; archaeological survey or excavation would be a useful means of investigating these sites further in order to establish their antiquity. Sites that are undated, but presumed to be prehistoric, Romano-British or later medieval might also be worth investigating in some cases, as demonstrated by early medieval radiocarbon dates obtained from Shoulthwaite hillfort (see Section 1.4.3, Chapter 1) (Newman *et al.*, 2004).

### 6.2. Summary of early medieval Loughrigg Tarn

The early medieval landscape around Loughrigg Tarn appears to have been much less open than that surrounding Barfield Tarn. As explained in the previous chapter, the pollen curves indicate that an agricultural/pastoral clearance phase beginning in the late Bronze/early Iron Age ends in the later Iron Age, followed by a period in which arboreal taxa expand (LPAZ 3) that spans the Romano-British and early medieval periods, continuing almost until the major expansion of open-ground taxa in the nineteenth and twentieth centuries AD (LPAZ 4) (Figures 4.28 to 4.30). The data suggest woodland regeneration beginning prior to Roman occupation, with a marked increase in oak occurring in the late-/post-Romano-British period. The continued presence of open-ground and 'grazing' taxa throughout this time, together with a reduction in oak woodland during the Anglo-Saxon and Norse periods, might support the hypothesis that livestock grazing was underway at this time, though as explained in Chapter 1 (Section 1.5.2), 'anthropogenic indicators' in pollen assemblages are problematic owing to problems of equifinality (*cf.* Buckland & Edwards, 1984; Behre, 2007). However, the diatom flora at Loughrigg Tarn is dominated by eutrophic and highly eutrophic diatoms, which become markedly more prevalent during the Romano-British and early medieval periods and may reflect an increase in nutrient status owing to inwash of dung or similar waste from the catchment area. This supports the presence of grazing animals around the tarn, although it is not possible to establish with certainty that these were livestock as opposed to wild herbivores such as deer.

As in the case of Barfield Tarn, comparison between the real data and those produced by HUMPOL simulations (Chapter 5) indicates that the landscape was more open than suggested by the pollen data alone, particularly in the Anglo-Saxon and Norse periods when mixed oak woodland is reduced substantially from its peak values in the preceding zone. The corresponding increase in wet woodland might reflect the climatic deterioration of the sixth century AD (*cf.* Blackford & Chambers, 1991), but is perhaps exaggerated by the impact of changes in the wider landscape on the overall composition of the pollen assemblage. Various studies have highlighted the importance of vegetation distribution within the landscape in determining the extent of the pollen source area and the character of the assemblage (*e.g.* Sugita, 1994; Calcote, 1995; Jackson & Kearsley, 1998; Koff *et al.*, 2000; Parshall & Calcote, 2001; Bunting *et al.*, 2004; Nielsen & Sugita, 2005; Hellman *et al.*, 2009a), which is supported by comparison of scenarios LGT_LPAZ3B_3 and LGT_LPAZ3C_2 presented in the previous chapter; in these simulations changing the distribution of the two dominant vegetation types (mixed woodland and grassland) had surprising impacts on pollen types that were not derived from either of these communities.

To summarise the points above, the pollen and diatom data tentatively support grazing in the landscape around Loughrigg Tarn throughout the Romano-British and early medieval periods, with a period of intensification and probable oak clearance in the mid- to late-Anglo-Saxon and Norse periods. An expansion of oak in the late- or post-Roman period appears to support the 'traditional' theory that anthropogenic activity in the landscape was reduced at this time. As mentioned in Chapter 3, this is not altogether unexpected considering the proximity of Loughrigg Tarn to Galava Roman fort; the withdrawal of troops is more likely to have impacted on this area than at sites further removed from military establishments. Galava lies within the estimates of RSAP for more than half of the simulations (Map 5.2) and the construction and operation of the fort is likely to have affected the surrounding landscape (*e.g.*

through use of timber and possibly agriculture or pastoralism in the area), thus influencing local/extralocal pollen inputs to Loughrigg Tarn.

As in the case of Barfield Tarn, there is no recorded early medieval archaeology within a 2 km radius of Loughrigg Tarn and Romano-British remains within this area are limited to the road from Ambleside to Ravenglass and a rotary quern dated tentatively to this period (Table 3.5). There appears to be little change in the vegetation (and presumably land-use) from the late Iron Age to the late-/post-Romano-British period in this area (LPAZ 3a), which does not support significant disruption or large-scale clearance by the invading Roman army. However, considering the error ranges associated with the radiocarbon dates and the probability that rates of sediment accumulation have been inconstant, it is possible that the end of the 'clearance' phase in LPAZ 2 actually coincides with the movement of Roman troops into the region, in which case it is possible that the invasion caused significant disruption of farming practices in the surrounding landscape. Unfortunately, further dating evidence would probably not resolve this either way owing to the errors associated with radiocarbon dates and the uncertain history of Roman activity in the area (*i.e.* the invasion of the Northwest is thought to have occurred between AD 69 and AD 84, but the date of arrival at specific locations would be difficult to establish).

Interestingly, the significant reduction of oak woodland at the start of LPAZ 3c appears to occur in the early post-Roman/early Anglo-Saxon period, much earlier than the 'Norse' upland oak clearances conjectured by Oldfield (1963, 1969). Pennington also identified a 'Norse' valley alder clearance at several sites in the Lake District, although the age estimate was based largely on the prevalence of Scandinavian place names (Pearsall & Pennington, 1947; Pennington, 1965, 1970). This phase might be represented by the temporary decline in alder at the end of LPAZ 3c, which is thought to correspond to late Norse/early Norman times (Figure 4.28). The expansion of birch at the end of LPAZ 3c and of ash in LPAZ 3d, which is followed by a rise in oak, may correspond to the woodland regeneration phase that Oldfield (1963) identified with the 'harrying of the North'. The initial rise in birch and ash appear to occur in the late Norse and early Norman periods, but oak increases later and is perhaps more likely to result from land-use changes relating to the monastic dissolution.

### 6.3. Early medieval Lakeland

Drawing together information gleaned from the palynological records of Barfield Tarn, Loughrigg Tarn and other sites in the in the area, it is clear that the scale and type of land-use varied significantly between locations during the early historical period (Maps 6.1-6.4). The landscape around lowland Barfield Tarn seems to have been largely open throughout the historical period, providing a stark contrast to the wooded landscape inferred for the central, more mountainous area of the Lake District around Loughrigg Tarn. At the latter, the Romano-British phase appears to be characterised by an expansion of woodland, although as explained previously pastoral farming probably continued in the vicinity of the tarn. The late- to post-Roman period sees a substantial expansion of oak woodland and at Loughrigg Tarn the traditional pattern of post-Roman abandonment and woodland regeneration appears to be followed, succeeded by early Anglo-Saxon clearances and a slight expansion of pasture that is sustained throughout the Norse period. In contrast, the landscape around Barfield Tarn seems to have remained largely open from the late-/post-Romano-British period onwards, with heathland spreading significantly in the early Anglo-Saxon period. The pollen and diatom data suggest continuity of land-use from the start of the available record, with agriculture and pastoralism being practised in the catchment area throughout this time and a probable intensification of grazing occurring in the late Anglo-Saxon and Norse periods. As explained in Chapter 3, the landscape around Barfield Tarn is more amenable to agriculture than that around Loughrigg Tarn, the catchment of which is steep and rocky in comparison to the relatively flat grassland around Barfield Tarn.

Maps 6.1-6.4 show the patterns of vegetation change across the region from the late Iron Age to the end of the Norse period (see Table 6.1 for site names). Sites for which relatively secure dating evidence was not available have been excluded *(e.g.* Table 1.9, pp77-82) and some are present on a map for one period, but not another, depending on the data available. Owing to the uncertainties relating to time scales based on radiocarbon dates, especially for sites where only radiometric data are available, the periods for which vegetation patterns are illustrated last between two and four hundred years (approximately) in each case; further division (*e.g.* into centuries) would require a great many more assumptions about the precise dating of changes in the pollen data than the approach used here and would be difficult to justify. The maps highlight the variability and localised nature of land-use and vegetation change before and during the early medieval period; there are broad patterns, but even sites in close proximity to each other do not always share the same land-use history.

The late Iron Age to mid-Romano-British period (Pennington's (1970) 'Brigantian' phase) is characterised by clearance for pastoralism and agriculture in most areas with a few notable exceptions (Map 6.1). Woodland regeneration appears to have occurred at Loughrigg Tarn in the central Lake District (although as explained above grazing continued at this time) and at White Moss in southern Lakeland (Wimble *et al.*, 2000); there was also a decline of agriculture at nearby Deer Dyke Moss (Coombes *et al.*, 2009), perhaps suggesting abandonment of farmland in this area. A similar decline in farming is seen at Butterburn Moss in northern Cumbria (Yeloff *et al.*, 2007), which is somewhat surprising considering the proximity of the site to Bolton Fell Moss and Walton Moss, both of which are characterised by clearances and farming at this time (Barber, 1981; Dumayne-Peaty & Barber, 1998).

Table 6.1: Pollen sites shown on Maps 6.1-6.4

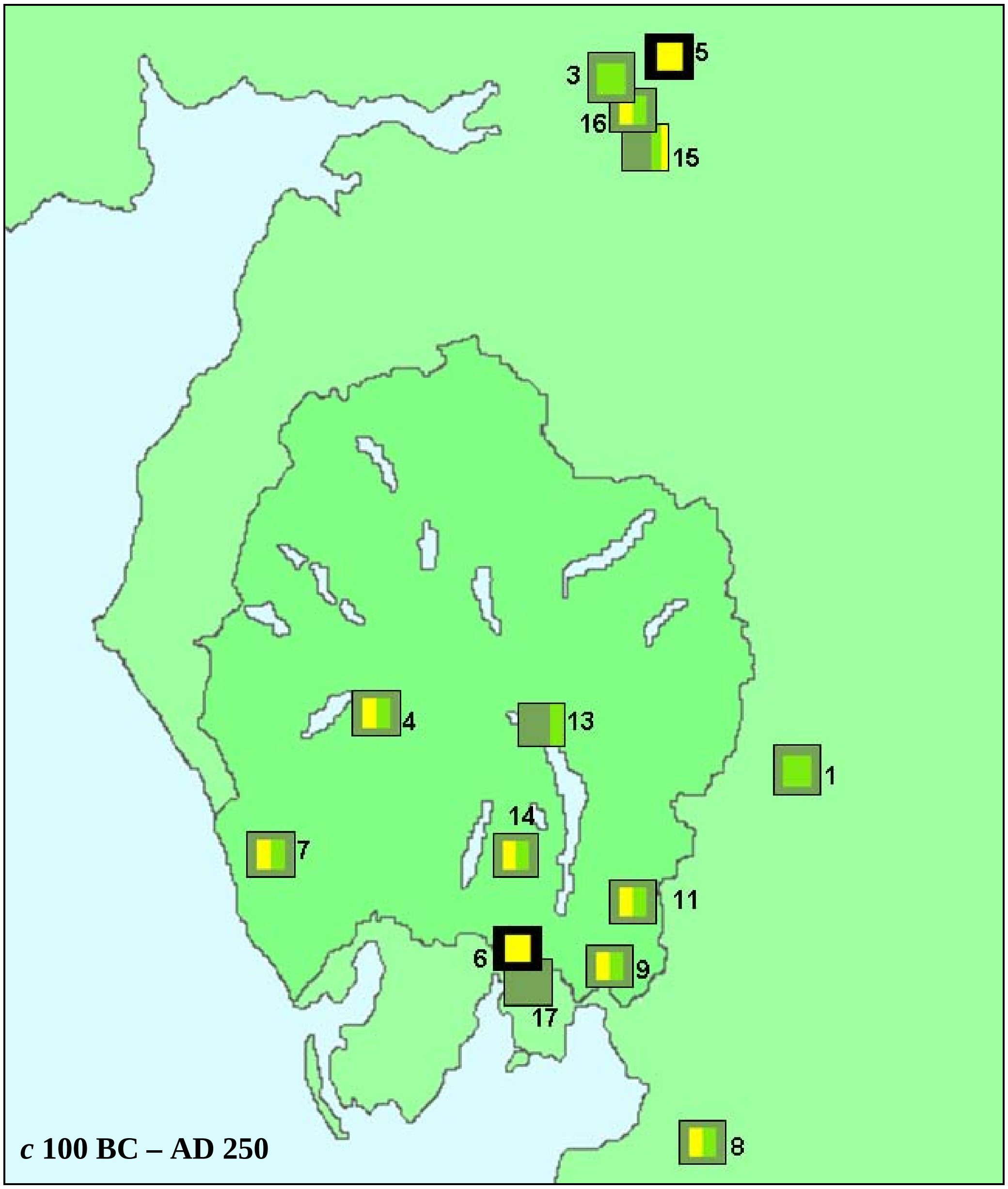
| **Number** | **Site name** | **Number** | **Site name** |
|---|---|---|---|
| 1 | Archer Moss | 10 | Glasson Moss |
| 2 | Barfield Tarn | 11 | Helsington Moss |
| 3 | Bolton Fell Moss | 12 | Huletter Moss |
| 4 | Burnmoor Tarn | 13 | Loughrigg Tarn |
| 5 | Butterburn Flow | 14 | Rusland Moss |
| 6 | Deer Dyke Moss | 15 | Talkin Tarn |
| 7 | Devoke Water | 16 | Walton Moss |
| 8 | Fairsnape Fell | 17 | White Moss |
| 9 | Foulshaw Moss | | |

Many of the sites follow the 'traditional' pattern of mid-/late- to post-Romano-British abandonment of farmland and subsequent woodland regeneration, particularly in the Southeast Lake District and northern Cumbria, although farming continues at a low level at Talkin Tarn (Langdon *et al.*, 2004), Bolton Fell Moss and Walton Moss (Barber, 1981; Dumayne-Peaty & Barber, 1998) and there is evidence for a small-scale agri-pastoral clearance at Butterburn Flow (Yeloff *et al.*, 2007) (Map 6.2). Dickinson identified a woodland clearance event followed by cereal cultivation at this time in the pollen data from Rusland Moss, followed by woodland regeneration in the post-Romano-British/early Anglo-Saxon period (Dickinson, 1975). Clearances also occurred at Fairsnape Fell to the southwest of the study area and at Deer Dyke Moss (pastoral) (Chiverrell *et al.*, 2008; Coombes *et al.*, 2009), while mixed farming continued at Devoke Water and Burnmoor Tarn, which also features an expansion of *Calluna* heath at this time (Pennington, 1965, 1970).

The early to middle-Anglo-Saxon period features clearance and mixed farming in many areas, though this is small-scale and subdued at the majority of sites (Map 6.3). Interestingly, Rusland Moss seems to be characterised by woodland regeneration at this time (Dickinson, 1975), but neighbouring Huletter Moss sees a clearance event followed by agricultural and pastoral farming (Coombes *et al.*, 2009). This might indicate that the two sites are sensing localised vegetation changes in close proximity to the sampling locations, which could be a reflection of the land management practices of different communities or of one community utilising different parts of the landscape at different times. However, further (AMS) radiocarbon dating of changes at Rusland Moss would be necessary to confirm this as the radiometric techniques used on material from the site require a substantial quantity of material, which may cover a considerable depth range and lead to chronological inaccuracies.

The later Anglo-Saxon and Norse period is characterised by pastoral and to a lesser extent agricultural clearances across much of the study area (Map 6.4). Interestingly, Dickinson identified clearance and arable farming at Rusland Moss in the later Norse period (1975), while Huletter Moss sees woodland regeneration at this time (Coombes *et al.*, 2009), suggesting that both abandonment of farmland and clearance for agriculture were happening concomitantly within a relatively small area. Similarly, in the north of the region, farming continued at subdued levels at Talkin Tarn (Langdon *et al.*, 2004) and nearby Walton (Dumayne & Barber, 1998) and Bolton Fell Mosses (Barber, 1981), but seems to have declined at Butterburn Flow (Yeloff *et al.*, 2007).

To summarise, based on palynological evidence, the broad pattern of vegetation change and land-use in this area fits the traditional view of the Romano-British and early medieval periods quite well, but there is considerable variability across the region. Farming, at least at a subdued level, continued in many places throughout the 'Dark Ages' and in some cases 'woodland regeneration' began during the Roman occupation, ending with post-Roman or early Anglo-Saxon clearances. In light of the findings of simulation experiments in the previous chapter, it is also worth considering the possibility that an expansion of arboreal pollen does not always equate to a decline in land-use; the impact of changes in the vegetation distribution and abundance on both the pollen source area and composition of assemblages is complicated and cannot easily be determined through examination of the pollen data. Modelling and simulation are useful tools in this respect and should perhaps be used more widely to investigate the range of landscape scenarios that might produce a 'regeneration' effect in the pollen curves.

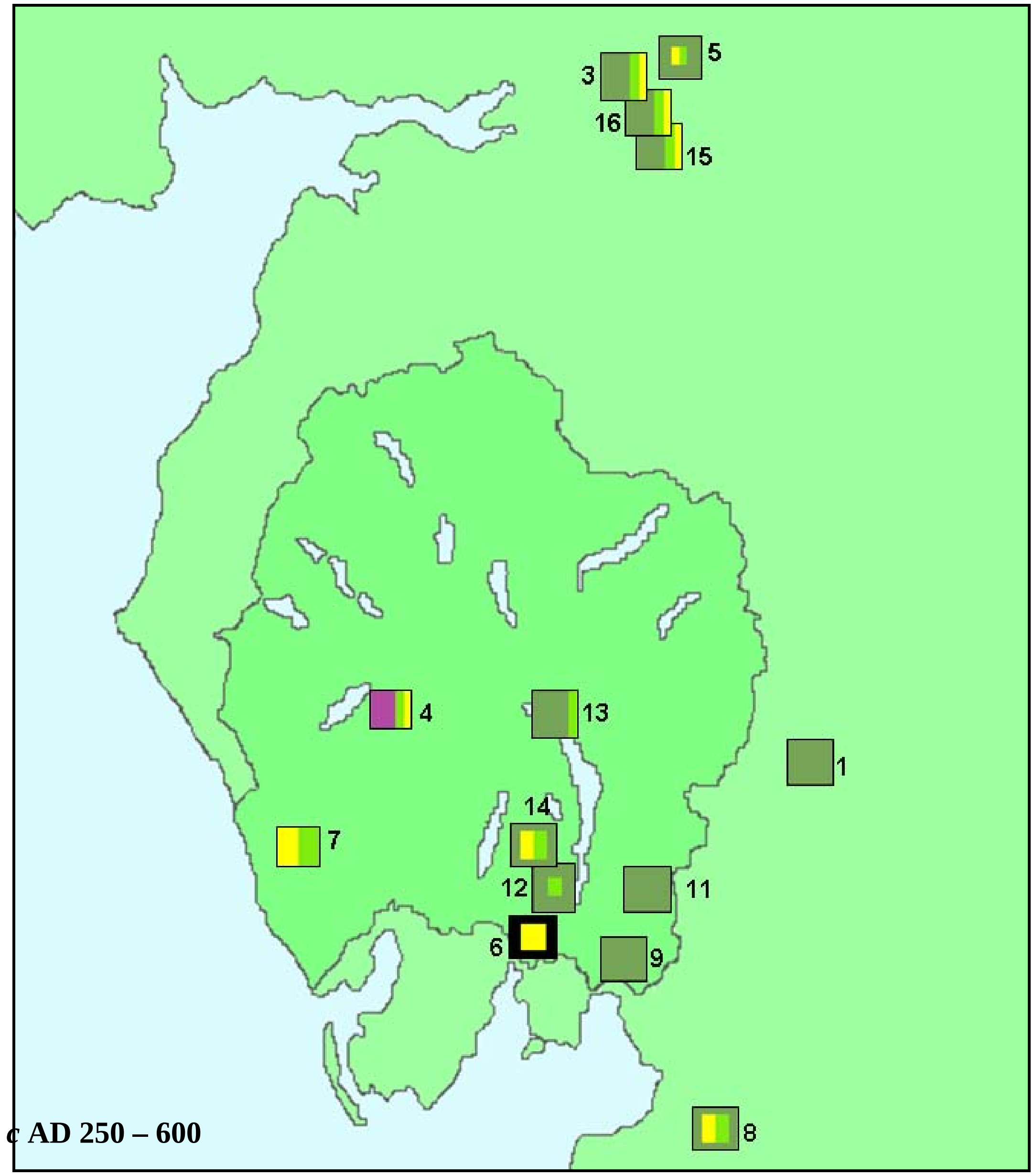



Map 6.1. Late Iron Age to mid-Romano-British vegetation patterns in Northwest England

**KEY:**

**Colours:**
- Woodland
- Agriculture
- Pastoralism
- Mixed farming
- Heathland
- Hemp-retting

**Symbols:**
- Regeneration/spread (solid square)
- Continued, subdued presence (bands -width of band indicates importance/extent)
- Decline (black border - of heathland in this example)
- Low-level clearance (pastoral)
- Extensive clearance (mixed farming)




Map 6.2. Mid-/late- to post-Romano-British vegetation patterns in Northwest England

**KEY:**

**Colours:**

Woodland

Agriculture

Pastoralism

Mixed farming

Heathland

Hemp-retting

**Symbols:**

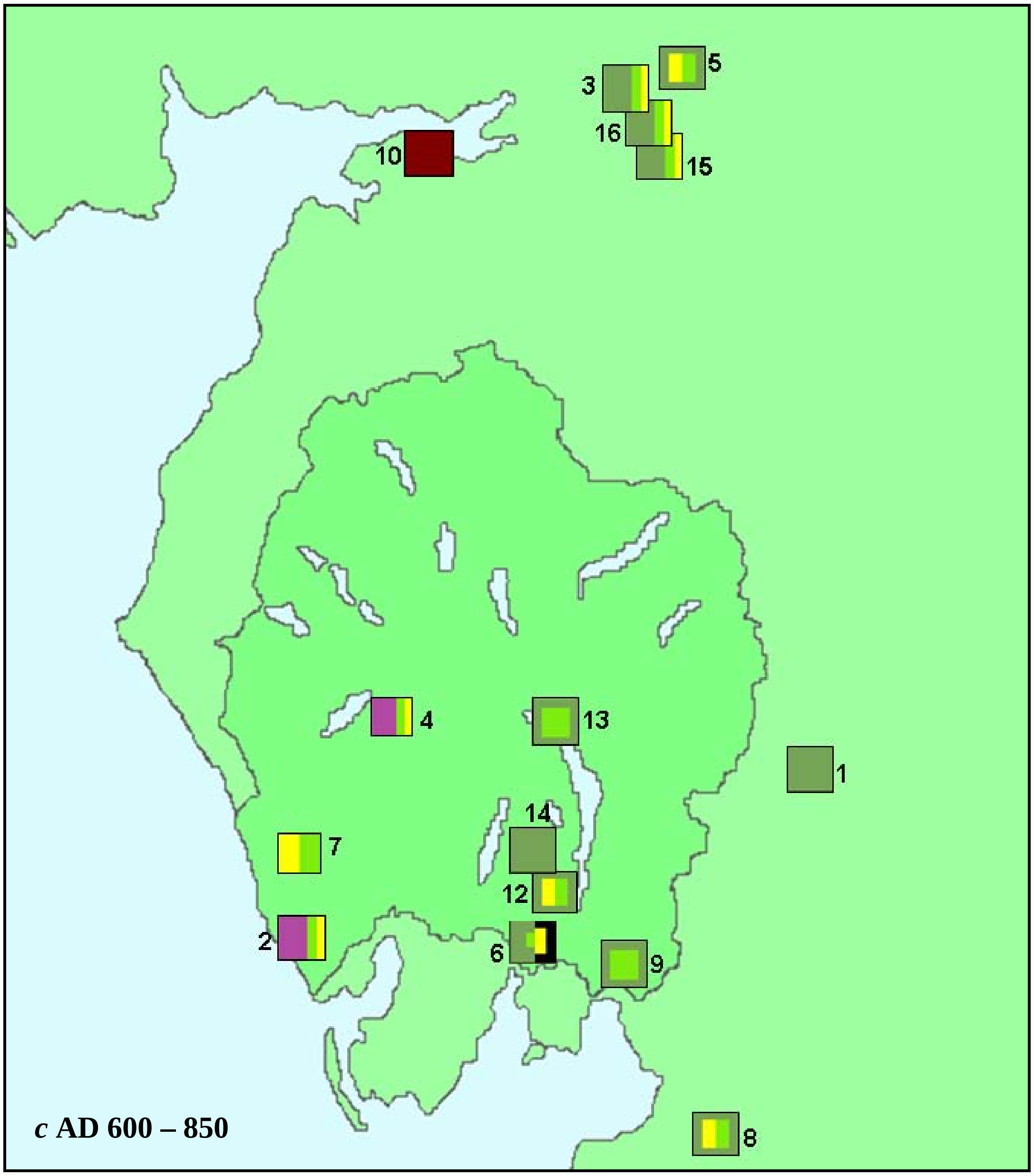
Regeneration/spread (solid square)

Continued, subdued presence (bands -width of band indicates importance/extent)

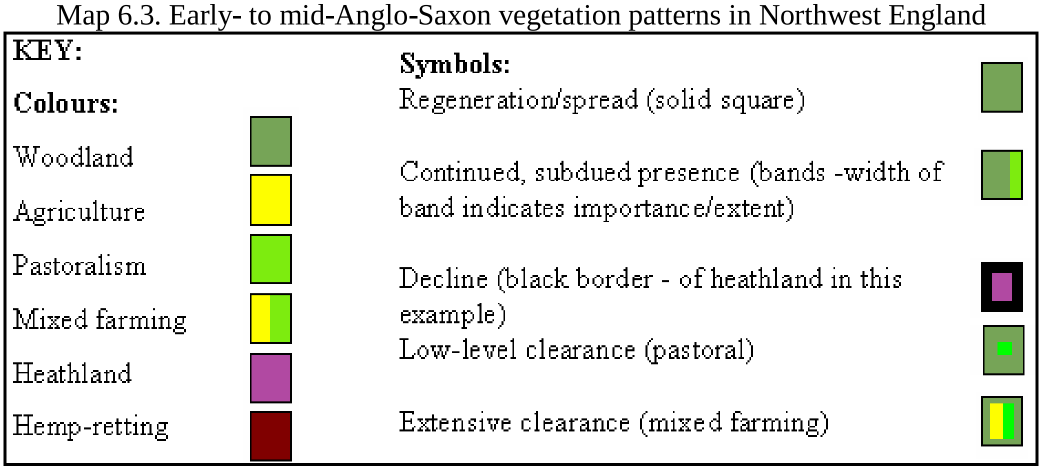
Decline (black border - of heathland in this example)

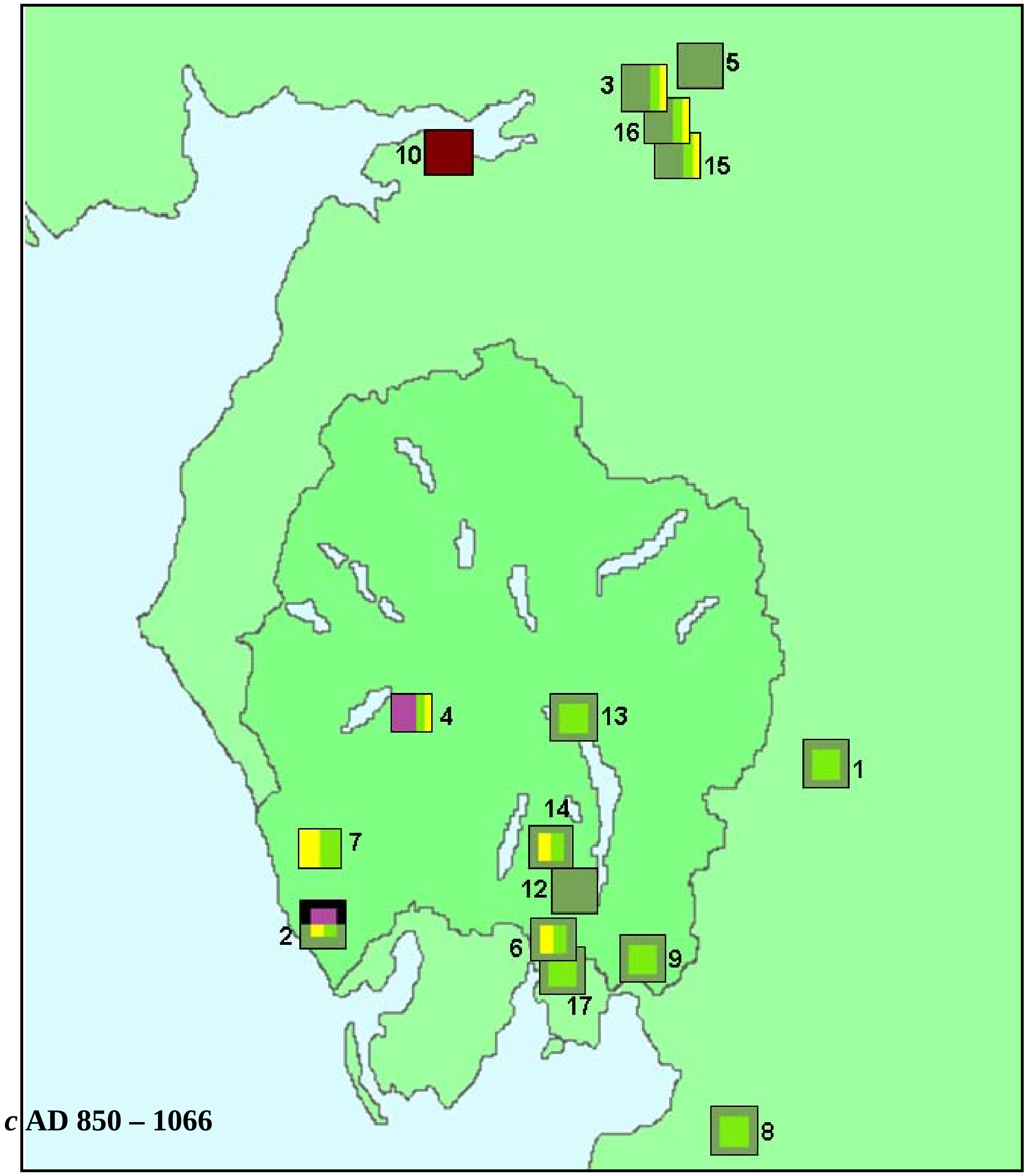
Low-level clearance (pastoral)

Extensive clearance (mixed farming)




Map 6.3. Early- to mid-Anglo-Saxon vegetation patterns in Northwest England






Map 6.4. Mid- to late-Anglo-Saxon and Norse vegetation patterns in Northwest England

**KEY:**

**Colours:**
Woodland
Agriculture
Pastoralism
Mixed farming
Heathland
Hemp-retting

**Symbols:**
Regeneration/spread (solid square)
Continued, subdued presence (bands -width of band indicates importance/extent)
Decline (black border - of heathland in this example)
Low-level clearance (pastoral)
Extensive clearance (mixed farming)

The small number of recorded early medieval archaeological remains in the Lake District and Cumbria does not reflect the level of anthropogenic activity within the landscape, suggesting that the dearth of early medieval artefacts and monuments is the result of poor survival and visibility of remains rather than a dramatic reduction in population at this time. As mentioned in Chapter 1 (Section 1.4.3), this is also implied by the widespread distribution of Anglo-Saxon and Norse placenames in the region, and by the presence of ecclesiastical centres and carved stone crosses dating from approximately the 8$^{th}$ century AD onwards; presumably settlement remains were also widespread, but have not survived as well as the stone monuments of religious establishments. The seeming disparity between the archaeological and palynological records for the period also demonstrates the value of the palaeoecological record in terms of archaeological investigation, both as a means of checking the validity of interpretations based on archaeological remains alone, and as a way of identifying areas worthy of further investigation (*i.e.* around study sites with clear evidence for anthropogenic disturbance, but little or no related archaeology). Modelling and simulation programs are also valuable in this respect, particularly in terms of the estimation of a catchment area (RSAP) for pollen reaching a site, which helps to limit the potential 'search area' for archaeological remains to some extent. In the two cases where suitable, undisturbed deposits were found, the simulated values for RSAP suggest that the small lakes/tarns utilised in this study are of an appropriate size for sensing changes in the vegetation cover and land-use patterns within a relatively small area; although a substantial component of the pollen assemblage may be derived from the regional vegetation, by comparing the data for sites across the area (as in Maps 6.1-6.4) it is possible to identify qualitative differences between locations.

### 6.4. Benefits and limitations of modelling and simulation techniques in pollen analysis

The simulation experiments employed to aid interpretation of data in this study were useful and produced interesting results, which have a bearing not only on the interpretation of data from the study sites, but also in the wider context of identification of land-use histories through pollen analysis. The simulated data demonstrate that in the modelled landscape, and presumably in the 'real' landscape, the relationship between pollen proportion and vegetation abundance is complicated. The general pattern of over- and underrepresentation of taxa within an assemblage can be approximated through a cursory examination of pollen productivity data, together with a consideration of the size and morphology of pollen grains (as for simulations BFT_LPAZ1_1 and LGT_LPAZ3B_1, Chapter 5). However, the complexities arising from changes in the RSAP and the relative contributions of local and regional vegetation to the pollen sum, which may be directly or indirectly influenced by changes in the composition or distribution of vegetation communities within the landscape, are difficult to grasp, even with the aid of numerical modelling. Similarly, the likely *scale* of over- or underrepresentation is hard to judge from PPEs and fall speeds alone, particularly as the relative values for a large number of taxa should be considered simultaneously. Pollen models such as the LRA and HUMPOL are able to perform thousands of calculations relatively quickly, providing a simple transformation of the data to account for differences in the pollen productivity and dispersal properties of plants. The calculations upon which HUMPOL and LRA are based are relatively simple and work on many assumptions, which are important to bear in mind when interpreting the results (Prentice 1988; Sugita, 1993, 1994, 2007a & b; Bunting *et al.*, 2008).

### 6.4.1. Assumptions and 'unknowns' within the model

Simulated landscapes are, by necessity, far less complex than the real world; some of the key assumptions made by the models are that the sampling site (lake or bog) is a perfectly circular opening in the vegetation canopy, that all pollen reaching the site originates from above-canopy air-flow and that the vegetation is all of equal height (Bunting *et al.*, 2008). Clearly none of these statements is likely to be true of a real landscape, yet the models have been shown to work well when tested on modern assemblages and seem to provide more accurate 'reconstructions' than can easily be achieved through interpretation of the pollen percentage data (Nielsen & Sugita, 2005; Sugita, 2007b). Hellman *et al.* (2009a) note that some internal factors within the modelling process are poorly understood, such as the impact of altering the number of sampling sites used and the effects caused by overlapping of communities in HUMPOL (where one community patch in Mosaic overlies another to some extent); the authors suggest that further experiments are required to gain a better understanding of these aspects of the model and their impact on simulated pollen proportions (Hellman *et al.*, 2009). Concern has also been expressed over the number of factors that are 'unknown' or 'unaccounted for' within the modelled landscape, particularly where seemingly arbitrary values are applied to the data. For example, Jackson and Lyford (1999) note that for their experiments using the Sutton equation (for particle dispersal) the differences in pollen deposition arising from 'neutral' and 'unstable' atmospheric conditions appear to be dramatic. They argue that pollen is more likely to be dispersed from a plant in unstable, gusty conditions and question the validity of applying a wind speed of 3 $ms^{-1}$ in all directions within the simulated landscape (Jackson & Lyford, 1999). Following on from this, Nielsen (2004) found that increasing the wind speed in POLLSCAPE (a predecessor of HUMPOL) increased the distance travelled by grains (as could be expected), but with greater impact on pollen types with high fall speeds (*i.e. Fagus,* Cerealia). This implies that windier conditions might improve representation of the heavier pollen types in an assemblage, although subsequent work suggests that the impact of altering wind speed is limited unless very high or low values are applied to the data (Bunting & Middleton, 2005; Nielsen & Sugita, 2005).

Although it might be useful to consider the potential impact of environmental conditions on the composition of the pollen sample, discussions such as this are largely academic with regard to the fossil pollen assemblage. It is practically impossible to establish something as ephemeral as wind speed and direction for the past and attempting to model conjectured changes in atmospheric conditions for an individual pollen assemblage would remove the modelled data increasingly from the collected data. Similarly, adapting the model equations to allow for factors such as the input of pollen from trunk-flow within woodland (Bunting, pers. com.) or the filtering effects of trees (Tauber, 1967) might be an interesting exercise, but application to past assemblages would increase the complexity of the modelling process and necessitate an growing number of assumptions about the nature of the former landscape.

One aspect of the model that is potentially problematic for studies such as this is the assumption that all pollen reaching the sampling site is derived from above canopy flow; despite the author's efforts to avoid tarns with inflows (Chapter 3) most of the study sites had small incoming streams, which are likely to have boosted pollen percentages of taxa growing along their banks such as alder (*Alnus glutinosa*) and willow (*Salix*) (see Figures 1.2 and 1.3 a & b) (Pennington, 1964; Bonny, 1978). These taxa could perhaps be excluded from simulations for lakes with inflows, but as they are likely to grow around the edges of the tarn they might comprise a significant component of the local vegetation, so this was not attempted here. Specifying the location of community patches could alleviate this problem (*i.e.* placing wet woodland close to waterbodies and streams), but would remove the element of randomness from the simulations as locations of both vegetation types and sampling sites would need to be defined. Increasing the complexity of the modelled landscape in this manner would also increase the time required for modelling; although using HUMPOL is very fast in comparison to carrying out the individual calculations, the overall process of preparing the files and running the various programs is time-consuming. Brown *et al.* (2007) recommend development of a different algorithm to account for pollen accumulating in lakes with inflows, as additional to the issues of overrepresentation described, the streamborne component can increase the extent of the pollen source area dramatically (see Figures 1.3 and 1.4, p59) (Jacobson & Bradshaw, 1981; Davies & Tipping, 2004; Brown *et al.,* 2007). The simplest way to account for this would be to increase the simulated lake diameter to account for the increase in source area where streams are present, or perhaps to adapt existing equations to model for deposition in a long, thin lake as opposed to a circular one.

#### 6.4.1.1. Variability of pollen productivity

As mentioned in Chapter 1, both modelling and simulation programs require input values for fall speed and pollen productivity in order to calculate distance-weighted plant abundances. Assignation of these values is based on an assumption of uniformitarianism, both in terms of the grain size/morphology and the average rate at which a given species produces pollen. The former applies to all fossil pollen analysis; if grains had changed significantly in shape or size over time, identification, particularly where measurements of pollen are required (*e.g.* cereal pollen types or *Betula nana* (dwarf birch)), would be very difficult if not impossible. Assumptions about pollen productivity are harder to justify; measurements of relative rates of production using a combination of modern surface samples and vegetation surveys have been found to vary substantially between regions. Heather (*Calluna vulgaris*) has been found to have PPE values ranging from 0.93 - 4.7 in Sweden alone (Nielsen, 2004; Broström *et al.*, 2005); experimental simulations have demonstrated that changing the input value for PPE has a dramatic impact on the analysis (Nielsen, 2004). As explained in Chapter 1, acquiring an average PPE for several years allows for seasonal and annual variations in productivity and if productivity covaries among species these variations will in any case have little impact on pollen percentages, although they should be apparent in concentration diagrams. Unfortunately, the assumption of covariance has also been questioned (Calcote, 1995) as conditions that produce abundant flowering may be species-specific (Bonny, 1980), resulting in spuriously high pollen counts for one type of vegetation and not for another. Differences in productivity resulting from the plant's location in a landscape (*e.g.* in dense woodland or on open ground) and from management practices such as burning, grazing and coppicing will also impact on the assemblage in ways that are not easy to establish, particularly as they are likely to affect specific taxa in different ways and to varying extents (*e.g.* Aaby, 1986; Groenman van

Waateringe, 1993; Nielsen, 2004; Nielsen & Odgaard, 2004)   In terms of identifying patterns of human impact in the landscape, the suppression of grass pollen values under heavy grazing is perhaps the most difficult problem to surmount (*cf.* Groenman van Waateringe, 1993); as shown for Loughrigg and Barfield Tarns, information arising from non-pollen environmental proxies such as diatoms can be an invaluable aid to interpretation in this respect.

The problems outlined above potentially affect all interpretations of pollen data, with or without the application of numerical modelling.  Perhaps assigning a fixed value to pollen productivity gives a false impression of accuracy, but papers relating to pollen modelling are generally explicit about all the assumptions and uncertainties associated with the process and the resulting data.  Whether a specific measure of PPE is given or not, most pollen studies assume implicitly that variations in pollen productivity are less important in determining the composition of a pollen assemblage than the relative abundances of vegetation types present. Work is currently in progress to obtain PPEs from a variety of habitats and regions around the world (for example, the 'Crackles' project (Farrell & Bunting, in progress)), which may shed some light on the impact of inconsistent pollen production on species representation in a wider context..

### 6.4.2.  Pollen models: a useful tool for interpretation

Overall, pollen modelling programs have a lot to offer as an aid to interpretation; they make us more aware of the limitations of our data and the assumptions inherent in palynology, while providing a relatively simple means of assessing the impact of differential productivity and dispersal properties on the pollen assemblage.  The modelling process also encourages exploration of different landscape 'designs', by enabling the vegetation patterns to be adjusted with relative ease (*e.g.* Bunting & Middleton, 2005, 2009).  This helps to address the problem of equifinality in pollen analysis to some extent, although as explained above, modelling is time-consuming and it would be impractical to 'test' every possible landscape scenario for an assemblage using HUMPOL (Caseldine *et al.,* 2007).  Testing a large number of scenarios may, however, be possible when the MSA becomes more widely available (*cf.* Bunting *et al.,* 2008; Bunting & Middleton, 2009).  Where problems arise, these are most likely to stem from failure to appreciate the limitations of the technique; although the models are becoming increasingly sophisticated, they are still very simple in comparison to a real-world situation and with the exception of the MSA, are unable to differentiate between ecologically possible and impossible/unlikely scenarios; in their work on the Neolithic vegetation of Achill Island (County Mayo, Ireland) Caseldine *et al.* (2007) found that the most unlikely scenario in terms of ecology provided the best fit for the real data. Furthermore, as Hellman *et al.* (2009a) point out, some aspects of the modelling process are not fully understood; for example, in HUMPOL, it is possible to overlap vegetation patches of different types, yet it is not clear what effect this has on the data produced. As the authors suggest, further work is required to understand the complexities of the simulation outputs and the interaction between different aspects of the model (Hellman *et al.*, 2009a). Careful consideration of the data is therefore necessary both prior to modelling and when interpreting the results.

The assumptions described in Section 6.4.1 essentially serve to simplify the modelled landscape and together with the limitations of the modelling, are only a cause for concern if users are unaware of them or take the outputs of simulations too literally; although the LRA, HUMPOL and the MSA represent a significant advancement from the R-value approach, they remain relatively unsophisticated in comparison to the real world. Simulation neither gives definitive answers (except perhaps in proving that a landscape scenario is incapable of producing a given pollen assemblage) nor removes the need for interrogation of the data, but facilitates exploration of numerous landscape scenarios in terms of their likely pollen outputs, providing a valuable aid to interpretation (*e.g* Middleton & Bunting, 2004; Bunting & Middleton, 2005, 2009; Caseldine *et al.*, 2007; Bunting *et al.*, 2008). There is potentially endless scope for experimentation in HUMPOL and similar programs (*e.g.* Bunting & Middleton, 2005; Caseldine *et al.*, 2007; Bunting *et al.*, 2008; Hellman *et al.*, 2009a & b), but the time required makes it impractical to incorporate a large number of simulations to a project such as this, where the focus of research was not on the modelling process in itself. Recently developed programs such as the Multiple Scenario Approach should facilitate more complex simulation approaches, incorporating data relating to elevation, terrain and soils and running thousands of scenarios through the model to identify all ecologically possible scenarios (Bunting *et al.*, 2008; Bunting & Middleton, 2009).

Apart from providing a means of testing the data and visualising the landscape, the estimation of the site's relevant source area for pollen is a very useful aspect of the modelling and simulation approach; not only does this improve our ability to interpret the pollen data, but establishing the area from which cereal pollen in particular is likely to originate may help in the identification of areas for targeted aerial photography, landscape and geophysical surveys and potentially even fieldwork. Application of modelling could therefore make palynology a powerful tool for identifying areas or periods worthy of further study.

## 6.5. Difficulties associated with lake coring: lessons learnt in the course of this project

Identifying suitable tarns for inclusion in this study was difficult; some sites were inaccessible considering the mass and bulk of equipment required for coring, while at others (*e.g.* BLT) samples could not be collected from deeper waters as these were beyond the reach of the modified Livingstone corer (see Chapter 3). A gravity corer would have been easier to transport and could perhaps have been deployed from a lighter, less robust boat than that required for the Livingstone, but this equipment was not available[1] at the time and would probably have struggled to collect cores of sufficient length for this type of study. It was also hard to find information about sites where work had not been carried out previously; the data from Tewet Tarn suggest that dredging might have occurred here, yet no record of this was found prior to sampling. This tarn was far shallower than was anticipated and no bathymetric information could be located; if it had been possible to establish the depth of the tarn prior to fieldwork the site would have been excluded from the study owing to the likelihood of disturbance (through turbulence in windy conditions and reed growth facilitated by the shallow water depth) (Pennington, 1981). Similarly, Burney Tarn appeared to be reasonably accessible from inspection of aerial photographs and maps (Map 3.6 and Image 3.7), but on arrival at the site the tarn was found to be shrunken in extent while the surrounding ground was boggy and/or flooded (Images 3.7 and 3.8) and the main body of water could not be reached safely with the coring equipment. As these examples suggest, it would have been useful to visit numerous potential study sites to establish the bathymetry and suitability for coring prior to collecting samples. Unfortunately, owing to the time, expense and organisation involved in fieldwork, in addition to the need to acquire permission from landowners, it was impractical to do this within the constraints of this project.

As seen in Chapter 4, further problems were encountered on the acquisition of radiocarbon dates; most of the sites featured dating reversals and this, combined with the fact that the first set of AMS measurements had focused on the most significant changes in the pollen and diatom records (Table 2A, Appendix 2), meant that it was not possible to justify follow-up

[1] A Uwitec corer was purchased by PLUS after the fieldwork for this project was completed.

dates to the satisfaction of the NERC steering committee. Even if further measurements had been granted, it is likely that these would also have been problematic as the lack of suitable plant material for dating necessitated the use of bulk sediment dates. While these worked well for Loughrigg Tarn, which had a high organic content, the minerogenic sediment from Barfield Tarn was less successful and similar difficulties have been encountered at many other lake sites (Pennington *et al.,* 1976; Pennington, 1981, 1991; Oldfield, 2010). As Pennington noted (1981), an 'orderly' sequence of dates for a lake core is indicative of a steady rate of deposition of organic sediment from the catchment; unlike peat, lake sediment is mostly derived from allochthanous sources rather than plants growing and decaying *in situ* (Pennington, 1981). Where the organic material washed into the tarn is contemporary with the pollen and diatoms being deposited at the time, the radiocarbon dates will reflect the age of deposition, but the possibility of 'old' organics skewing the dates is unavoidable where bulk sediment dates are employed. Dramatic inwash episodes are interesting as a record of land-use history and disturbance in the catchment, but highly problematic when attempting to establish chronological sequence.

It is possible that sieving a large amount of sediment might have yielded material suitable for radiocarbon dating, but owing to the limited quantity of sediment available for the various analyses this was not practicable. There were no sand lenses suitable for OSL dating (Optically Stimulated Luminescence) in any of the cores and techniques such as $^{210}$Pb or $^{137}$Cs dating would not have extended the record beyond the SCP curves or clarified the chronology of the study period. One technique that might have been successful for Barfield Tarn is tephra analysis; tephras derived from large volcanic eruptions in Iceland (*e.g.* Hekla-4) are widely distributed in Scottish peat bogs (Langdon & Barber, 2004) and have recently been identified as far south as Devon (Matthews, 2008). Ash from the larger medieval eruptions (*e.g.* Hekla-AD 1104) is likely to have reached the southern Lake District (*cf.* Dugmore *et al.,* 1996). However, even in this case caution is needed when interpreting the age estimates; while ash landing on the surface of the lake is likely to be incorporated to the sediment with contemporary pollen and diatoms, thus providing an accurate date for the deposition of these, the processes of erosion and inwash that result in reversed radiocarbon dates could also lead to the introduction of 'old' tephras from peat bogs or soils. Searching for, preparing and identifying tephra samples is time-consuming and costly, but if work is continued on Barfield Tarn in future this may warrant further investigation.

### 6.6. Summary

This study focused on sediments from small lakes as it was hoped that these would be less prone to disturbance than peat bogs, where cutting for fuel can cause truncations and loss of more recent material. The diatom analysis carried out for this project proved useful as a check on the palynological evidence (*e.g.* in showing disturbance during the Roman woodland regeneration phase at Loughrigg Tarn) and was a further incentive for using tarns rather than bogs. Unfortunately, inwash events (Barfield Tarn), disturbance (Little Langdale Tarn and Blelham Tarn) and truncation (Tewet Tarn) episodes seem to affect many sites and are not always easy to identify in the sediment sequence or in the preliminary phase of analysis. However, for the two sites that yielded data on the study period the results have proved useful; the simulations of RSAP suggest that these sites were appropriate for sensing vegetation changes within a small area and the combination of pollen and diatom records provided a good indication of vegetation and land-use histories. Studies such as this also have the potential to further archaeological knowledge, both through identification of anthropogenic activity at times for which recorded sites and finds are limited or absent, and by providing an estimate for the pollen source area within which remains are likely to be present.

# CHAPTER 7: CONCLUSIONS

Romano-British and early medieval patterns of vegetation and land-use in Northwest England suggest that developments occurred on a local rather than a regional scale at this time. There are overall trends across the area, but considerable variation can be seen in both the timing of changes and the scale and type of activity underway (*e.g.* clearance, agriculture, pastoralism). Loughrigg and Barfield Tarns produced markedly different pollen and diatom records, reflecting the contrast between the level and nature of anthropogenic activity in the two areas. The palaeoecological record from Loughrigg Tarn evinces a largely wooded landscape wherein grazing was probably important, while for Barfield Tarn the data indicate a mixture of open, grazed grassland and heather moorland, perhaps best described as a 'rough grazing' community, together with low-levels of agriculture. As the former lies in a relatively mountainous part of the central Lake District, whereas the latter is situated near the coast, surrounded by land more amenable to farming, this is unsurprising. However, stark differences are also seen between sites in close proximity to one another; the timing of changes at Rusland Moss and neighbouring Deer Dyke Moss appears to differ significantly, although this might be related to the imprecision of radiometric dating at the former, while the vegetation history of Butterburn Flow contrasts dramatically with that at nearby Walton and Bolton Fell Mosses (Dickinson, 1975; Barber, 1981; Dumayne & Barber, 1998; Yeloff *et al.*, 2007; Coombes *et al.*, 2009). In some areas the traditional theory of abandonment and woodland regeneration in the 'Dark Ages' appears to hold true, yet in others farming seems to have continued or even increased at this time.

The non-universal nature of vegetation change and land-use in the study period demonstrates the need for 'local' pollen studies that capture developments within a small area; a 'regional' pollen diagram might show the general trends, but is unlikely to sense the small-scale farming activities identified in parts of early medieval Cumbria. The simulation work carried out for this project indicates that the sites selected were of an appropriate size to detect local changes in the landscape around the tarns, as well as showing the degree to which the source area for pollen might vary depending on the type and distribution of vegetation communities. Estimation of RSAP is a valuable output of pollen modelling software and is not only an important point to consider when interpreting pollen data, but is also useful when considering the relationship between archaeology and vegetation history. Identifying the approximate area within which significant changes are likely to have occurred could be used to justify detailed investigation in that location, which would be impractical to carry out at a larger scale. For example, high-resolution aerial photography, landscape survey, geophysical survey and perhaps even fieldwalking or exploratory excavation (*i.e.* test-pitting) within the RSAP of a site for which agriculture has been identified (*e.g.* Barfield Tarn) is perhaps more likely to be fruitful than a general survey of the broader region. The continuation or resumption of farming in several, discrete locations during the 'Dark Ages' suggests that the dearth of archaeological remains from the period in much of the Lake District is more likely a reflection of limited survival, visibility and recognition of remains than of abandonment or cultural 'deterioration' at this time. Further investigation of the landscape around Barfield Tarn is recommended as the presence of cereals in the pollen assemblage indicates farming close to the site, which in turn suggests settlement.

The evidence for anthropogenic activity around Loughrigg Tarn is subtler and less easy to interpret than that at Barfield Tarn. The pollen curves for the Romano-British and early medieval periods appear to indicate woodland regeneration at this time, most notably in the late- to post-Romano-British phase, together with limited grazing in the area. The temporary expansion of oak towards the end of the Roman period supports traditional views of abandonment and deterioration of farmland at this time, probably owing to the desertion of military sites such as the nearby Roman fort at Waterhead (Galava). This phase is followed by a fall in oak, which is here interpreted as clearance for grazing and is thought to date to the early Anglo-Saxon period based on the age-depth model employed for the site (Figure 5.14, p240). Simulation experiments suggest that a much more open landscape than that indicated by the pollen diagram could have produced the assemblage seen at this site, and this, together with the profusion of diatoms relating to eutrophic environments and rare occurrences of pollen indicative of grazing and disturbance, implies that grazing was underway in the tarn's catchment area during this period. The patterns seen could result from a range of scenarios, including grazing of natural clearings or a wood-pasture habitat by livestock or wild herbivores, or clearance of woodland for pastoral farming (*cf.* Buckland & Edwards, 1984; Göranssen, 1988; Edwards, 1993; Brown, 1997; Behre, 2007). In this case, the diatom flora is perhaps more telling than the pollen record; the scale of change in the taxa present seems likely to result from a significant input of organic matter, such as would comply with a large number of animals grazing in the catchment, and hence with livestock-grazing as opposed to wild herbivores. Another important consideration is the potential for grass pollen production to be suppressed by intensive grazing, which can be sufficient to give the appearance of woodland regeneration (Groenman van Waateringe, 1993). Although the evidence for human activity is less convincing than that at Barfield Tarn, the Anglo-Saxon clearance and inferred grazing activity suggest that ‘Dark Age’ settlement remains might be found in this part of the central Lake District. This is supported by the presence of the (presumably) Norse Ting mound and rectangular buildings in nearby Little Langdale (Collingwood, 1930; Fell, 1973c; Newman *et al.*, 2004; E.H. NMR, 2009).

Unfortunately, problems of disturbance and truncation at several of the study sites precluded use of the Landscape Reconstruction Algorithm (Sugita, 2007a and b), which might have facilitated a more accurate ‘reconstruction’ of local and regional vegetation in the area. Nevertheless, HUMPOL has proved a valuable asset to interpretation and was used to test the simulated pollen output for various landscape scenarios at Barfield and Loughrigg Tarns with intriguing results. To provide an example from Barfield Tarn, simulation experiments demonstrate that the birch woodland regeneration seen in the later Anglo-Saxon/Norse period might have been far less substantial than the pollen curves imply. The coinciding loss of heather complies with an intensification of grazing and despite a slight fall in herbaceous pollen percentages, simulation experiments indicate that the extent of grazed land probably increased at this time. Pollen modelling and simulation programs can be highly beneficial if used prudently, but should be viewed as a tool to interrogate the data rather than as a solution in themselves; it is important to consider carefully the design of landscape scenarios, the choice of pollen inputs and parameters and the assumptions and limitations inherent in the process, when interpreting model outputs. The Multiple Scenario Approach (Bunting & Middleton, 2009) has the advantage over older models in that it can incorporate elevation data and other germane information, and may go further in addressing problems of equifinality, yet even this sophisticated tool requires careful thought in order to avoid spurious conclusions (*cf.* Caseldine *et al.*, 2007).

The problems encountered in the course of this project have been informative as regards the difficulties inherent in lake sediment studies. The results presented here suggest that instances of truncation and mixing are often not identifiable in preliminary analyses, making it difficult to establish the integrity of the pollen/diatom sequence before dating evidence is obtained. Unfortunately, in order to obtain ‘free’ radiocarbon dates from the NERC facility it is usually necessary to produce a substantial quantity of data, meaning that time and resources that could be used for targeted, high-resolution analysis are sometimes wasted in analysing disturbed deposits. If identifiable, terrestrial plant remains are not present for radiocarbon dating, establishing the chronology of the record is also troublesome; highly organic deposits such as those at Loughrigg Tarn are generally suitable for AMS dating, but lakes like Barfield Tarn, which produced minerogenic sediments, are problematic on account of their low organic carbon content. In addition, dramatic inwash events may carry ‘old’ carbon from eroded sediments or peat into a lake, which results in dating reversals when incorporated to younger sediment (Pennington *et al.*, 1976; Pennington, 1981, 1991; Oldfield, 2010). Although inwash is in itself revealing in terms of the history of erosion and land-use in the catchment, where multiple reversals occur it might be impossible to establish the chronology of the site using radiocarbon dates. Follow-up dates are also unlikely to be awarded by the NERC Radiocarbon Steering Committee where preliminary dates are seen to be reversed. In cases such as these it would be advisable to seek funding for alternative dating techniques such as tephra analysis or OSL (where appropriate).

As suggested above, further archaeological investigation in the study area would be useful to search for previously undiscovered or unidentified sites from the study period. Excavation is expensive and time-consuming, while landscape or resistivity/ magnetometry surveys could be carried out relatively quickly over larger areas, but in order to obtain radiocarbon or other forms of dating evidence, excavation would almost certainly be required. Targeted work based on environmental evidence would take less time than large-scale survey/excavation, particularly where the approximate catchment area (or RSAP) can be established in advance. Further palynological work on small lake or bog sites in the region, combined with aerial photography and perhaps landscape survey, would be a useful means of identifying areas with good potential for early medieval archaeology, hopefully leading to recognition of further material evidence from this intriguing period of history. Although suitable sites are difficult to find and are not guaranteed to yield deposits appropriate for answering the research questions, use of easily transportable coring equipment (such as a gravity corer, if long enough sequences could be obtained with this equipment) would facilitate investigation of less accessible sites than those presented here and would perhaps enable a larger number of cores to be subjected to preliminary analyses. Following on from this, it could be argued that problematic palaeoecological studies should be published in some format, partly to highlight the difficulties that might be encountered when embarking on such a study and partly to prevent duplication of unfruitful work.

APPENDIX 1: Table 1A: Basic ecological information and habitat groupings for all plant taxa encompassed by pollen types found in this project. Pollen nomenclature follows Bennett (1994), plant names follow Clapham *et al.*, 1962, from which habitat information was also obtained (additional information from Stace, 1997, other sources are noted in the table).

| **Species/genus/family (pollen)(Bennett, 1994)** | **Common name** | **Habitat(s)/ecological or other info** |
|---|---|---|
| TREES/SHRUBS | | |
| *Acer campestre* | Common maple | Woods, hedges, old scrub. Small deciduous tree/shrub, mostly basic soils |
| *Alnus glutinosa* | Alder | Tree. Wet woodland, by lakes and rivers. |
| *Betula* | Birch | Trees and shrubs. B. pendula on light soils - colonising woodland. B. pubescans also on wet soils |
| *Corylus avellana*-type (includes *Myrica gale*, but most pollen is thought to originate from *C. avellana* as *M. gale* is poorly represented in surface pollen even where well-represented (Birks, unpublished data, cited in (Huntley and Birks, 1983) | Hazel (*Corylus avellana*) | Shrub/small tree, woodland, scrub, hedges. Often coppiced. Wind pollinated. Damp/dry basic to moderately acid soils. |
| | Bog myrtle/sweet gale (*Myrica gale*) | Bogs, wet heaths and fens. Deciduous shrub |
| *Fagus sylvatica* | Beech | Large tree, woodland. Wind pollinated |
| *Fraxinus excelsior* | Ash | Deciduous tree, mostly calcareous soils, wetter places, in oakwoods, scrub and hedges. Wind pollinated. |
| *Hedera helix* | Ivy | Woody climber, woodland, hedges, on rocks/walls, very acid, dry or waterlogged soils. Very tolerant of shade. |
| *Ilex aquifolium* | Holly | Evergreen small tree/shrub. Woodland, scrub, hedges, among rocks, not on wet soils. |
| *Lonicera periclymenum* | Honeysuckle | Twining shrub, pollinated by dwarf-moths and other insects. Woods, hedges, scrub, shady rocks. |
| *Juglans regia* | Walnut | Large tree. Wind pollinated. Introduced, Romans (Godwin, 1975; Huntley & Birks, 1983) |
| *Picea* | Spruce | Evergreen trees, introduced. Forestry plantations. |
| *Pinus sylvestris* | Scots pine | Tree, ?re-introduced to England (native to Scotland). Wind-pollinated - pollen travels vast distances due to presence of air sacs. |

| **Species/genus/family (pollen)(Bennett, 1994)** | **Common name** | **Habitat(s)/ecological or other info** |
|---|---|---|
| *Quercus* | Oak | Large deciduous trees, woodland. |
| *Salix* | Willow | Small trees/shrubs, often wet ground by streams, etc. |
| *Taxus baccata* | Yew | Tree. Woods and scrub on limestone. Shade-tolerant. Highly toxic. Traditionally in churchyards. |
| *Ulex*-type<br>*[Cytisus scoparius*<br>*Genista*<br>*Ulex]* | Gorse/furze/whin/broom/greenweed | Shrubs. Rough grassland, heaths. *C. scoparius* also in woods. +G. tinctoria in rough pastures. |
| *Ulmus* | Elm | Large trees, woods and hedges, beside streams. |
| HEATHS | | |
| *Calluna vulgaris* | Heather, Ling | Evergreen shrub. Heaths, moors, bogs (well-drained/drier parts), open woodland, acid soils. |
| *Empetrum nigrum* | Crowberry | Small shrub. Moors, mountaintops and dry parts of bogs. |
| *Erica*<br>[*Erica tetralix* and *E. cinerea* in this area] | Cross-leaved heath, bog heather (E. tetralix)<br>Bell-heather (E.cinerea) | Evergreen shrubs, bogs, wet heaths, moors. |
| *Vaccinium*-type<br>*[Andromeda polifolia*<br>*Erica*<br>*Vaccinium*<br>+ *Pyrola* (Pyrolaceae)] | Cowberry, whortleberry, cranberry, marsh andromeda, wintergreens (pyrola) (various) | Shrubs, mostly on moors and in woodland, acid soils, heaths, bogs. |
| ARABLE WEEDS | | |
| *Centaurea cyanus* | Cornflower, bluebottle | Cornfields and waste places. Herb. |
| *Polygonum* | Knotgrass, bistort, red shank, willow weed, persicaria, water pepper, bindweed | Annual and perennial herbs, some aquatic. Mostly waste or cultivated ground, some in streams and wet places. |
| ARABLE/RUDERAL | | |
| *Artemisia*-type | Mugworts, wormwood | Perennial aromatic herbs. Waste places, hedgerows. Arable weeds. Survived shallow ploughing but not deep ploughing (therefore 'lost' *c* AD 1800 in cultivated fields) (Oldfield, 1963, 1969) |
| Chenopodiaceae | Fat hen and goosefoot | Herbs and small shrubs - mostly waste and cultivated ground |
| *Plantago major/media* | Great/hoary plantain | Perennials. Great - farmyards, cultivated ground, always open. Hoary - grassy places, neutral/basic soils |
| *Campanula*-type<br>*[Campanula*<br>*Legousia hybrida*] | Bellflower, bats-in-the-belfry, harebell, bluebell Venus's looking-glass | Woods hedgebanks grassy places on calcareous soils,<br>arable fields |

| **Species/genus/family (pollen)(Bennett, 1994)** | **Common name** | **Habitat(s)/ecological or other info** |
|---|---|---|
| ARABLE/PASTORAL/RUDERAL | | |
| *Cichorium intybus*-type<br>[ *Cichorium intybus*<br>*Lapsana communis*<br>*Hypochaeris*<br>*Leontodon*<br>*Picris hieracioides*<br>*Lactuca* (some spp)<br>*Taraxacum*<br>*Crepis*<br>*Pilosella*<br>*Hieracium*<br>] | Chicory, nipplewort, cat's ear, hawkbit, ox-tongue, lettuce, dandelion, hawkweed, hawks-beard, thistles | Perennials - various habitats, often grassy/waste ground, some on pasture/derelict arable fields. Some types in woodland and by streams. |
| *Plantago lanceolata* | Ribwort plantain | Perennial, Grassy places, neutral/basic soils. |
| Poaceae undiff. | Grasses | Annual and perennial herbs. Very varied habitats includes aquatic/wetland species (*e.g. Phragmites communis*). |
| *Rumex acetosa* | Sorrel | Perennial, grassland, open places in woods. |
| *Rumex acetosella* | Sheep's sorrel | Heaths, grassland, cultivated land. Perennial. |
| *Trifolium*-type | Trefoil, clover | Grassy places, some types can be cultivated. |
| *Urtica dioica* | Stinging nettle | Hedgebanks, woods, grassy places, fens<br>Nitrate-rich soils (urine, fertilisers) (Olsen, 1921). |
| *Centaurea nigra* | Lesser knapweed, hardheads | Perennial herb, grassland, waysides. |
| WETLANDS/WET MEADOWS | | |
| Cyperaceae undiff. | Rushes, sedge, cotton-grass, | Wet places. |
| *Filipendula* | Dropwort and meadowsweet | Perennial herb, grassland, swamps, marshes, fens, wet rock ledges. |
| *Valeriana dioica* | Marsh valerian | Marshy meadows, fens and bogs. Perennial herb. |
| HERBS (various habitats) | | |
| *Achillea*-type<br>[ *Tanacetum vulgare*<br>*Achillea*<br>*Anthemis*<br>*Leucanthemum vulgare*<br>*Matricaria recutita*<br>*Tripleurospermum*] | Tansy<br>Sneezewort, milfoil<br>camomile and mayweed<br>marguerite, moon-daisy, ox-eye daisy<br>wild chamomile<br>Mayweed | Perennial herbs<br>damp meadows and marshes, waysides, hedgerows<br>arable and waste places<br>grassland<br><br>arable and wasteland |
| Circaea | Enchanter's nightshade | Perennial herbs - woods and shaded rocky places |

| Species/genus/family (pollen)(Bennett, 1994) | Common name | Habitat(s)/ecological or other info |
|---|---|---|
| *Cirsium*-type<br>[ *Carduus*<br>*Cirsium*] | Thistle | Pastures, waysides, arable fields, grassland, open scrub, gardens, marshes, hedgerows, woods |
| *Helianthemum* | Rockrose | grassland and scrub, rocky limestone pastures |
| *Potentilla*-type<br>[*Potentilla*<br>*Sibbaldia procumbens*<br>*Fragaria vesca*] | Cinquefoils and tormentils<br>*F. vesca* is wild strawberry | Herbs/small shrubs. Numerous habitats (encompasses many spp). |
| *Ranunculus acris*-type<br>[*Anemone nemorosa*<br>*Pulsatilla vulgaris*<br>*Ranunculus* undiff.] | wood anemone, pasque flower, buttercup, spearwort, crowfoot | Perennial herbs - varied habitats (many types) Woodland, meadows, in/beside streams, bogs and fens. Some Ranunculus spp are aquatic. |
| Rubiaceae<br>[*Sherardia arvensis*<br>*Asperula cynanchica*<br>*Galium sp.*] | Field madder, squinancy wort, crossword, mugwort, sweet woddruff, bedstraw, goosegrass, cleavers, hairif, sticky Willie | Woody plants/herbs. Arable and waste ground, dry calcareous pastures, open woodland, scrub, hedges, waysides, rocky slopes, scree, stream-sides, heaths, moors, fens, marshes |
| *Saxifraga granulata*-type<br>[ *Saxifraga hirculus*<br>*Saxifraga granulata*<br>*Saxifraga hypnoides*<br>*Saxifraga tridactylites*] | Saxifrages | Perennial herbs. Wet grassy moors, walls, grassland, rock ledges and scree. |
| *Saxifraga stellaris*-type<br>[ *Saxifraga nivalis*<br>*Saxifraga stellaris*] | Starry saxifrage, alpine saxifrage | Perennial herbs. Wet rocks on mountains, by mountain streams. |
| *Scabiosa columbaria* | Small scabious | Perennial herb. Dry, calcareous pastures and banks. |
| *Scutellaria*-type<br>[ *Scutellaria*<br>*Ajuga*] | Skull-cap, Bugle | Edges of streams, wet heaths, fens and wet meadows, damp woodland, rock crevices. |
| *Silene vulgaris*-type<br>[*Silene vulgaris*<br>*Silene uniflora*<br>*Silene acaulis*] | Campion, catchfly | Grassy slopes, arable land, broken ground, mountains ledges and scree |
| *Solidago virgaurea*-type<br>[ *Filago germanica*<br>*Antennaria dioica*<br>*Gnaphalium*<br>*Inula conyza*<br>*Pulicaria*<br>*Solidago virgaurea*<br>*Erigeron*<br>*Bellis perennis*<br>*Senecio*<br>*Tephroseris*<br>*Tussilago farfara*<br>*Bidens*<br>*Eupatorium cannabinum*] | Golden-rod, fleabane, daisy, hemp agrimony, ragwort, groundsel, coltsfoot, bur-marigold, ploughman's spikenard, cudweed, cat's-foot, fleawort. | Perennial herbs - varied habitats. Woodland, grassland, rocks, hedgebanks, walls, marshes, fens, streambanks, wasteland, waysides, neglected/overgrazed pastures, arable land.<br><br>*Bidens* (bur-marigold) is an aquatic found in lake margins, ditches, ponds, standing water |

| **Species/genus/family (pollen)(Bennett, 1994)** | **Common name** | **Habitat(s)/ecological or other info** |
|---|---|---|
| *Teucrium* [only *T. scorodonia*?] | Wood sage | Woods, grassland, heaths. Perennial. |
| *Valeriana officinalis* | Valerian | Perennial herb, rough, grassy and bushy places, mostly damp soils. |
| AQUATICS | | |
| *Menyanthes trifoliata* | Buckbean, bogbean | Aquatic or bog plant. Ponds, edges of lakes, wetter parts of bogs. |
| *Myriophyllum alterniflorum* | Alternate-flowered water-milfoil | Water-plant. Lakes, streams, ditches. Particularly in base-poor and peaty water. |
| *Nuphar* | Yellow water-lily | Lakes, streams and ponds. |
| *Nymphaea alba* | White water-lily | Lakes and ponds |
| *Potamogeton natans*-type [ *Potamogeton subgenus Potamogeton Groenlandia densa* + *Triglochin* (Juncaginaceae)] | Pondweed, marsh arrow-grass | Ponds, lakes, streams, bog-pools, ditches, marshes. |
| *Sparganium emersum*-type [ *Sparganium* undiff. + *Typha angustifolia* (Typhaceae)] | Bur-reeds, lesser reedmace | Lakes, pools, ditches, rivers, reed-swamps. |
| *Equisetum* | Horsetail | Various spp. Shallow water at edges of lakes, ponds, ditches, bogs, fens, marshes, wet heaths, meadows and woods, fields, hedgebanks, grassy streambanks. |
| FERNS | | |
| *Cryptogramma crispa* | Parsley-fern | Screes, acid soils and mountains. Quarries also (Page, 1997) |
| *Dryopteris dilitata* | Broad buckler-fern | Woods, hedgebanks, wet heaths, shady rock ledges, crevices. |
| *Polypodium* | Polypody | Ferns. Woodland - on trees and the ground, on rocks and walls. |
| *Pteridium aquilinum* | Bracken | Ferns. Woods, heaths, mainly light, acid soils. Spreads over land previously covered in grasses or heather. Favoured by grazing of sheep and rabbits (eaten by neither). |
| *Pteropsida* (Polypodiaceae, Thelypteridaceae, Athyriaceae, Woodsiaceae, Dryopteridaceae, and Blechnaceae) | Ferns | Very varied (many types). |
| *Selaginella selaginoides* | Lesser clubmoss | Damp grassy/mossy ground, mainly on mountains. |

The species listed in brackets are those included within the ‘type’ group by Bennett, 1994. Species that are confined to areas very detached from the study region or that are unlikely to be found within the environs of the sites (*e.g.* saltmarsh species) have been excluded from these lists to reduce the amount of information present and make a more accurate summary of the likely habitats. Where there are many species within a genus that are likely to be found in the Lake District these are not named individually, but when the likely candidates can be narrowed down (from Bennett's list) species names are given. Brassicaceae, Rosaceae, Caryophyllaceae and Apiaceae are not included as the families are too large and diverse to summarise easily and the resulting ecological information would probably be unhelpful because of the number of possible habitats. Anthropogenic indicator species are covered in more detail in Chapter 1 (Table 1.6).

APPENDIX 2: Table 2A: Justification for radiocarbon sampling depths, submitted to NERC October, 2007 (all dates granted)

| DATE | SITE | DEPTH/CM | JUSTIFICATION FOR DATING AT THIS DEPTH |
|---|---|---|---|
| 1 | BFT | 112-114 | Base of core and rangefinder for start of pollen and diatom records. |
| 2 | BFT | 73-75 | **Woodland taxa decline concomitant with expansion of agricultural and pastoral types – this indicates clearance for farming.**<br>-Decrease in arboreal taxa (*Pinus sylvestris, Alnus glutinosa, Betula, Corylus avellana*-type and *Quercus*)<br>-Increase in heathland taxa (*Calluna vulgaris* and *Erica*)<br>-Increase in/more consistent presence of types indicative of agricultural and pastoral activity (e.g. Poaceae, *Hordeum*-type, *Cichorium intybus*-type, etc.) – Clearance/farming<br>-Increase in wetland taxa indicates changes in local conditions |
| 3 | BFT | 40-42 | **Expansion of heathland and reduction of pastoral indicator species indicate deterioration/abandonment of farmed land.**<br>-Increase in heathland taxa (*Calluna vulgaris* and *Erica*)<br>-Decline in most of the pastoral taxa } Farmed land abandoned/deteriorating<br>-Decrease in *Alnus glutinosa*<br>-First occurrence of *Juglans regia* (post-Roman (Clapham et al., 1962)) |
| | | | |
| 4 | BLT | 112-114 | Base of core and rangefinder for start of pollen and diatom records. |
| 5 | BLT | 85-87 | **Decrease in woodland taxa and expansion of pastoral types suggests clearance for grazing.**<br>-Decrease in *Ilex aquifolium*<br>-Increase in *Salix* in conjunction with overall decrease in woodland taxa } Clearance for grazing<br>-Gradual increase in *Plantago major/media* and Poaceae<br>-Decrease in *Erica* |

| DATE | SITE | DEPTH/CM | JUSTIFICATION FOR DATING AT THIS DEPTH |
|---|---|---|---|
| **6** | BLT | 55-57 | **Changes in pollen types show clearance for agriculture/grazing and the diatom taxa suggest eutrophication.**<br>-Decrease in woodland taxa (*Quercus, Corylus avellana*-type, *Ilex aquifolium*)<br>-Expansion of heathland taxa (*Calluna vulgaris* and *Erica, Vaccinium* also present)<br>-Expansion of arable and pastoral taxa<br><br>Increase in centric diatoms (*Cyclotella radiosa* and *C. pseudostelligera*) and *Asterionella formosa* may indicate eutrophication and possible addition of fertilisers/manure to soils in the catchment area.<br>} Clearance for agriculture/grazing |
| | | | |
| **7** | BYB | 67-69 | Base of monolith and rangefinder for start of pollen and diatom records. |
| **8** | BYB | 50-52 | Rangefinder between SCP curve and basal date. This is applied for as a date in principle as additional pollen data are being analysed to clarify vegetation changes at this depth. |
| | | | |
| **9** | LLT | 142-144 | Base of core and rangefinder for start of pollen and diatom records. |
| **10** | LLT | 110-112 | **Pollen taxa indicate clearance for agriculture and grazing.**<br>-Expansion of pastoral taxa (Poaceae, *Plantago lanceolata* and *Urtica dioica*)<br>-First occurrence of cereal types (*Avena-Triticum*-type, *Hordeum*-type)<br>-Slight decrease in *Corylus avellana*-type and *Calluna*<br>} Clearance for grazing/agriculture |
| **11** | LLT | 63-65 | **Pollen data indicate changes in woodland structure (may relate to management). Changes in water chemistry are inferred from changes in diatom flora.**<br>-Increase in *Betula*<br>-Decrease in *Ilex aquifolium*<br>} Change in land management or local conditions<br>-Decrease in *Brachysira serians* and *Tabellaria flocculosa*<br>-Increase in *Frustulia rhomboidea* and *Pinnularia undulate*<br>} Changes in water chemistry, nutrient status or tarn depth |

| DATE | SITE | DEPTH/CM | JUSTIFICATION FOR DATING AT THIS DEPTH |
|---|---|---|---|
| **12** | LGT | 153-155 | Base of core and rangefinder for start of pollen and diatom records. |
| **13** | LGT | 115-117 | **Decline in woodland taxa indicates clearance and expansion of pastoral types suggests this was to provide open ground for grazing. Diatoms suggest eutrophication and disturbance in the catchment. Bracken may be evidence of burning.**<br>-Decrease in arboreal taxa (*Alnus glutinosa, Quercus, Corylus avellana*-type)<br>-Expansion of Poaceae and *Plantago lanceolata*<br>-Increase in *Pteridium aquilinum*<br><br>Increase in *Asterionella formosa* and high levels of centric diatoms (*Aulocoseira subarctica* and *Cyclotella pseudostelligera*) may indicate eutrophication and possible addition of fertilisers/manure to soils in the catchment area<br>} Clearance (bracken may indicate burning) for grazing |
| **14** | LGT | 60-62 | **Woodland taxa decrease and pastoral types increase, suggesting clearance for grazing. This is supported by expansion of diatom types linked with eutrophication and disturbance.**<br>-Peaks in pastoral taxa (Poaceae, *Plantago lanceolata, Rumex acetosa, Cichorium intybus*-type and *Urtica dioica*)<br>-Gradual decrease in *Quercus* and *Alnus glutinosa*<br><br>Elevated levels of *Cyclotella radiosa* and *Cyclostephanos dubius* (centric diatoms) may indicate eutrophication<br>} Clearance for grazing |
| | | | |
| **15** | TWT | 74-76 | Base of core and rangefinder for start of pollen and diatom records. |
| **16** | TWT | 55-57 | **Return of birch concomitant with decline in taxa associated with farming suggests abandonment of farmed land.**<br>-Rapid increase in *Betula*<br>-Decrease in *Quercus*<br>-Decline of agricultural/pastoral indicator species (*Artemisia*-type, Poaceae, *Rumex acetosella, Urtica dioica*)<br>} Farmed land abandoned, woodland regeneration |

APPENDIX 3: Table 3A. Potential coring sites in the Lake District/Cumbria

| Site | Grid reference | NGR | Altitude/ mOD | Access | Inflows/ outflows | Background information | Previous work | Possible study site? |
|---|---|---|---|---|---|---|---|---|
| Arnsbarrow Tarn | SD310917 | 331021E 491715N | 300 | Very poor | No | ? | ?None | N |
| Barfield Tarn | SD108869 | 310785E 486912N | 24 | Good/ medium | Yes | Prehistoric and medieval (later) archaeology nearby. Mesolithic/ Neolithic clearance. Remained open? | 'Prehistoric pollen' studied (Pennington, 1970; Clare *et al.*, 2001). 3 diatom samples analysed. Included in Smyly's (1958) crustacean survey. | Y |
| Blea Tarn, Langdale | NY293044 | 329314E 504415N | 187 | Good | Yes – few, small | Problems with previous work | Sediment record shows non-continuous records for the Holocene (Van der Post *et al.*, 1997; Haworth *et al.*, 2003). Included in Smyly's (1958) crustacean survey. | N |
| Blelham Tarn | NY366005 | 336616E 500468N | 50 | Good | Yes, small | Rate of erosion (and therefore sediment accumulation) has increased greatly in recent years – longer core required if possible? | Much work on rates of erosion and accumulation of radionuclides (Van der Post et al., 1997). Many cores collected; recent diatoms and some pollen (Pennington, 1965, 1981; Pennington *et al.*, 1976; Oldfield, 1970 (Blelham Bog); Haworth, 1976, 1980) | Y |
| Burney Tarn | SD254859 | 325425E 485933N | 161 | Good* | Yes, outflow | SSSI | ?None | Y |

| **Site** | **Grid reference** | **NGR** | **Altitude/ mOD** | **Access** | **Inflows/ outflows** | **Background information** | **Previous work** | **Possible study site?** |
|---|---|---|---|---|---|---|---|---|
| Elterwater | NY333041 | 333346E 504145N | 64 | Good | Yes, big ones | Problems with previous work | Previous work on pollen/sediments has been problematic (e.g. Coombes, 2003) (too big, sediments too mobile? Inflows are problem? | N |
| Green Hows Tarn | SD363907 | 336267E 490685N | 150 | Good | Yes, small ones | Private property In plantation and attached to reservoir – probably disturbed/artificial? | ?None | ?N |
| Kelly Hall Tarn | SD288932 | 328863E 493268N | 120 | Good | Yes | Drinking water supply | ?None | N |
| Knipe Tarn | SD427944 | 342663E 494394N | 145 | Excellent | Yes, 1 small one | Has been dammed and is on private property | Included in Smyly's (1958) crustacean survey. | N |
| Knottallow Tarn (Or Knottalow) | SD272802 | 327179E 480215N | 206 | Okay | Yes | Dammed/modified (clear change in shape from 19th century map) | Included in Smyly's (1958) crustacean survey. | N |
| Little Langdale Tarn | NY309032 | 330917E 503230N | 104 | Good (though depends on parking) | Yes | Sediment cores collected - work on recent diatoms and sediment accumulation rates shows increased erosion in the catchment (Haworth *et al.*, 2003: 135) | Only on recent material? Copper enriched horizon at 1900 linked to local coppermining (Haworth et al., 2003: 135) Included in Smyly's (1958) crustacean survey. | Y |
| Little Tarn | NY249338 | 324890E 533794N | 198 | Okay | No | None? | Included in Smyly's (1958) crustacean survey. | ?N |

| Site | Grid reference | NGR | Altitude /mOD | Access | Inflows/ outflows | Background information | Previous work | Possible study site? |
|---|---|---|---|---|---|---|---|---|
| Loughrigg Tarn | NY344043 | 334473E 504351N | 94 | Good | Yes, very small | Surrounded by grazed land - relatively nutrient rich tarn (Haworth *et al.*, 2003: 139) | Sediment cores collected 1962, 1975. Unpublished basic pollen diagram shows postglacial woodland. Some work on modern diatoms and aquatic flora (Haworth et al., 2003: 139-141). Included in Smyly's (1958) crustacean survey. | Y |
| Middlerigg Tarn | NY397011 | 339728E 501140N | 84 | Good | Yes | Artificial tarn (Nuttall & Nuttall, 1996: 130) | Included in Smyly's (1958) crustacean survey. | N |
| Moss dub | NY146137 | 314597E 513728N | 130 | Okay, but potential unsurfaced forestry tracks (permission issues too?) | Yes | In Ennerdale Forest Archaeology nearby? (report) Historic homestead near it (OS map NW lakes) Shallow tarn/?bog pool? (Nuttall, 1995: 41-2) In woodland/Ennerdale plantation | ?None | N |
| Overwater Tarn (or Over Water) | NY252350 | 325207E 535058N | 198 | | | National Trust owned, no public access. Possible disturbance due to damming at one end in 1920s. Also a trout fishery [now closed down]. | Included in Smyly's (1958) crustacean survey. | |

| **Site** | **Grid reference** | **NGR** | **Altitude /mOD** | **Access** | **Inflows/ outflows** | **Background information** | **Previous work** | **Possible study site?** |
|---|---|---|---|---|---|---|---|---|
| Parkgate Tarn | NY118005 | 311802E 500574N | 58 | Okay, though potential unsurfaced forestry tracks | Yes, 1 small one | Extended to make ornamental fishing pool - possible disturbance. | Included in Smyly's (1958) crustacean survey. | ?N |
| Ponsonby Tarn | NY047045 | 304651E 504528N | 60 | Good | Yes | Artificial Tarn - Windscale/Sellafield (Oldfield *et al.*, 1999) | Bonnett & Cambray, 1991 on radionuclide content of sediment.<br>Oldfield *et al.*, 1999 on sediment sourcing and yield estimation. | N |
| Priest pot | SD358979 | 335751E 497852N | 70 | Not bad | Yes | Near Hawkeshead - eutrophic. | Work on modern spp/water by BODC Liverpool. Study of sediments - bacteria and protozoa (Finlay, CEH Dorset), FBA too. How much disturbance through all this? | |
| Ratherheath Tarn | SD484958 | 348443E 495845N | 114 | Good | No | Fishing - possible problems of access and dredging? | Included in Smyly's (1958) crustacean survey. | ? |
| Ratherheath Tarn Small (Unnamed on OS maps) | SD484960 | 348444E 496002N | 114 | Medium | No | Very small, no information found as yet. Could just be a pool on the bog surface. | ?None | ?N |

| Site | Grid reference | NGR | Altitude/ mOD | Access | Inflows/ outflows | Background information | Previous work | Possible study site? |
|---|---|---|---|---|---|---|---|---|
| Sawrey Stricely Tarn (Unnamed on OS maps) | SD339907 | 333877E 490726N | 60 | Good, but private | No | None - needs investigation. Used for fishing. | ?None | ? |
| School Knott Tarn (Unnamed on OS maps) | SD428972 | 342813E 497250N | 213 | Poor | No | Small and shallow, relatively closed system. Possible problems relating to shallow depth and drying out. Access will be difficult. | None on palaeoecology - bathymetry available (Haworth *et al.*, 2003: 156-7) Included in Smyly's (1958) crustacean survey. | ?N |
| Skelsmergh Tarn | SD533967 | 353341E 496685N | 109 | Good | No | Marl tarn – difficulty with radiocarbon dating of lake sediment. Steepsided valley. SSSI. | Low resolution pollen analysis (Walker, 1954) Included in Smyly's (1958) crustacean survey. | N |
| Stonehills Tarn | SD418944 | 341776E 494382N | 117 | Good | Yes, small | Private property | ? | ?N |
| Tewet Tarn | NY30523 5 | 330452E 523537N | 198 | on top of a small hill and 290m from road… | Small outflow | None | Included in Smyly's (1958) crustacean survey. | Y |
| Urswick Tarn | SD270744 | 327039E 474425N | 38 | Very good | 1, very small | Carbonate – problematic for radiocarbon dating. ?Duplication of Richard Jones' work too (now). | Oldfield & Statham, 1963, Oldfield, 1963, 1965, 1969 Included in Smyly's (1958) crustacean survey. | N |

| Site | Grid reference | NGR | Altitude /mOD | Access | Inflows/ outflows | Background information | Previous work | Possible study site? |
|---|---|---|---|---|---|---|---|---|
| Wharton Tarn | SD331988 | 333113E 498811N | 198 | Medium | No | Marshy edges (could be difficult with boat). Awaiting report on depth/suitability from Liz Haworth. | Included in Smyly's (1958) crustacean survey. | ?Y |
| Yew Tree Tarn | NY322004 | 332183E 500422N | 107 | Good | Yes | Artificial tarn, created 1930s (Nuttall & Nuttall, 1995: 199) | Included in Smyly's (1958) crustacean survey. None | N |
| Unnamed tarn near Satterthwaite | SD335929 | 333497E 492855N | 90 | Good | No | Not present on older maps of the area, suggesting it is a wet hollow rather than a tarn (Liz Haworth pers. comm.) | ? | N |
| Unnamed tarns (two) near Knipe Tarn | SD424945 SD424946 | 342394E 494478N 342415E 494574N | 150 | Good | No | Not present on older maps of the area, suggesting it is a wet hollow rather than a tarn (Liz Haworth pers. comm.) | ? | N |
| Unnamed tarn near Borwick Fold | SD443969 | 344332E 496928N | 200 | Excellent | No | Not present on older maps of the area, suggesting it is a wet hollow rather than a tarn (Liz Haworth pers. comm.) | ? | N |

E = Easting, N = Northing, both in metres.
Y = yes, N = no, ?Y or ?N = inclined one way or the other, but further information needed

As the table shows there was considerable difficulty identifying sites within the study area that met all of the criteria; the majority of sites encountered had inflows/outflows and those that did not were generally inaccessible. If there had been sufficient time and funding and radiocarbon dating had been more readily available, it would have been interesting to check more of the sites, especially those about which little is known. Ideally, a large number of sites would be cored multiple times and dates and preliminary data obtained, so that the most useful sites for the study could be identified and taken further, but sadly this was unrealistic for the current project.

APPENDIX 4: Table 4A: Diatom authorities, common synonyms, information on observed nutrient status of habitats and highest percentages (of the TDC) at each site.

| **GENUS/SPECIES (synonyms in brackets)** | **AUTHORITY** | **TROPHIC STATUS** | **TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994)** | **ANY ADDITIONAL INFORMATION** | **PRESENT AT** | **MAX % AT SITE (3s.f.)** |
|---|---|---|---|---|---|---|
| *Aulacoseira granulata (var. angustissima)* | (Ehrenb.) Simonsen 1979 ((O.Müll.) Simonsen 1979) | EUTROPHIC (Denys, 1991-2, Hübener and Dörfler, 2002) HIGHLY EUTROPHIC (Hübener and Dörfler, 2002, Bennion et al., 2004) | 126.5 (refers to *A. granulata var. angustissima*) | | BFT | 0.984 |
| *Aulacoseira subarctica* | (O.Müll.) E.Y.Haw. 1988 | MESOTROPHIC (Bennion et al., 2004) MESOTROPHIC - EUTROPHIC (Bennion et al., 2004) | | Appears where there are moderate increases in nutrient status, disadvantaged by further enrichment (Gibson et al., 2003) | BFT | 3.57 |
| | | | | | BLT | 5.33 |
| | | | | | LLT | 0.65 |
| | | | | | LGT | 37.5 |
| *Cyclostephanos dubius* | (Fricke) Round 1982 | EUTROPHIC (Denys, 1991-2, Hübener and Dörfler, 2002) HIGHLY EUTROPHIC (Bennion et al., 2004) | 214.8 (highly eutrophic) | | BFT | 0.518 |
| | | | | | BLT | 14.2 |
| | | | | | LLT | 1.43 |
| | | | | | LGT | 16.1 |
| *Cyclotella krammeri (C. kuetzingiana)* | Håk. 1990 (Thwaites 1848) | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) OLIGOTROPHIC (Bennion et al., 2004, Bennion and Simpson, 2010) | | Circumneutral species (Jones et al., 1993) | BLT | 18.1 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Cyclotella meneghiniana* | Kütz. 1844 | EUTROPHIC (Denys, 1991-2) | 408.3 | | BFT | 0.245 |
| | | | | | BLT | 0.458 |
| *Cyclotella pseudostelligera* | Hust. 1939 | EUTROPHIC (Denys, 1991-2) | 158.1 | Circumneutral (Denys, 1991-2) | BFT | 5.24 |
| | | | | | BLT | 40.4 |
| | | | | | LLT | 5.38 |
| | | | | | LGT | 64.3 |
| *Cyclotella radiosa (C. comta)* | (Grunow) Lemmerm. 1900 ((Ehrenb.) Kütz. 1849) | | 70.8 | | BFT | 0.237 |
| | | | | | BLT | 14.9 |
| | | | | | LLT | 0.443 |
| | | | | | LGT | 35.9 |
| *Stephanodiscus hantzschii* | Grunow in Cleve et Grunow 1880 | EUTROPHIC (Denys, 1991-2) HIGHLY EUTROPHIC (Bennion et al., 2004) | 288.4 | Has one of the highest values in the N Ireland TP dataset (Anderson and Rippey, 1994). Can be found in less productive waters, but in very small numbers except where (natural) Phosphorous levels are unusually high (Bennion and Simpson, 2010). | BLT | 0.937 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Stephanodiscus parvus* | Stoermer et Håk. 1984 | HIGHLY EUTROPHIC (Bennion, 1994, Bennion et al., 1996) EUTROPHIC - MESOTROPHIC (Bennion et al., 2004) | 200.9 (highly eutrophic) | | BLT | 0.677 |
| | | | | | LGT | 3.39 |
| *Achnanthes divergens* | A.Cleve 1953 | | | | BFT | 5.36 |
| *Achnanthidium minutissimum (Achnanthes minutissima)* | (Kütz.) Czarnecki 1994 (Kütz. 1833) | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) OLIGOTROPHIC(Bennion et al., 2004, Bennion and Simpson, 2010) | 66.1 | Circumneutral species (Jones et al., 1993) | BFT | 46.5 |
| | | | | | BLT | 6.09 |
| | | | | | LLT | 8.76 |
| | | | | | LGT | 5.65 |
| *Amphora* sp. (undiff.) | Ehrenb. ex Kütz. 1840 | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | | | LLT | 0.974 |
| | | | | | LGT | 0.639 |
| *Asterionella* | Hassall 1855 | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) MESOTROPHIC (Bennion et al., 2004) MODERATELY EUTROPHIC (Hübener and Dörfler, 2002) | 152.8 | | BFT | 2.47 |
| | | | | | BLT | 2.38 |
| | | | | | LLT | 7.69 |
| | | | | | LGT | 6.56 |

| **GENUS/SPECIES (synonyms in brackets)** | **AUTHORITY** | **TROPHIC STATUS** | **TP OPTIMUM μgl$^{-1}$ (Bennion, 1994)** | **ANY ADDITIONAL INFORMATION** | **PRESENT AT** | **MAX % AT SITE (3s.f.)** |
|---|---|---|---|---|---|---|
| *Brachysira serians* | (Bréb. ex Kütz.) Round et D.G.Mann 1981 | OLIGOTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | BFT | 1.68 |
| | | | | | LLT | 0.443 |
| *Brachysira vitrea* | (Grunow) R.Ross in B.Hartley 1986 | OLIGOTROPHIC (Bennion et al., 2004, Bennion and Simpson, 2010) | | Circumneutral species (Jones et al., 1993) | BFT | 17.3 |
| | | | | | BLT | 6.32 |
| | | | | | LLT | 38.3 |
| *Caloneis bacillum* | (Grunow) Cleve 1894 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | BLT | 0.704 |
| | | | | | LGT | 0.213 |
| *Caloneis undulata (Pinnularia undulata)* | (Greg.) Krammer 1985 | | | | LLT | 7.16 |
| *Cavinula cocconeiformis (Navicula cocconeiformis)* | (Greg. ex Grev.) D.G.Mann et A.J. Stickle in Round et al. 1990 (Greg. ex Grev. 1855) | OLIGOTROPHIC (Denys, 1991-2) | | | BFT | 0.490 |
| | | | | | BLT | 0.703 |
| | | | | | LGT | 0.259 |
| *Cocconeis placentula* | Ehrenb. 1838 | EUTROPHIC - MESOTROPHIC (Denys, 1991-2, Bennion et al., 2004) | 89.9 | Typical of eutrophic conditions (Kelly and Whitton, 1995). | BFT | 0.699 |
| | | | | | BLT | 0.458 |
| | | | | | LLT | 0.476 |
| | | | | | LGT | 1.55 |
| *Cymbella aequilis* | W.Sm. ex Grev. 1855 | | | | LLT | 3.35 |

| **GENUS/SPECIES (synonyms in brackets)** | **AUTHORITY** | **TROPHIC STATUS** | **TP OPTIMUM µgl$^{-1}$ (Bennion, 1994)** | **ANY ADDITIONAL INFORMATION** | **PRESENT AT** | **MAX % AT SITE (3s.f.)** |
|---|---|---|---|---|---|---|
| *Cymbella affinis* | Kütz. 1844 | EUTROPHIC (Denys, 1991-2) | | Alkaliphilous (Denys, 1991-2) | BFT | 2.56 |
| | | | | | BLT | 2.13 |
| | | | | | LLT | 2.96 |
| | | | | | LGT | 0.426 |
| *Cymbella amphicephala* | Nägeli ex Kütz. 1849 | OLIGOTROPHIC (Denys, 1991-2) | | | BFT | 0.475 |
| | | | | | BLT | 0.703 |
| *Diatoma* spp. [*D. hymale* in this case] | Bory 1824 [(Roth) Heib. 1863] | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | | Alkaliphilous to Circumneutral (Denys, 1991-2) | BFT | 10.5 |
| | | | | | BLT | 0.677 |
| | | | | | LLT | 0.862 |
| | | | | | LGT | 0.0972 |
| *Encyonema silesiacum (Cymbella silesiaca)* | (Bleisch in Rabenh.) D.G.Mann in Round et al. 1990 (Bleisch in Rabenh. 1864) | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | BFT | 1.48 |
| | | | | | BLT | 1.13 |
| | | | | | LLT | 2.71 |
| *Epithemia sorex* | Kütz. 1844 | EUTROPHIC (Denys, 1991-2) | | | LGT | 0.493 |
| *Eunotia arcus* | Ehrenb. 1837 | OLIGOTROPHIC (Denys, 1991-2) | | Circumneutral to acidophilous (Denys, 1991-2) | BFT | 3.71 |
| | | | | | BLT | 1.41 |
| | | | | | LLT | 2.72 |
| *Eunotia bigibba (E. praerupta var. bigibba)* | Kütz. 1849 (Ehrenb. 1843) | MESOTROPHIC - OLIGOTROPHIC (Denys, 1991-2) | | | LLT | 0.494 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM µgl$^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Eunotia curvata (E. bilunaris, E. lunaris)* | (Kütz.) Lagerst. 1884 ((Ehrenb.) Mills 1934 (Ehrenb.) Grunow in van Huerck 1881) | MESOTROPHIC - OLIGOTROPHIC (Denys, 1991-2) | 65.6 | | BFT | 2.20 |
| | | | | | BLT | 1.17 |
| | | | | | LLT | 8.26 |
| | | | | | LGT | 0.518 |
| *Eunotia diodon* | Ehrenb. 1837 | OLIGOTROPHIC (Denys, 1991-2) | | | BLT | 0.915 |
| | | | | | LLT | 0.443 |
| | | | | | LGT | 0.253 |
| *Eunotia exigua* | A.Berg ex A.Cleve 1953 | OLIGOTROPHIC - DYSTROPHIC (Denys, 1991-2) | | Acidobiontic (van Dam, 1988) | BFT | 3.90 |
| *Eunotia incisa* | Greg. 1854 | | | Increase may signal increasing acidity (Flower et al., 1997) | BFT | 13.0 |
| | | | | | BLT | 3.28 |
| | | | | | LLT | 3.35 |
| *Eunotia monodon* | Ehrenb. 1843 | OLIGOTROPHIC (Denys, 1991-2) | | | BLT | 1.17 |
| | | | | | LLT | 0.936 |
| *Eunotia pectinalis* | (Dillwyn) Rabenh. 1864 | MESOTROPHIC - OLIGOTROPHIC (Denys, 1991-2) | 63.2 | | BFT | 24.8 |
| | | | | | BLT | 2.86 |
| *Eunotia pectinalis var. minor* | (Dillwyn) Rabenh. 1865 | MESOTROPHIC – OLIGOTROPHIC (Denys, 1991-2) | | Acidophilous (Denys, 1991-2) | BFT | 18.3 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Eunotia pectinalis var. ventricosa* | (Ehrenb.) Grunow 1881 | MESOTROPHIC - OLIGOTROPHIC (Denys, 1991-2) | | | LLT | 0.951 |
| *Eunotia praerupta var. inflata* | Grunow 1881 | MESOTROPHIC - OLIGOTROPHIC (Denys, 1991-2) | | | BLT | 0.468 |
| *Fragilaria capucina* | Desm. 1925 | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | 132.7 | | BFT | 12.2 |
| *Fragilaria crotonensis* | Kitton 1869 | MESOTROPHIC (Bennion et al., 2004) MILDLY EUTROPHIC (Hübener and Dörfler, 2002) | | | BFT | 4.71 |
| | | | | | LLT | 3.19 |
| *Fragilaria vaucheriae* | (Kütz.) Petersen 1938 | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | 100.5 | | BFT | 12.8 |
| *Fragilariforma bicapitata (Fragilaria bicapitata)* | (A.Meyer) D.M.Williams et Round 1988 (A. Meyer 1917) | MESOTROPHIC (Denys, 1991-2) | | | BFT | 1.40 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Frustulia rhomboides* | (Ehrenb.) De Toni 1891 | OLIGOTROPHIC - DYSTROPHIC (Denys, 1991-2) | | Acidobiontic (van Dam, 1988) | BFT | 2.19 |
| | | | | | BLT | 1.60 |
| | | | | | LLT | 19.2 |
| | | | | | LGT | 1.85 |
| *Gomphonema acuminatum var. brebissonii* | (Kütz.) Grunow in Van Heurck 1880 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | BFT | 0.496 |
| | | | | | BLT | 0.426 |
| *Gomphonema acuminatum var. coronatum* | (Ehrenb.) W.Sm. 1853 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | BLT | 0.937 |
| | | | | | LLT | 1.38 |
| | | | | | LGT | 0.319 |
| *Gomphonema gracile* | Ehrenb. 1838 | OLIGOTROPHIC (Denys, 1991-2) | | | BFT | 2.21 |
| | | | | | BLT | 0.257 |
| | | | | | LLT | 1.33 |
| | | | | | LGT | 0.425 |
| *Gomphonema parvulum* | (Kütz.) Kütz. 1849 | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | 138.4 | | BLT | 0.239 |
| *Gomphonema vibrio* | Ehrenb. 1843 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | | Tolerant to organic pollution (Kelly and Whitton, 1995) | BFT | 0.825 |
| *Gyrosygma acuminatum* | (Kütz.) Rabenh. 1853 | EUTROPHIC (Denys, 1991-2) | 104.2 | | LGT | 0.528 |

| **GENUS/SPECIES (synonyms in brackets)** | **AUTHORITY** | **TROPHIC STATUS** | **TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994)** | **ANY ADDITIONAL INFORMATION** | **PRESENT AT** | **MAX % AT SITE (3s.f.)** |
|---|---|---|---|---|---|---|
| *Navicula harderi* | Hust. 1949 | | | | BFT | 9.07 |
| *Navicula hoefleri* | Cholnoky in Cholnoky et Schindler 1953 | | | | BFT | 3.63 |
| *Navicula integra* | (W.Sm.) Ralfs | EUTROPHIC (Denys, 1991-2) | | | BFT | 1.68 |
| *Navicula krasskei* | Hust. 1930 | | | | BFT | 6.34 |
| *Navicula leptostriata* | E.G.Jørg. 1948 | | | | BFT | 4.15 |
| | | | | | BLT | 2.11 |
| | | | | | LLT | 2.58 |
| *Navicula medioconvexa* | Hust. 1961 | | | | BFT | 2.67 |
| *Navicula molestiformis* | Hust. 1949 | | | | BFT | 2.49 |
| *Navicula radiosa (N. radiosa var tenella)* | Kütz. 1844 (Bréb. ex. Kütz.) Grun. ex Van Heurck | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | 60.0<br>101.6 | | BFT | 1.24 |
| | | | | | BLT | 1.60 |
| | | | | | LLT | 2.62 |
| | | | | | LGT | 3.17 |
| *Navicula rhynchocephala* | Kütz. 1844 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | 107.9 | | BFT | 0.496 |
| | | | | | LLT | 0.195 |
| *Navicula soehrensis (N. hassiaca)* | Krasske 1923 (Krasske 1925) | OLIGOTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | LGT | 0.213 |

| **GENUS/SPECIES (synonyms in brackets)** | **AUTHORITY** | **TROPHIC STATUS** | **TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994)** | **ANY ADDITIONAL INFORMATION** | **PRESENT AT** | **MAX % AT SITE (3s.f.)** |
|---|---|---|---|---|---|---|
| *Navicula subtilissima (N. cumbriensis?)* | Cleve 1891 | | | Characteristic of humic waters – declines on acidification (van Dam, 1988) | BFT | 6.60 |
| | | | | | BLT | 6.40 |
| | | | | | LLT | 13.4 |
| | | | | | LGT | 4.66 |
| *Navicula tenuicephala* | Hust. 1949 | | | | BLT | 2.34 |
| *Neidium bisculcatum* | (Lagerst.) Cleve 1894 | OLIGOTROPHIC (Denys, 1991-2) | | | BFT | 0.559 |
| *Neidium iridis* | (Ehrenb.) Cleve 1894 | MESOTROPHIC (Denys, 1991-2) | | | BLT | 0.451 |
| *Nitzschia fonticola* | Grunow in Van Heurck 1881 | EUTROPHIC (Denys, 1991-2) | | Alkaliphilous (Denys, 1991-2) | BFT | 3.94 |
| *Nitzschia gracilis* | Hantzsch 1860 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | 78.3 | | BFT | 0.476 |
| | | | | | BLT | 0.677 |
| | | | | | LLT | 2.14 |
| *Nitzschia recta* | Hantzsch ex. Rabenh. 1861 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | 141.9 | | BFT | 0.476 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Nitzschia* sp. (undiff.) | Hassall 1845 | | 116.9 | Tolerant of organic pollution (Kelly and Whitton, 1995) | BFT | 0.492 |
| | | | | | BLT | 2.11 |
| | | | | | LLT | 2.96 |
| | | | | | LGT | 1.12 |
| *Peronia fibula* | (Bréb. ex.Kütz.) R.Ross 1956 | OLIGOTROPHIC (Denys, 1991-2) | | | BFT | 11.4 |
| | | | | | BLT | 6.32 |
| | | | | | LLT | 9.82 |
| | | | | | LGT | 0.253 |
| *Pinnularia interrupta (P. biceps)* | W.Sm. 1853 (Greg. 1856) | OLIGOTROPHIC (Denys, 1991-2) | | | BFT | 2.00 |
| | | | | | BLT | 1.43 |
| | | | | | LLT | 1.60 |
| | | | | | LGT | 0.213 |
| *Pinnularia microstauron* | (Ehrenb.) Cleve 1891 | OLIGOTROPHIC (Denys, 1991-2) | | | LGT | 0.748 |
| *Pinnularia rupestris* | Hantzsch in Rabenh. 1861 | | | | LLT | 3.35 |
| *Pinnularia subcapitata* | Greg. 1856 | OLIGOTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | BFT | 1.65 |
| *Pinnularia viridis* | (Nitzsch) Ehrenb. 1843 | MESOTROPHIC (Denys, 1991-2) | | | LLT | 2.13 |

| **GENUS/SPECIES (synonyms in brackets)** | **AUTHORITY** | **TROPHIC STATUS** | **TP OPTIMUM μgl$^{-1}$ (Bennion, 1994)** | **ANY ADDITIONAL INFORMATION** | **PRESENT AT** | **MAX % AT SITE (3s.f.)** |
|---|---|---|---|---|---|---|
| *Planothidium oestrupii (Achnanthes lanceolata)* | (A.Cleve) Round et L.Bukhtiyarova 1996 ((Bréb.) Grunow in Cleve et Grunow 1880) | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) HIGHLY EUTROPHIC (Bennion, 1994) | 254.7 | Found in rivers with high nutrient levels in England (Kelly and Whitton, 1995) | BFT | 0.518 |
| *Psammothidium marginulatum (Achnanthes marginulata)* | (Grunow) L.Bukhtiyarova et Round 1996 (Grunow in Cleve et Grunow 1880) | OLIGOTROPHIC (Denys, 1991-2) | | Acidophilous species (Jones et al., 1993) | BFT | 2.44 |
| | | | | | BLT | 3.39 |
| | | | | | LLT | 4.62 |
| *Pseudostaurosira brevistriata (Fragilaria brevistriata)* | (Grunow in Van Heurck) D.M.Williams et Round 1987 (Grunow in Van Heurck 1885) | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) MESOTROPHIC (Bennion et al., 2004) | 94.8 | | BFT | 10.2 |
| | | | | | BLT | 5.85 |
| | | | | | LLT | 9.75 |
| | | | | | LGT | 18.2 |
| *Rossithidium pusillum (Achnanthes pusilla)* | (Grunow) Round et L.Bukhtiyarova 1996 | OLIGOTROPHIC (Hübener and Dörfler, 2002) | | | BFT | 2.43 |
| | | | | | BLT | 2.52 |
| | | | | | LLT | 1.18 |
| | | | | | LGT | 2.34 |
| *Sellaphora pupula (Navicula pupula)* | (Kütz.) Mereschk. 1902 (Kütz. 1844) | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | 112.2 | *Sellaphora* are tolerant to organic pollution (Kelly and Whitton, 1995) | BFT | 1.46 |
| | | | | | BLT | 3.04 |
| | | | | | LLT | 0.741 |
| | | | | | LGT | 2.91 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Stauroneis anceps* | Ehrenb. 1843 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | LLT | 0.493 |
| *Stauroneis phoenicenteron* | (Nitzsch.) Ehrenb. 1843 | EUTROPHIC - DYSTROPHIC (Denys, 1991-2) | | | BLT | 0.234 |
| | | | | | LLT | 0.973 |
| | | | | | LGT | 0.350 |
| *Staurosira construens (Fragilaria construens)* | Ehrenb. 1843 F2136 ((Ehrenb.) Grunow 1862) | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | 97.9 | Alkaliphilous (Denys, 1991-2) | BFT | 11.7 |
| | | | | | BLT | 8.67 |
| | | | | | LLT | 13.4 |
| | | | | | LGT | 20.6 |
| *Staurosira construens var. binodis (Fragilaria construens var. binodis)* | (Ehrenb.) P.B.Hamilton in P.B.Hamilton et al. 1992 ((Ehrenb.) Grunow 1862) | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | 150.0 | Alkaliphilous (Denys, 1991-2) | BFT | 6.19 |
| | | | | | BLT | 9.55 |
| | | | | | LLT | 10.9 |
| | | | | | LGT | 3.70 |
| *Staurosira construens var. venter (Fragilaria construens var. venter)* | (Ehrenb.) P.B.Hamilton in P.B.Hamilton et al. 1992 ((Ehrenb.) Grunow in Van Heurck 1881) | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) MESOTROPHIC-EUTROPHIC (Bennion et al., 2004) | 71.1 | Alkaliphilous (Denys, 1991-2) | BFT | 6.86 |
| | | | | | BLT | 0.23 |
| | | | | | LGT | 0.700 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM µgl$^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Staurosirella pinnata (Fragilaria pinnata)* | (Ehrenb.) D.M.Williams et Round 1987 (Ehrenb. 1843) | EUTROPHIC (Denys, 1991-2) MESOTROPHIC - EUTROPHIC (Bennion et al., 2004) | 93.8 | | BFT | 1.55 |
| | | | | | BLT | 1.64 |
| | | | | | LLT | 0.461 |
| | | | | | LGT | 4.87 |
| *Surirella biseriata* | Bréb. in Bréb. et Godey 1835 | EUTROPHIC (Denys, 1991-2) | | | BFT | 0.731 |
| | | | | | LLT | 2.16 |
| | | | | | LGT | 0.389 |
| *Surirella linearis* | W.Sm. 1853 | MESOTROPHIC - OLIGOTROPHIC (Denys, 1991-2) | | | BFT | 0.951 |
| | | | | | LLT | 1.17 |
| *Synedra acus* | Kütz. 1844 | EUTROPHIC - MESOTROPHIC (Denys, 1991-2) | 148.9 | | LGT | 2.85 |
| *Synedra rumpens* | Kütz. 1844 | | 89.7 | | BLT | 1.49 |
| | | | | | LLT | 1.30 |
| | | | | | LGT | 2.45 |
| *Tabellaria flocculosa* | (Roth) Kütz. 1844 | OLIGOTROPHIC - DYSTROPHIC (Denys, 1991-2) OLIGOTROPHIC (Bennion et al., 2004, Bennion and Simpson, 2010) | 50.2 | Circumneutral species (Jones et al., 1993). Increase may signal increasing acidity (Flower et al., 1997). | BFT | 9.75 |
| | | | | | BLT | 5.16 |
| | | | | | LLT | 37.7 |
| | | | | | LGT | 2.78 |

| GENUS/SPECIES (synonyms in brackets) | AUTHORITY | TROPHIC STATUS | TP OPTIMUM $\mu gl^{-1}$ (Bennion, 1994) | ANY ADDITIONAL INFORMATION | PRESENT AT | MAX % AT SITE (3s.f.) |
|---|---|---|---|---|---|---|
| *Tabellaria quadriseptata* | Knudson 1952 | | | Found in strongly acidified environments (Flower et al., 1997). Acidobiontic species (Jones et al., 1993) | BFT | 2.47 |
| | | | | | BLT | 2.56 |
| | | | | | LLT | 10.7 |
| | | | | | LGT | 2.03 |

All diatoms for which useful ecological information was available have been included; types for which no data are available (or where data from two or more sources are conflicting) were only included for sites where they were present at a maximum value of 2% of more of the TDC. For example, *Caloneis undulata* was found at all of the sites, but is only present in significant quantities at LLT.

# APPENDIX 4: Sediment descriptions for all sites (following Troels-Smith, 1955)

The characteristics denoted by numbers 1-8 and the relevance of the associated scores are defined in Chapter 2, Section 2.2.1. The abbreviated names for components (under 'composition') are explained in Table 2.1 and follow Troels-Smith (1955). Brief sediment descriptions expressing only the salient points can be found in Chapter 4 and simplified lithologies are plotted alongside the age estimation figures for each site.

## Barfield Tarn (BFT):

115 (base of core)-93 cm:
1) 2
2) 0
3) 0
4) 2
5) 0
6) 5YR 3/2 dark reddish brown
7) Homogeneous
8) Arbitrary – base of core
Composition: $Ld^4$2 Ag2 Ga+ Dh+ Dg+

93-80 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 10YR 3/3, dark brown
7) Homogeneous
8) 1
Composition: $Ld^4$2 Ag2 Dg+ Dh+

80-62 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 5YR 3/2, dark reddish brown
7) Homogeneous
8) 1
Composition: $Ld^4$2 Ag1 As1 Ga+ Dg+ Dh+
Yellow clay band (As4) approximately 1 mm thick at 75 cm.

62-43 cm
1) 2
2) 1
3) 0
4) 2
5) 0
6) 7.5YR 3/2, brownish black
7) Homogeneous
8) 2
Composition: $Ld^4$1 As3 Ga+ Dg+

43-37.5 cm
1) 2
2) 1 (slight, discontinuous banding)
3) 0
4) 2
5) 0
6) 5YR 3/2, dark reddish brown
7) Homogeneous
8) 1
Composition: $Ld^{4}$2 As2 Dg+

37.5-35 cm
1) 1
2) 2
3) 0
4) 2
5) 0
6) 10YR 3/4, dark brown
7) Homogeneous
8) 2
Composition: As3 $Ld^{4}$1 Greasy clay.

35-33 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 5YR 3/1, brownish black
7) Homogeneous
8) 2
Composition: $Ld^{4}$2 As2 Ag+ Ga+

33-29.5 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 5YR 3/2, dark reddish brown
7) Homogeneous
8) 2
Composition: $Ld^{4}$2 As2 Ag+ Ga+

29.5-22 cm
1) 1
2) 1
3) 0
4) 2
5) 0
6) 10YR 3/4, dark brown
7) Homogeneous
8) 2
Composition: As3 $Ld^{4}$1

22-18.5/19 cm
1) 3
2) 0
3) 0
4) 2
5) 0
6) 5YR 1.7/1, black
7) Homogeneous
8) 3
Composition: $Ld^4$2 As1 Ag1 Ga+ Dg+

18.5/19-14.5 cm
1) 1
2) 1
3) 0
4) 2
5) 0
6) 7.5YR 3/4, dark brown
7) Homogeneous
8) 1
Composition: As3 $Ld^4$1

14.5-0 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 5YR 3/2, dark reddish brown
7) Slightly fibrous
8) 3
Composition: $Ld^4$2 As2 Ag+ Dg+

**Blelham Tarn (BLT):**
115- *c* 49 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 5YR 3/1 brownish black
7) Homogeneous
8) Arbitrary – base of core
Composition: $Ld^4$2 As2 Ag+ Ga+ Dg+ Dh+ (very infrequent - rootlets)

*c* 49-0 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 7.5YR 2/2, brownish black
7) Homogeneous
8) 0
Composition: $Ld^4$2 As2 Ag+ Ga+

**Burney Tarn (BYT):**
35-0 cm (base of core - undifferentiated)
1) 4
2) 0
3) 0
4) 2
5) 0
6) 10R 1.7/1, reddish black
7) Homogeneous
8) Arbitrary – base of core
Composition: Ag1 Dg1 As1 $Ld^4$1 Dh++ Greasy, peaty mud with lots of herbaceous fragments, reeds (*Phragmites communis*), etc.

**Burney Bog (BYB):**
70-28 cm (base of monolith)
1) 4
2) 0
3) 1
4) 1-2
5) 0
6) 7.5R 1.7/1, reddish black
7) Homogeneous, slightly fibrous
8) Arbitrary – base of monolith
Composition: Sh4 Dh+ Dg++ Dl+ Humified peat.
Humicity: 3 very humified…

28-9 cm
1) 3
2) 0
3) 3
4) 1
5) 0
6) 10R 1.7/1, reddish black
7) Fibrous
8) 1
Composition: Sh1 Th3 Slightly humified, fibrous peat.
Humicity: 1 slightly humified

9-0 cm
1) 1
2) 0
3) 4
4) 1
5) 0 N/A
6) 7.5YR 4/4, brown
7) Fibrous
8) 1
Composition: $Tb^0$3 $Th^0$1 $Tl^0$+ Unhumified *Sphagnum* peat, becoming mixed with fibrous, humified peat towards the base. Rare fragments of ericaceous roots.
Humicity: 0 – unhumified

## Little Langdale Tarn (LLT):

150-86 cm (base of core)
1) 2
2) 0
3) 0
4) 2
5) 0
6) 5YR 3/1, brownish black
7) Homogeneous
8) Arbitrary – base of core
Composition: $Ld^4$2 As2 Dg++ Dh++ Ag+ Ga+

86-74.5 cm
1) 1
2) 0
3) 0
4) 2
5) 0
6) 5YR 3/1, brownish black
7) Homogeneous
8) 0
Composition: $Ld^4$2 As2 Greasy clay-mud.

74.5-14 cm
1) 3
2) 0
3) 0
4) 2
5) 0
6)10R 1.7/1, reddish black
7) Homogeneous
8) 3
Composition: $Ld^4$2 As1 Ag1 Dg+ Dh+ Ga+ Far fewer plant remains than in overlying sediment.

14-0 cm
1) 3
2) 0
3) 0
4) 2
5) 0
6)10R 1.7/1, reddish black
7) Fibrous/homogeneous
8) 2
Composition: $Ld^4$1 As2 Dg1 Ag+ Dh++ Small herbaceous rootlets - ?aquatic.

## **Loughrigg Tarn (LGT):**

164-29 cm (base of core)
1) 2
2) 0
3) 0
4) 2
5) 0
6) 10R 1.7/1, reddish black
7) Homogeneous
8) Arbitrary – base of core
Composition: $Ld^4$2 As2 Ag+ Ga+

29-21 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 7.5YR 2/2, brownish black
7) Homogeneous
8) 0
Composition: $Ld^4$2 As2 Ag+

21-8.5 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 10YR 3/3, dark brown.  Darkens slowly on exposure to air.
7) Homogeneous
8) 0
Composition: $Ld^4$1 As2 Ag1 Ga+

8.5-5 cm
1) 1
2) 1
3) 0
4) 2
5) 0
6) 5Y 3/1, olive black.  Surface is mottled.
7) Homogeneous
8) 1
Composition: $Ld^4$1 As3 Ag+ Ga+

5-2 cm
1) 2
2) 0
3) 0
4) 2
5) 0
6) 5Y 3/1, olive black
7) Homogeneous
8) 1
Composition: $Ld^4$2 As2 Ag+ Ga+

**Tewet Tarn (TWT):**
77-72 cm (base of core)
1) 4
2) 0
3) 1
4) 2
5) 0
6) 10R 1.7/1, reddish black
7) Homogeneous
8) Arbitrary – base of core
Composition: $Ld^4$2 Ag1 As1 Dg+ Dh+ Dark, greasy, organic sediment.

72-68 cm
1) 1
2) 2
3) 0
4) 2
5) 0
6) 10YR 2/2, brownish black
7) Homogeneous
8) 2
Composition: As3 $Ld^4$1 Ga+ Clay.

68-64 cm
1) 2
2) 2 – slight laminations
3) 0
4) 2
5) 0
6) 10R 2/1, reddish black
7) Homogeneous
8) 2
Composition: As2 $Ld^4$2 Ga+ Dg+ Dh+ Organic clay – transitional between layers above and below.

64-29.5 cm
1) 4
2) 0
3) 0
4) 2
5) 0
6) 7.5YR 1.7/1, reddish black
7) Fibrous
8) 0
Composition: $Ld^4$1 Dh1 As2 Dg+ Ag+ Ga+ (large fragments of reed stems)

29.5-0 cm
1) 3
2) 0
3) 1
4) 2
5) 0
6) 10YR 1.7/1, reddish black
7) Homogeneous
8) 0
Composition: $Ld^4$2 As2 Ag+ Ga+ Dg+ Dh+ Greasy clay/mud.

APPENDIX 5:

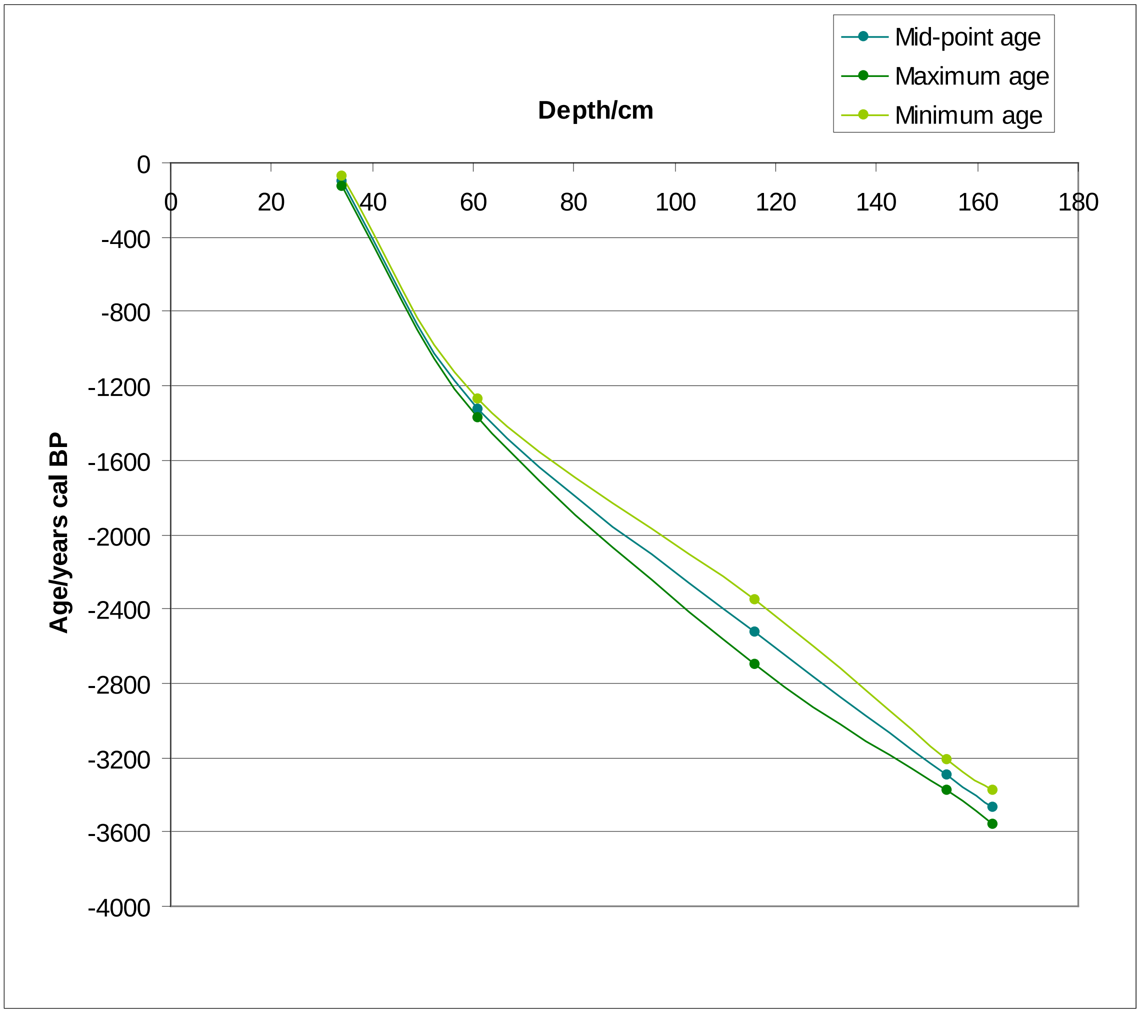



Figure 5A: Full age-depth model for LGT. This is based on all unreversed radiocarbon dates and the age derived from the base of the SCP curve (*c* 100 +/- 25 years BP, after Rose *et al.*, 1995).

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