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Sustainable Management of the Historic Environment Resource in Upland Peat: A Study from Exmoor

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SUSTAINABLE MANAGEMENT OF THE HISTORIC ENVIRONMENT RESOURCE IN UPLAND PEAT: A STUDY FROM EXMOOR

By

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ABSTRACT

Sustainable Management of the Historic Environment Resource in Upland Peat: A Study from Exmoor

Heather Joy Davies

UK uplands preserve a rich history of human inhabitation and environmental change through standing monuments, archaeological sites, and within peat deposits. Palaeoenvironmental remains within peat can be used to reconstruct environmental histories throughout the Holocene. Small mires in varied topographic locations can allow detailed local landscape reconstruction, setting archaeological sites in environmental context, or building up a picture of the mosaic of changing landscapes through time. Recent moves towards assessing the ecosystem services provided by different landscapes mean that, to make a case for preserving upland peatlands for the palaeoenvironmental remains they preserve, we must be able to demonstrate their archaeological potential or value. This project investigated methods for identifying the extent of this 'hidden' resource, as well for assessing its current condition and historic environment value, through the case study of valley, spring and soligenous mires on Exmoor. The lack of known archaeological or material culture remains from upland peatlands in the UK and on Exmoor means that the project focussed solely on the palaeoenvironmental resource. The methods used combined desk-based survey and spatially-extensive walkover survey to assess the overall extent and condition of the palaeoenvironmental resource in mires across Exmoor. Alongside this, a site-based programme of water-table monitoring and coring was undertaken to look at the effects of recent land management practices on the condition of this resource. The results demonstrated that walkover survey and peat depth probing were necessary to define the spatial extent and depth of mires, and assess mire condition. A standardised key was developed to allow the baseline mire condition survey to be repeated. The site-based study demonstrated the negative impact of water-table draw-down on the condition of palaeoenvironmental remains. However, it also demonstrated that a multiproxy approach is necessary to allow the complex palimpsest of the effects of human impact, climate change, and recent damage to mires, to be disentangled. The results of both levels of survey fed into the development of a flexible heritage valuation system for the palaeoenvironmental resource, which highlighted mires with high-potential for future investigation, whilst indicating mires which will require management intervention to prevent further losses to the resource. The datasets provided by this project will be used to identify palaeoenvironmental sampling locations for future archaeological investigations and allow heritage managers to make active contributions to the selection of sites for mire restoration. It provides a baseline survey against which future mire condition monitoring can be compared and which can be extended to other regions. It also offers a dataset against which to test or ‘ground-truth’ new methods for identifying the extent and condition of peatlands using remote-sensed data.

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LIST OF ABBREVIATIONS

AHAHI	Area of Exceptional Archaeological and Historical Importance
ANOVA	Analysis of variance
AP	Aerial photograph
BADC	British Atmospheric Data Centre
CASI	Compact Airborne Spectrographic Imaging
CRoW	Countryside and Rights of Way
DCA	Detrended correspondence analysis
DCMS	Department for Culture, Media and Sport
DEFRA	Department for Environment, Food and Rural Affairs
DoE	Department of the Environment
EH	English Heritage
EIA	Environmental Impact Assessment
EN	English Nature *(now Natural England)*
ENP RF	Exmoor National Park Archaeological Research Framework
ENPA	Exmoor National Park Authority
GIS	Geographical Information System
GWR	Great Western Research
HELM	Historic Environment Local Management
HER	Historic Environment Record
HFA	Hill Farm Allowance
HMSO	Her Majesty's Stationery Office
JNCC	Joint Nature Conservation Committee
LiDAR	Light Detection and Ranging
LFA	Less Favoured Areas
LOI	Loss on ignition
Lpaz	Local pollen assemblage zone

LPPZ	Local pollen preservation zone
LTZ	Local testate amoebae zone
MAFF	Ministry of Agriculture, Fisheries and Farming
MAREW	Monuments at Risk in England's Wetlands
MARSIP	Monuments at Risk in Somerset's Peatlands
NE	Natural England
NIR	Near infrared radiation
NNR	National Nature Reserve
PCA	Principle components analysis
PPG	Planning and policy guidance
PPS	Planning and policy statement
RIGS	Regionally Important Geological Sites
RPZ	Regional pollen zone
RSAP	Relevant Source Area for Pollen
SAC	Special Area for Conservation
SAM	Scheduled Ancient Monument
SSSI	Site of Special Scientific Interest
SWARF	South West Archaeological Research Framework
TW	Taxon-weighted

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CHAPTER 1: INTRODUCTION

1.1. Project Rationale

Upland landscapes preserve a rich archaeological heritage, retaining physical traces of the ways in which societies from prehistory to modern times have inhabited their local landscapes (Darvill 1986; Simmons 2003). Rather than areas of untouched wilderness, the uplands that we engage with today are predominantly cultural artefacts which reflect this long and varied use over the last 5000-8000 years. Highly visible and impressive archaeological sites such as stone circles and rows, burial mounds or prehistoric field systems sit at the forefront of the public perception of upland archaeology in the UK, but these sites have provided longstanding difficulties for archaeologist: few excavations have taken place; little dateable material has been discovered through excavation (e,g, Fyfe and Greeves 2010; Gillings *et al.* 2010); and the functions or understandings of these sites remains difficult to access (e.g. Burl 2005; Tilley 2010). Palaeoenvironmental reconstructions of past upland landscapes from sampled peat deposits have therefore provided an important tool for providing context to human land use in upland areas (Simmons 2003). Upland peatlands preserve a record of changing landscapes, climate and society-environment interactions over the last 10,000 years. In contrast to lakes or large ombrotrophic mires, smaller valley, soligenous, and spring mires preserve local records of environmental change (e.g. Jacobson and Bradshaw 1981; Fyfe *et al.* 2003a; Davies and Tipping 2004). Their varied size and topographic positioning in the landscape allows mosaics of upland land-use to be reconstructed. Finally, they are often found in close proximity to archaeological sites, enabling archaeologically-relevant narratives of vegetation change to be described (e.g. Dumayne-Peaty and Barber 1998; Fyfe *et al.* 2008; Verrill and Tipping 2010). Although there are some archaeological material culture remains from upland peatlands in UK (Gearey *et al.* 2010), the low numbers of known sites and finds means that this project focuses on the palaeoenvironmental resource, using the case study of valley, spring and soligenous mires on Exmoor.

The heritage value of peatlands has been highlighted through a number of large-scale archaeological investigations which have included extensive palaeoenvironmental assessment programmes (e.g. The English Heritage lowland wetlands projects: Minnitt and Coles 1996; Van de Noort and Ellis 2000; Pryor 2001; Hodgkinson *et al*. 2001). However, the drivers for these projects – primarily damage to peat caused by urban development, intensive arable agriculture and industrial peat extraction – mean they have focussed on lowland rather than upland areas of the UK. Despite the great potential of the palaeoenvironmental resource preserved in upland peatlands for environmental reconstruction (demonstrated by numerous small-scale and *ad hoc* research projects), until recently, there have been few drivers and little funding for large scale archaeological investigations of peatlands in these areas. However, spatially-extensive peatland restoration projects, underway in upland areas across Britain (DEFRA 2008; Lindsay 2010), have brought the need to assess the historic environment value of upland peatlands to the attention of archaeologists and historic environment managers. Extensive moorland drainage (or 'gripping') and peat cutting has taken place across UK uplands, largely during the last century, causing peatland erosion and water-table draw-down (Holden et al. 2007). These restoration projects have targeted damaged upland peatlands with the explicit aims of restoring peatland ecosystems and hydrological function, reducing sediment and carbon loss, and restoring the function of peatlands as carbon sinks (Worrall *et al.* 2003; Evans 2005; Holden *et al.* 2007; Lindsay *et al.* 2010). Although the aims of restoration projects are often in harmony with archaeological interests (e.g. rewetting and maintenance of high water tables: Coles 1995), they have highlighted a number of problems that archaeology increasingly faces: firstly, that a resource or 'asset' (be it archaeological or palaeoenvironmental) (DCMS 2010) must be defined in terms of its extent and baseline condition for it to be protected or managed sustainably; and secondly, the increasing focus in policy-making on the ecosystem services that a landscape can provide (Costanza 2002; Bonn *et al.* 2009) means that setting priorities for conservation, or valuation of mires, from a *heritage perspective* is important.

If we consider palaeoenvironmental remains as a distinct category - aside from artefacts or structures beneath, within, or on the surface of peatlands – we encounter a number of problems when we consider how to sustainably manage the palaeoenvironmental resource within upland peat. Firstly, the extent and condition of the palaeoenvironmental resource within peatlands is largely unknown. Projects to assess the area covered by peat and peat depth, have taken place in some regions (e.g. Merryfield [1977] and Bowes [2006] in Exmoor; Fyfe *et al.* [2010] and Parry [2011] in Dartmoor; and The English Heritage Upland Peat Project in North-West England: Quartermine *et al.* [2007]). However, these projects are either rare or small-scale, due to their labour-intensive nature, or may be too low-resolution to detect smaller mires, which have particular value for local landscape reconstruction (see above). Attempts to model peatland extent mathematically based on topography (e.g. Parry 2011) may also not be sensitive enough to detect these smaller mires. Carver (1996, 52) identifies a paradox in the management of the historic environment, that whilst "...the point of archaeology is to know more; the resource on which it depends is managed so as to favour what is already known". This is an even more acute problem for peatland archaeology and palaeoecology, as the resource in question is, by its very nature, held within or sealed beneath peat deposits and therefore 'hidden' from view. This has resulted in the often frustrating problem of having to argue for the historic environmental *potential*, rather than clearly defined and audited assets, within upland peat: what could be termed 'known unknowns'. A system for identifying and cataloguing mires, and assessing the condition of the palaeoenvironmental resource, is clearly necessary.

Secondly, there are no established methodologies for assessing the heritage value of sites or locations which *only* preserve palaeoenvironmental remains. In effect, our inability to point to tangible archaeological (or material culture) remains within upland peat has resulted in a situation whereby there is no system for resource assessment on the basis of its palaeoenvironmental potential or value (as opposed to its biodiversity, geological or hydrological values). Recent heritage protection guidelines promote the integration of archaeological and palaeoenvironmental research (English Heritage [EH] 2010), and suggest that locations which preserve palaeoenvironmental remains should be viewed as heritage 'assets' (Department of Culture, Media and Sport [DCMS] 2010). These guidelines press us to consider on what basis we could value the palaeoenvironmental resource within peatlands. How do we determine which mires contain the palaeoenvironmental remains that are most useful or important to archaeology? The spatial distribution and size of mires, their location in relation to known archaeological sites, and the potential of peat within mire to preserve a high resolution and intact, representative, or undamaged record of the past environment, are all important factors to consider in addressing this question.

Thirdly, because we have had difficulty in defining the heritage value of palaeoenvironmental sites which preserve no known material cultural remains, we are unable to protect these sites. Peatlands are not covered by legislation to protect the historic environment, as this was designed primarily with standing monuments or excavated sites in mind (i.e. the Ancient Monument and Archaeological Areas Act: HMSO 1979). This problem is compounded by the fact that palaeoenvironmental sites sampled for research projects are often not recorded in local Historic Environment Records (HERs), particularly if no archaeological remains were discovered. Furthermore, many smaller peatland sites (such as small upland mires) may be considered too small or not significant enough for protection under either the Ramsar Convention (1971) guidelines (Coles 2001), or other environmental designations (e.g. National Nature Reserves [NNRs] or Sites of Special Scientific Interest [SSSIs]). Thus small upland peatlands tend to fall through both heritage and environmental protection ‘nets’.

The sustainable management of the palaeoenvironmental resource in upland peat will rely on our ability to assess the extent, condition, and heritage value of this resource. Clear communication of the results of such assessments to different stakeholder groups should facilitate both future archaeological and palaeoenvironmental research and the development of measures to protect the resource.

1.2. Project aims

(i) To define the extent and condition of the palaeoenvironmental resource in uplands

(ii) To assess the potential heritage value of the palaeoenvironmental resource

(iii) To develop a flexible valuation system for the palaeoenvironmental resource

1.3. Project objectives

The aims above are deliberately broad, as the results of this project may have wide applicability for peatlands, particularly in upland or moorland areas, across Northern Europe. These aims will be explored through a case study based on Exmoor in Southwest England, and will be fulfilled through seven major objectives:

(i) to undertake spatially extensive survey of Exmoor's moorland to define the extent of peat (in terms of spatial extent of mires and depth of peat) in valley, spring and soligenous mires;

(ii) to define the condition of mires identified through spatially-extensive survey in terms of threats or damage to the integrity of the peat, and the condition of the peat matrix;

(iii) to assess the effects of both precipitation and visible damage features (i.e. peat cutting and drainage ditches) on the vertical and horizontal extent of water-table draw-down in upland mires;

(iv) to assess the condition of palaeoenvironmental remains within upland mires;

(v) to assess the relative importance of modern water-table draw-down and the effects of climate and human impacts through time on the condition of palaeoenvironmental remains;

(vi) to describe the preservation conditions within the peat matrix;

(vii) to develop a system for assessing the palaeoenvironmental potential, or value to archaeology, of upland mires.

1.4. Thesis outline

This chapter has provided a general introduction to the project, as well as outlined its aims and objectives. Chapter 2 includes review of a number of topics touched on by the research including: research in peatland archaeology and palaeoecology focussing on upland areas of the UK; outlines of the physical and chemical properties of peat; an overview of the components of palaeoenvironental resource; discussions of the conservation, management, assessment and valuation of the archaeological and palaeoenvironmental resource in the UK; and an introduction to the Exmoor study area. The following chapter (3) describes the methodological approach and procedures employed in carrying out the research. Chapters 4 to 6 present the results of the research: chapter 4 presents the results of the spatially-extensive survey; chapter 5 presents the result of the intensive site-based study; whilst chapter 6 focuses on analysing the effects of water-table draw-down and other environmental factors through time on the condition of the palaeoenvironmental resource. The major findings and implications of these results are discussed in chapter 7, and chapter 8 presents conclusions drawn from the research, as well as suggestions for further work.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter provides and introduction to a number of research areas that are encompassed by this project. It begins with a brief overview of peatland archaeology, before moving on to introduce upland peatlands as the focus of this study. The following sections introduce the properties of peat, and the palaeoenvironmental remains which may be preserved within peat profiles, as well as describing a number of threats to the preservation of these remains within upland peat. Finally, a case study of Exmoor includes background to the current project, as well an overview of previous archaeological and palaeoenvironmental research in the region.

2.2. Introduction to the palaeoenvironmental resource

2.2.1. Peat and archaeology

From the 19th century discoveries of preserved wooden piles, baskets and other organic material at the "Swiss lake village" sites (Keller and Lee 1886), to Bulleid and Greys' excavations at Glastonbury (Clarke 1972; Coles *et al.* 1992), to the Coppergate excavations in York (Hall 1984), the potential of waterlogged and anaerobic conditions to preserve biodegradable materials and artefacts has long been clear. In most cases, wetland archaeology has focussed on the potential of artefacts preserved in wetland sites to give us an insight into the everyday lives of people in the past, which would not be accessible through dry land archaeology (Van de Noort and O'Sullivan 2006). Owing to their particular environmental conditions, peatlands have preserved a long list of visually striking archaeological sites, including Nydam and Hjortspring boats in Danish raised bogs (McGrail 2004), and the Sweet Track (Brunning *et al.* 2000). Developments in landscape archaeology mean that, in terms of both archaeological research and management, monuments no longer tend to be considered as isolated features of interest imposed on a landscape ‘backdrop’. Rather, the landscape context of a monument is integral to its meaning or significance (Edmonds 1999; Thomas 2001). Furthermore, the landscape as a whole (including manmade features) is often seen as developing recursively with the human societies which inhabit it: as people ‘create’ the landscape, so the landscape ‘creates’ their social identities (Barrett 1999). As a result, archaeological research increasingly attempts to link small-scale human action to patterns of social practice and wider environmental changes (Brück 1999; Ralston 1999; Edmonds 1999, 2004). Palaeoecology is one of a number of techniques used to examine the ways in which past peoples inhabited landscapes.

Peatlands provide unusual and important sediments of scientific importance, for example in reconstructing palaeoclimates and palaeoenvironments (Barber, 1981; Charman 1994; Cox 1995; Charman, 2002). They are also a potential source of preserved archaeological remains due to their anaerobic, waterlogged conditions (Coles and Coles, 1986; Coles 1995; Fyfe and Greeves 2010), and can preserve earthwork evidence of past human exploitation of the landscape, such as peat cutting (Charman 1994; Newman 2010). Over the past 50 years the peatland palaeoenvironmental record has provided great insights into the development of upland landscapes, their function for past societies, and the complex interrelationships between people and their environment (Simmons 2003). The role of peatlands with regard to heritage is increasingly being recognised; for example, the International Union for the Conservation of Nature’s review of peatlands within the UK took the Historic Environment into consideration (Gearey *et al.* 2010). A whole suite of palaeoenvironmental remains (including pollen, plant macrofossils, testate amoebae, chironomids) is now used by archaeologists to reconstruct past environments at a range of chronological and spatial scales (Charman 2002; Bell and Walker 2005). These have provided proxies for past climate (Charman 2002; Amesbury *et al.* 2008), as well as giving insights into the effects of land management practice and changing climate on upland vegetation change (e.g. Chambers *et al.* 1999; 2007). Furthermore, it can be argued that these palaeoenvironmental archives are unique in offering data on long-term sustainability of practice across fields such as nature conservation and the management of the historic environment resource (Chambers *et al*. 1999; 2007; Louwe Kooijmans 1995).

It has often been through the destruction of the peatlands of northern Europe that the archaeological potential of these areas has emerged. The discoveries of 'bog bodies' by peat cutters, and sites such as Flag Fen (Pryor 2001) in the wake of agricultural improvement and urban development, have shown that peatland areas are a rich source of archaeological evidence, but also a fragile one. The past exploitation of peat for fuel, and the drainage of peatlands to improve grazing, is preserved in the patterns of peat cuttings and drainage ditches visible today. These scars also remind us that in some areas peat cutting is still occurring, and that the effects of past peat cutting, drainage and overgrazing, means that the condition of many peatlands is poor or declining (e.g. Thorne Moors: Buckland et al. 1994). Changing environmental policy (Hanley *et al.* 2006) and climate change projections (e.g. Murphy *et al.* 2009) have brought the protection of peatlands to forefront of environmental policy (Holden *et al.* 2007; Lindsay 2010).

2.2.2. Focus on uplands

The term 'upland' is one which many have found a challenge to define (Bonn *et al*. 2009). For land management purposes, the definition of upland areas in the UK has been based on a number of factors including: particular habitats (e.g. heather moorland); altitude; or socio-economic designations, such as Less Favoured Areas (LFAs), a term which encompasses areas with a harsher climate, poorer soil, and a shorter growing season then lowland areas (Natural England [NE] 2001; Bonn *et al.* 2009). However, definition by altitude can also vary by region, even within the UK; particularly if we contrast the altitude, climate and expose of mountainous areas such as Snowdonia, with the lower elevations and milder climate of upland areas in Southwest England (Exmoor, Dartmoor, and

Bodmin Moor). The openness, lack of current inhabitation, proliferation and visibility of archaeological monuments, and perceived marginality of British uplands mean that they have also been set apart from lowland areas, both in public perception and academic studies (Darvill 1986). However, studies of upland settlement, palaeocology, and palaeoclimates, have begun to suggest that the perception of upland areas as marginal cannot be uncritically projected onto the past (e.g. Coles and Mills 1998; Winchester 2000; Tipping 2002; Altenberg 2003; Amesbury *et al*. 2008; Davies 2007; Horning 2007). Postmodern discourse has led numerous authors to question the way archaeologists project their own concepts of upland marginality – based on an economic or functionalist view of uplands as unproductive or barren (Winchester 1987; Bailey 1989; Dyer 1989); or a romantic view of uplands as idealised, picturesque 'wilderness' (Simmons 2003; Edmonds 2004) – onto past peoples (Bender 1999; Thomas 2001). This process of deconstruction, has led to a routine questioning among archaeologists of whether or not people in the past would have shared our perceptions of areas that we might consider 'marginal'. On the simplest level this could involve the consideration of what resources upland areas might offer (e.g. mineral resources: Winchester 2000). On a more complex level, this might involve trying to decipher, from a multiplicity of sources (art, literature, settlement patterns, land use patterns, etc), how uplands fitted into the world-view of past communities, and how their inhabitation perpetuated these views (Altenberg 2003). Reconstruction of palaeoenvironments can 'add another layer' to our interpretations of how uplands were used and perceived in the past. For example, in the Mesolithic, when both uplands and lowlands were largely wooded, the distinction between higher and lower ground may have been less perceptible than today (Caseldine 1999).

The argument that that 'upland' and 'lowland' may not have been seen as separate classifications of landscape in the past, particularly if patterns of vegetation or land-use were very different to today, could indicate that that categorising landscapes in this way may be inappropriate. However, divergent management regimes in the modern period and differing threats to the archaeological record between uplands and lowlands has resulted in different approaches to research in these areas (Darvill 1986). This means that our knowledge of peatland archaeology and the palaeoenvironmental archive differs markedly between upland and lowland areas, justifying a separate approach to these landscape types. Furthermore, the use of this distinction is supported by the separation of upland and lowland peat in a number of English Heritage research framework and planning documents (e.g. Darvill 1987; Van de Noort *et al.* 2002; Webster 2008; Davies 2009).

2.2.2.1. Heritage values of upland peat

Upland landscapes preserve a rich archaeological heritage, retaining physical traces of the ways in which societies from prehistory to modern times have inhabited their local landscapes (Darvill 1986; Simmons 2003). Rather than areas of untouched wilderness, the uplands that we engage with today are predominantly cultural artefacts which reflect this long and varied use over the last 5000-8000 years. Highly visible and impressive archaeological sites such as stone circles and rows, burial mounds or prehistoric field systems sit at the forefront of the public perception of upland archaeology, but these sites have provided longstanding difficulties for archaeologist: few excavations have taken place; little dateable material has been discovered through excavation; and the functions or understandings of these sites remains difficult to access (e,g, Fyfe and Greeves 2010; Gillings *et al.* 2010). Palaeoenvironmental reconstructions of past upland landscapes from sampled peat deposits have therefore provided an important tool for providing context to human land use in upland areas (Simmons 2003). Upland peatlands preserve a record of changing landscapes, climate and society-environment interactions over the last 10,000 years. In contrast to lakes or large ombrotrophic mires, small peatlands preserve local records of environmental change (e.g. Jacobson and Bradshaw 1981; Fyfe *et al.* 2003a; Davies and Tipping 2004). Their varied topographic positioning in the landscape allows mosaics of upland land-use to be reconstructed. Furthermore, they are often found in close proximity to archaeological sites, enabling archaeologically-relevant narratives of vegetation change to be described (e.g. Fyfe *et al.* 2008).

The relative lack of development and large-scale or industrial peat cutting in upland areas means that few archaeological sites have been discovered in upland peat. All significant finds from lowland peatlands have been a direct consequence of extraction or drainage of peat: actions which damage peatlands also tend to lead to archaeological discoveries. The locations of the many major research projects in the lowlands have been determined by these threats. For example, the Somerset Levels Project (e.g. Coles and Coles 1982, 1996; Minnitt and Coles 1996); the East Anglian Fens projects (e.g. Hall and Coles 1994; Crowson *et al.* 2000; Pryor 2001); the Humber Wetlands Projects (e.g. Van de Noort and Ellis 1995; 1997; 2000); and the North-West Wetlands Projects (e.g. Middleton *et al.* 1995; 2001, Hodgkinson *et al*. 2001). These have often led to important archaeological discoveries, such as the Sweet Track and Flag Fen (Coles and Coles, 1986; Pryor, 2001). The difficulty of identifying new archaeological sites within peat without development activity or extensive excavation are well-illustrated by the North West Wetlands Project, which failed to locate any previously unknown archaeological sites (e.g. Middleton *et al.*1995; 2001).

Both antiquarian and more recent accounts show that upland peat has yielded a number of isolated finds through time, including oak bowls, bronze lance-heads, rapiers and a stone axe head from Dartmoor (Crossing 1909; Burnard 1894; Butler 1997), a wooden bow from Rotten Bottom in Dumfries and Galloway (Sheridan, 1999), and a Late Bronze Age hoards discovered in 1995 at Corrymuckloch, Perthshire (Cowie *et al.* 1996). Buried archaeological sites are less commonly found in the uplands, although sites extending beneath peat deposits that accumulated after the site's period of use have been discovered; recent examples include the Cut Hill stone row on Dartmoor (Fyfe and

Greeves 2010) and cairnfields in North-West England, identified during work on the Upland Peat Project (Quartermaine *et al.* 2007). Estimates of the number of archaeological sites within peatlands have only been made from areas of lowland peat, where large excavations have provided a clear evidence base for these analyses (Van de Noort *et al.* 2002). In upland areas such as Exmoor, where few or no archaeological sites or finds have been recorded within peat, a claim that any *individual* peatland site has the potential to preserve archaeological material culture remains would be difficult to justify or test.

The lack of developer-led projects in uplands has meant that research in these areas has tended to focus on palaeoenvironmental reconstruction, which has been wide-ranging in many parts of the UK. For example, studies include: Simmons (1969) and Caseldine and Hatton (1994) on Dartmoor; Skinner and Brown (1999), Chiverell (2001) and Coombes *et al.* (2009) in Cumbria; Davies and Tipping (2004) in Northern Scotland; Merryfield and Moore (1984), Francis and Slater (1990; 1992), and Fyfe *et al.* (2003) on Exmoor; Tallis (1964) in the Pennines; and Gearey *et al.* (2000) on Bodmin Moor. Also, recent studies of earthworks of peat cutting can also give us an insight into past domestic or industrial use of peat, providing an additional 'layer' of archaeological value (e.g. Newman 2010).

2.2.2.2. Socio-economic and ecological values of upland peat

In the recent past, upland peatlands were primarily seen as a source of fuel. Peat cutting, on both an industrial-scale and for domestic use, has declined over the last century. Peatlands have also been used for agriculture, and in many cases extensively drained for the purpose. Many upland areas saw moorland drainage, or 'gripping', in the second half of the 20th century to expand areas suitable for grazing (Holden *et al.* 2007). The conservation and study of upland peatlands has most commonly been seen as the preserve of ecologists, who view peatlands as habitats for rare species or communities

(Cox 1995). However, peatlands are valued for other ecosystem services they provide, including: hydrological benefits such as flood, erosion, and pollution control (Holden *et al.* 2007; ENPA 2008; Bonn *et* al. 2009; Reed *et al.* 2009); acting as carbon sinks which could be used to offset our carbon emissions (Lindsay 2010; Worrall *et al.* 2003); and providing an attraction to tourists and a source of creative inspiration, owing to the part they play in creating a wild and open aesthetic in moorland areas (Daly 1994; ENPA 2007). A number of peatland restoration projects have taken place over the last decade, with the explicit aims of restoring ecosystems, reducing sediment loss, and restoring peatland hydrological function (Evans 2005; Holden *et al.* 2007; ENPA 2008). These projects demonstrate the socio-economic values placed on peatlands by a number of interest groups.

A key point to emphasise, when contrasting archaeological with other socioeconomic or ecological views of peatland, are their fundamentally different perception of restoration projects: if the major values of a peatland rest on its important vegetation communities, or ability to accumulate peat (and therefore sequester carbon) or reduce rapid water-runoff, then restoration of these functions after damage to the peatland is possible. In contrast, the archaeological and palaeoenvironmental remains retained within peat may be a finite resource, which, once lost, cannot be restored (e.g. Cox 1995; Coles 2001). This does not mean that restoration projects have no benefit to archaeology, as they can potentially improve preservation conditions and prevent erosion by blocking drainage and slowing groundwater runoff. This could prevent further losses to the palaeoenvironmental/archaeological resource. However, in the interest of preserving peat stratigraphy, the removal and relocation of peat to create dams should be minimised or carefully recorded.

2.3. Defining the palaeoenvironmental resource

2.3.1. Peatland formation processes

2.3.1.1. Peat inception and accumulation

Peat is essentially an organic sediment, formed by the build-up of partially decayed organic material in waterlogged conditions. Peat often has very high water content, but most definitions state that at least 65% of its dry mass should be composed of organic matter (Clymo 1983). The minimum depth of peat is not agreed upon between publications, but is generally around 40cm (Evans and Warburton 2007). The definition of a 'peat soil' used by the British Geological Survey states that it must be at least 40% organic and be 'decimetres' thick (Burton and Hodgson 1987). Peat begins to form when organic productivity exceeds decay, due to waterlogged and therefore anaerobic conditions, which reduce the rate of decay of organic matter. This means that water input to a site must be higher than output, owing to high rainfall or impeded drainage. Low temperatures and the presence of acid-loving bryophytes, primarily *Sphagnums*, which also act to reduce the pH at the peat surface, further reduce the actions of microbes and allow layers of vegetation to accumulate (Charman 2002). Peat only begins to form when a number of thresholds are crossed: **a.** there must be sufficient precipitation or groundwater supply to enable plant growth and allow areas to be waterlogged for part or all of the year; **b.** the temperature must be high enough to allow sufficient plant growth but low enough to limit evapotranspiration and maintain waterlogged conditions (Charman 2002); **c.** either the underlying geological substrate needs to be relatively impermeable, or impermeable layers must have formed in underlying soils (such as 'iron pan' in podzolized soils: Limbrey 1975) to prevent water from draining away; and **d.** the gradient of the formation site must be relatively shallow, to allow collection of water or restrict the runoff of water. These conditions may be caused by climatic change (e.g. increased precipitation), human impact (e.g. forest clearance: Moore 1993; Caseldine and Hatton

1994), chance events (such as falling trees), or the action of mammals to impede drainage (e.g. beavers: Coles 2006).

The variety of definitions of peat makes quantifying the global extent of peatlands difficult. The majority of peatlands are found in temperate zones, where the climate is relatively cold and wet. However, peatlands may also be found in tropical areas, where high rainfall and high primary productivity facilitate peat formation (Charman 2001). There has been relatively little research into the causes of increased plant productivity, which is controlled by a complex interdependence of a variety of factors, such as plant species, temperature, or the level of nutrients supplied (e.g. groundwater-fed mires are often more nutrient rich: Wheeler and Proctor 2000). However, in most cases, the driver for peat accumulation appears to be unusually low rates of decay, rather than the production of a high level of organic matter at the surface (Clymo 1992). Thus, more research has taken place into the way in which decay rates control the accumulation and level of humification of peat deposits (e.g. Belyea and Clymo 2001; Frolking *et al*. 2001).

2.3.1.2. Decay rates in peat

In discussing decay rates in peat, the majority of studies divide the peat profile into two layers: the *acrotelm* and the *catotelm* (e.g. Ingram 1978; Clymo 1983, 1992). The acrotelm is the the layer nearest to the surface, and can be defined as the area within which the water-table fluctuates on an annual basis (Ingram 1978). Decay rates are more rapid in this layer then in the catotelm, it has lower bulk density, and water can often flow more rapidly through it. The boundary between the acrotelm and the catotelm can often be difficult to define visually from the peat profile, but may be marked by an increase in bulk density (Charman 2002). The decline in the decay rates from the acrotelm to the catotelm facilitates the growth of peat sequences (Clymo 1983; Charman 2002). This means that mire surface wetness, and particularly the lowest level of the water-table (typically in summer), controls the level of peat humification at the peat surface, as layers of peat above the water-table are oxygenated and experience higher rates of breakdown by aerobic microbes (*ibid.*). Hence, in drier summers, peat formed at the surface of a mire is more humified, and the peat accumulation rate is lower. Humification stratigraphy can therefore be seen as a proxy record of mire palaeohydrology (Chiverell 2001).

Changes in temperature, pH, microbial population, and plant material also influence the rate of decay or organic matter. Allogenic factors, such as sediment influx, artificial lowering of water-tables due to drainage, and fire, can also alter decay rate of organics near the surface of the peat (Belyea and Warner 1996). This means that a variety of factors, including those caused by climate change and human impact can alter decay rates in peat. Current decay rates can be monitored directly or indirectly using a number of methods. These include: monitoring the weight loss of litter bags (Bragazza *et al.* 2007) or the loss of weight or tensile strength of cotton strips (Harrison *et al.* 1988; Doyle and Dowding 1990) placed at different levels in the peat profile; or monitoring the rates of carbon dioxide (or methane) release from the peat, for example as dissolved organic carbon in watercourses (Charman 2002; Worrall *et al.* 2002). Although alteration in decay rates through time can be identified through measuring changes in humification throughout the peat profile, the use of other proxy records (e.g. charcoal to identify burning, pollen to identify deforestation) may be necessary to infer the causes of changing decay rates.

2.3.1.3. Development of upland peat

Early work on upland peat development and stratigrapgy took place in Britain throughout the 1950s (Conway 1954), 60s (e.g. Simmons 1964; Pennington 1965; and Tallis 1964), and 70s (Godwin 1975), and rested on the tacit assumption that the initiation of blanket bog growth was the result of deteriorating climatic conditions (Moore 1993:218). Although many authors (e.g. Simmons 1969 and Moore 1975) suggested that human activity such as forest clearance or farming (identified from archaeological and palaeoecological evidence in upland areas) could have been a cause of blanket peat initiation, the precise mechanisms for this remain unclear (Moore 1993). It is now generally accepted that in areas such as England and Wales, which are at the climatic limits for peat growth, human impact would have been necessary for peat inception (Moore 1993; Edwards 1999). Many palaeoecological studies indicate that the use of fire to clear forest, felling of trees for fuel and building material, using leaf fodder, and increased grazing pressure from the Mesolithic/Neolithic onwards, all may have been key factors in peat initiation in British uplands in prehistory (Moore 1993; Caseldine and Hatton 1994). In general terms these factors can cause alteration to hydrological conditions and the breakdown of soil structure. This leads to increased acidity and impermeability of the soil (i.e. podzolisation and the formation of impermeable iron deposits, or 'iron pan'), and subsequent waterlogging and inhibited biological decay, resulting in peat growth (Limbrey 1975).

The development of small valley and soligenous mires in the uplands, as opposed to blanket peat, may however have followed a number of different trajectories. As waterlogging is the necessary factor for peat inception, the extent to which water is collected at a site is a key factor in the timing of peat development (Moore 1993). This means that peat inception of these small mire sites may have taken place at a variety of dates in the Holocene, for example, if drainage of a valley was impeded (e.g. by a felled tree, or sediment preventing outflow). Therefore small valley and soligenous mires may sometimes preserve much older peat deposits than blanket peat (Fyfe et al. 2008), or a very high resolution palaeoenvironmental record, due to rapid peat growth (Fyfe 2000).

This section acts as an important reminder for the following review, that landscapes synonymous with upland areas in the UK today, such as heather moorland and peatlands, are not natural. In many cases, the development of these landscapes, and of peatlands in particular, has been driven by human action. This means that human action and management is often necessary to maintain peatland areas, for example by preventing vegetation succession and scrub growth (Bragg and Tallis 2001; Simmons 2003).

2.3.2. The peatland palaeoenvironmental archive

Peat can be viewed as a 'recorder' of information in two ways: firstly by capturing information about the surrounding environment; and secondly, by effectively recording information about the development of the peatland itself (Charman 2002).

2.3.2.1. Palaeoenvironmental proxies: remains preserved within peat.

As well as larger organic archaeological remains, such as wooden artefacts and trackways, bog bodies, or basketry (Coles and Coles 1989), a number of much smaller, and often microscopic remains can be preserved within peat. Interpretation of assemblages of these remains, found in samples from different layers within the peat profile, can facilitate reconstructions of past environments, contemporary with peat formation. Table 2.1 lists a number of palaeoenvironmental proxies which can be preserved within peat, alongside the aspect of past conditions they can help to reconstruct, and the potential spatial scale of these reconstructions. The temporal scale of reconstructions can depend on both the rate of peat accumulation, as well as sampling resolution. The anoxic and waterlogged nature of peat inhibits chemical and microbial decay processes, promoting the preservation of organic remains (which would not normally be preserved in other soils or sediments). Whilst the low pH of peat also inhibits many microbes, it also facilitates the breakdown of carbonate-based materials due to chemical reactions with the acid. This means that bone, antler, and shell in particular are often broken down in peat deposits (Darvill 1987; Caple 1996), as demonstrated by the loss of bone, but the retention of skin hair, and body tissues in human bodies preserved within mires (Coles and Coles 1989).

Interpretation of remains, in terms of environmental reconstruction, relies on the principle of uniformitarianism: using knowledge of the niches of plants, animal, and insects, as well as knowledge of processes occurring in the modern environment, to interpret palaeoenvironmental assemblages (Charman 2002). This can only be effective if taxa are identifiable to a 'useful' taxonomic level (a species or genus specific to an identifiable ecological niche), and we can define with a reasonable degree of confidence where (or within what distance from the sampling site) they originated. Charcoal and spheriodal carbonaceous particles (SCPS) can provide the widest spatial scale reconstructions of fire histories and industrial activity, travelling long distances from their sources (Rose *et al*. 1995). However, the distance depends on prevailing winds as well as the size of the particles, so that large charcoal particles, for example, are likely to represent local fires. Pollen assemblages can be used to reconstruct either local or regional vegetation patterns, depending on the Relevant Source Area of Pollen (Jacobon and Bradshaw 1981; Sugita 1994: see section 2.3.2.2). Aquatic pollen and spores in particular can be indicators of vegetation growing on the mire itself. Insect remains, may reflect local environmental conditions, and can be interpreted by reference to the niches of the identified species in modern studies (Bell and Walker 2005). Other types of remains, particularly diatoms, testate amoebae, and plant macrofossils can provide an insight into the conditions at the suface of a mire itself whilst peat was forming. Plants, unlike insects or pollen grains are not mobile, and are particularly sensitive to factors such as mire surface wetness and pH. This means, for example, the incorporation of *Sphagnum* mosses into the peat matrix at a particular level, indicates that the surface of the mire was likely to be both wet and acidic as that particular layer of peat was forming. Diatoms (microscopic algae) and testate amoebae, have very specific environmental niches, and are very small (<180µm), allowing them to be used to reconstruct small scale changes in the environment on the surface of the peat. Using transfer functions established from modern assemblages can allow the reconstruction of nutrient status, pH or salinity (particularly in lakes or saltmarshes) from diatom assemblages, or surface wetness from testate amoeba assemblages (Lowe and Walker 1997; Charman 2002). Past climatic conditions have been modelled using surface wetness reconstruction from testate amoeba and peat humification analyses from ombrotrophic mires in a number of regions: for example Chiverrell (2001) in Cumbria; Blundell and Barber (2005) in Scotland; Hendon *et al.* (2001) and Charman *et al.* (2006) in Northern England; and Amesbury *et al.* (2008) in Southwest England. These studies have produced models illustrating wet and dry shifts from the Neolithic or Bronze Age onwards.

Using a 'multiproxy' approach can enable the spatial resolution of different proxies to be compared: for example, plant macrofossil data from plants that grew on the peat can be compared to palynological data from plants in the surrounding area or region (Evans and O'Connor 2005). Comparing more than one type of proxy data can also give support to one of a number of possible explanations or allow us to infer causality if different factors coincide (Charman 2002). For example, linking the evidence of the consistent presence of charcoal to a decrease in tree pollen in upland peat in the Mesolithic/Neolithic in Dartmoor, Caseldine and Hatton (1994) suggested that a decrease in tree cover in the uplands was caused by humans burning trees, perhaps to create clearings to attract grazing animals.

2.3.2.2. Taphonomic processes

Taphonomic processes acting on palaeoenvironmental remains refer to all processes which intervene to affect a palaeoenviromental assemblage between the living system and the recovery of palaeoenvironmental samples. In one sense, this alteration of an assemblage poses problems for interpreting data, as the recovered remains do not directly reflect the past environment. However, detecting taphonomic processes also provides evidence in itself for past environmental change. Taphonomic processes can affect both the plant macrofossils which form peat as well as the microfossils preserved within the peat matrix. As this project focuses primarily on pollen remains (and pollen taphonomy has been widely acknowledged and researched), the remainder of this section will be largely concerned with pollen taphonomy. However, sections 2.3.1.2 and 2.3.2.3. discuss factors affecting the decay rates of peat, and the detection of these processes through examining the chemical and physical properties of peat.

Numerous taphonomic processes alter a pollen assemblage between the release of plants and incorporation into peat. Firstly, there are between-taxa differences in pollen production and dispersal of pollen (e.g. grains of some taxa are lighter than other, or have features such as air sac to allow them to travel further) (Broström *et al*., 2008). This means, for example, that simple ratios of arboreal to non-arboreal pollen is not a direct indictor of the openness of the landscape, and calculations such as pollen productivity estimates (PPEs) can be used to interpret the raw pollen data (Sugita *et al.* 1999; Broström *et al*., 2008). Secondly, mire size, topographic location, and surrounding vegetation also affect the area over which pollen landing on the peat surface at any time is likely to reflect the living vegetation assemblage (Rasanen *et al.* 2004). This is known as the Relevant Source Area of Pollen (RSAP: Jacobson and Bradshaw 1981; Sugita 1994; Davies and Tipping 2004). The RSAP is a measure of the smallest spatial unit that can be distinguished within palynological studies. In effect, this means that pollen samples from mires with a small surface area are likely to reflect vegetation assemblages from a smaller area than samples from larger mires, giving a more 'local' picture of vegetation change through time. The actual RSAP of mires can involve complex calculations, as well as studies of modern vegetation and modern analogue pollen sampling (Prentice et al 1985; Bunting *et al*. 2004; Hellman *et al.* 2009), and can also vary through time, as the size and shape of the mire and climatic conditions change.

Pollen can also be eroded from sediments or sols and redeposited elsewhere (Campbell 1999; Wilmshust and McGlone 2005; 2005a). The incorporation of redeposited pollen can be detected in a number of ways: in the character of the sediment (for example changing particle size) indicating the sediment in-wash (Wilmshurst and McGlone 2005; 2005a); the biasing of an assemblage towards an assemblage reflecting characteristic vegetation of a much earlier period in time (e.g. Stanley 1966); or through differential sorting of pollen taxa (Campbell 1999). Campbell (1999) suggests that differential working of pollen can be caused by four factors: differential resuspension of taxa from the original sediment in which it was deposited; differential transportation of taxa; differential trapping of taxa in the receiving deposit; and differential preservation of taxa during transport. The concentration of pollen within a sample can also be affected by the pollen productivity of plants contributing to the assemblage, the rate of peat accumulation, and the effects of differential preservation of pollen within the peat matrix (Brunning 2007).

In addition to damage during transport and redeposition, differential preservation of pollen taxa within one sample can also be caused by varying thickness or resistance of the pollen grain exine (Campbell 1999; Bunting and Tipping 2000), and the resistance of grains to various environmental conditions. Cushing (1967) identified five categories for classifying the condition of pollen grains: grains in good condition; and corroded, degraded, broken, and crumpled grains. Corroded grains are those which are etched, pitted, or perforated, degraded grains are thinned or have fused or indeterminable features, broken grains are split or fragmented, and crumpled grains are squashed or folded in more than one plain (Cushing 1967; Jones *et al*. 2007). Investigations into the causes of damage to pollen grains can be split into three types: firstly, lab-based neotaphonomic experiments in which environmental conditions are simulated to recreate the effects of pollen transport or oxidation over short timescales (e.g. Holloway 1989; Campbell 1991; Campbell and Campbell 1994; Lebreton *et al.* 2010; Twiddle and Bunting 2010); secondly, palaeonvironmental investigations which infer the causes of damage through environmental reconstruction, for example detecting bands of sediment in-wash, and examining the condition of the pollen within these layers (e.g. Birks 1970; Lowe 1982; Wilmshurst and McGlone; Tweddle and Edwards 2010); and thirdly, investigations which combine testing the effects of environmental conditions on pollen over a limited time with placing pollen into ‘real’ rather than simulated environments over an extended period of up to 20 years (e.g. Sangster and Dale 1961,1964; Havinga 1964, 1984).

In summarising the results of a number of investigations, Jones *et al.* (2007) state that corrosion or degradation of grains is caused by biochemical factors such as chemical oxidation, and bacterial and fungal action associated with more oxygenated environments, whilst breakage and crumpling are caused by mechanical factors such as transport and compression of grains. However, reviews by both Twiddle and Bunting (2010) and Lebreton *et al.* (2011) suggest that a wider range of parameters may cause damage to pollen including: chemical oxidation (Twiddle and Bunting 2010; Campbell 1991); depositional environment and microbial action (Cushing 1967; Havinga 1984); cycles of wetting and drying or freezing and thawing (Holloway 1989; Campbell 1991); salination and desalination (Campbell and Campbell 1994), and transport in various sediments (Twiddle and Bunting 2010). The results of different types of experiments do not always correspond: for example, whilst Birks (1970) states that breakage of grains may be caused by transport, Lowe (1982) highlights ingestion by invertebrates as a cause of broken grains, and Campbell (1991) finds that oxidation due to wet and dry cycles was a more important cause of breakage of grains than transport in water. Furthermore, although the majority of investigations find that pollen taxa are differentially susceptible to different types of damage (indicating that although exine thickness may have some bearing on the susceptibility of a taxon to damage, it is not be the only controlling factor), they do not agree on which taxa are most affected by each damage type. For example investigations of corrosion susceptibility through oxidation both in 20-year field experiments (Havinga 1984) and lab-based simulations (Lebreton *et al*. 2011) show taxa in a different order of susceptibility to corrosion. Both Tweddle and Edwards (2010) and Lebreton *et al.* (2011) cite the lack of experimental data, and the relatively small number of investigations outside laboratory conditions, as a cause of these disparities. Lebreton *et al.* (2011) in particular, suggest that neotaphonomic experiments which focus on investigating a single cause of damage to pollen grains through laboratory simulations fail to identify the broad range of factors which may be acting on pollen *in situ* within sediments. Field experiments also indicate the combination of different soil or sediment substrate and varying water-table conditions (aerobic, anaerobic, or seasonally variable) may cause differential damage to pollen in both type and extent (Sangster and Dale 1961, 1964; Havinga 1984).

The results of pollen condition analysis have been used to determine how well the recovered assemblage reflects the deposited assemblage (Bunting and Tipping 2000), to interpret the formation of sediments in terms of climate change or human impact through time(e.g. Wilshurst and McGlone 2005; Tweddle and Edwards 2010), and as an indicator of the level of preservation, or threat to, remains within sediments, to aid management of palaeoenvironmental sites (Tinsley 2006; Jones *et al.* 2007).[1]

2.3.2.3. Physical and chemical properties of peat

The measurement of changing physical and chemical properties of the peat matrix through the peat profile can facilitate the reconstruction of past environments. It may also allow modern impacts on the condition of the peat to be detected (e.g. the effect of drainage and water-table draw-down peat humification). This section clearly overlaps with section 2.3.2.1, as plant macrofossils both *make up* and are *preserved within* the peat

[1] The original EH Monuments at Risk In Somerset's Wetlands (MARSIP) Pollen Report was produced by Tinsley in 2006 (revised from an earlier version submitted in 2004) but is later re-represented and summarised in Jones *et al.* (2007). Future references will only mention Jones *et al.* (2007), unless referring to something only mentioned in Tinsley (2006).

matrix. However, the focus is shifted to the way in which analyses of the chemical and physical properties of peat can tell us about the conditions under which peat formed, or that it has been subject to since formation. Table 2.2 describes a number of tests which can be carried out to determine the properties of peat samples.

The first stage in describing a peat core or profile is usually to visually describe ways in which the lithology changes with depth, using a standardised description scheme (Troels-Smith 1955) to classify the colour, humification (or *decayedness*), elasticity, wetness, composition (i.e. the type of vegetation which makes up the peat matrix), and inclusions in the peat matrix (e.g. gravel, roots, etc..). This can provide a basis for sampling strategy, and may indicate hiatuses in peat growth, in-wash from erosion events, or changing rates of peat decay due to climate change or human impact. Humification can be further measured by testing the percentage of light that is transmitted through a prepared solution of the peat using a spectrophotometer (Blackford and Chambers 1993). The level of humificaion of ombrotropic peat in particular has long been recognised as an indicator of past climate. In the early 20th century, Blytt and Sernander developed a system (the Blytt-Sernander climatic sequence) which related changes in peat humification to broad-scale regional climatic changes (Blackford 1993). Although a more nuanced, regional-scale approach is now favoured, the principles are essentially the same: peat accumulates more slowly and becoming more humified in warmer and drier periods, and accumulated more quickly and is less humified under wetter and cooler conditions (Lowe and Walker 1997; Charman 2002). Measurements of the bulk density, the percentage of organic, calcareous, and silicaceous material within peat samples, and analysis of the particle size of the non-organic fraction, can also shed light on the processes which formed the sampled sediment. For example: sandy layers or lenses within the peat may reflect erosion (perhaps due to anthropogenic disturbance of vegetation) or flood events; high bulk density may indicate compaction or slow peat accumulation (perhaps due to a warmer climate); and low organic or high mineral content may reflect very humified peat, slow peat accumulation, or incorporation of alluvial, colluvial, or aeolian deposits. Using a 'multiproxy' approach to analysing sediment, alongside palaeoenvironmental reconstruction and analysis of the condition of palaeoenvironmental remains, can allow a fuller picture of environmental change through time, and its potential causes, to be build up from a peat profile.

A focus on preserving archaeological sites and remains *in situ* (for example in PPG16: Department of the Environment 1990; Coles 2001; Lillie and Smith 2009) has led to a number of studies of the parameters that control organic decay in wetlands and peatlands (Caple and Dungworth 1995; Corfield 1998, Chapman and Cheetham 2002; Lillie and Smith 2009). Analysing the physical and chemical properties of peat can allow current decay rates, and the current condition of the peat matrix and preserved organic remains, to be monitored. Experiments have been carried out using lysimeters to artificially mimic the effect of changing water-table levels on peat profiles and the preservation of organic remains (such as wood) in laboratory conditions (Lillie and Smith 2007; Lillie 2007). These studies demonstrate that reduced water-table levels cause more oxygenation of the upper layers of the peat, this increases the activity of the majority of (aerobic) micro-organisms (e.g. Coles and Coles 1986), causes elevated redox potential (increased rates of oxidation and reduction reactions within the peat, and therefore higher decay rates of both the peat itself and other organic remains within the peat matrix (Caple 1996; Brunning *et al.* 2000; Lillie and Smith 2009). Acidic conditions within peat (low pH) can also inhibit the actions of many microbes (Caple 1996); slowing decay rates of organic material and aiding peat accumulation. However, pH levels can vary between mires, being generally lower in ombrotophic than minerotrophic mires. Although more commonly an issue in lowland than upland mires, changing pH levels can be an indicator of alterations in groundwater source (often due to groundwater abstraction or changing drainage systems) or the introduction of pollutants such as nitrates from fertilisers in groundwater supplies (French 2004; Holden *et al*. 2006a).

The impact of recent or ongoing processes, such as climate change or land management practices (e.g. drainage or peat cutting) on peat deposits can therefore be assessed. This could include monitoring water-table levels using dipwells or piezometers, and recording pH and redox potential (the oxidation-reduction status of the peat: Caple 1996; Caple and Dungworth 1995) throughout peat profiles. This is particularly important in peat deposits which are known to preserve important archaeological or palaeoenvironmental remains (Lille and Ellis 2009). To this end, *in situ* monitoring has taken place to assess the potential for deterioration of organic archaeological remains at a number of locations, including the Sweet Track in the Somerset Levels (Brunning *et al.* 2000; Brunning 2007), crannogs in Southwest Scotland (Lillie *et al*. 2007); and at the site of two Iron Age enclosures at Sutton Common in South Yorkshire (Van de Noort *et al.* 2001; Chapman and Cheetham 2002). However, Lillie and Smith (2009) suggest that more studies are necessary to fully understand how the effect of water-table fluctuation, peat chemistry, and microbial action on the preservation of organics. Techniques for monitoring, in many cases, require refinement, if the action of monitoring itself is not to alter the monitored conditions within the peat matrix. For example monitoring procedures may introduce oxygen through the insertion of probes, or through the removal of cores or monoliths. Studies (e.g. Matthieson 2004) indicate that measurement of pH with *in situ* probes may result in different pH measurements to readings taken in pore water, or using standardised procedures in the lab. Further lab and field-based studies could potentially allow the development of methods for monitoring oxygen content within peat profiles, as well as improving our understanding of the effects of different dissolved ions or types of microbes on the preservation of organic materials (Lillie and Smith 2009).

2.3.2.4. Creating chronologies: dating methods

To allow effective palaeoenvironmental reconstructions from peat, dating samples from profiles is essential (see table 2.3 for a summary of dating techniques used on peat samples). Before the advent of absolute dating techniques, vegetation changes, such as the elm decline and changes in humification were used as dating markers. These changes were seen as marking periods of climate change or human impact which were assumed to be concurrent across large areas of Europe (Roberts 1998; Lowe and Walker 1997). Systems such as the Blytt-Sernander scheme allowed relative dating of sediments according to these broad-scale climate chronologies (Lowe and Walker 1997). However, the advent of radiocarbon dating in the 1950s (Libby 1955) has radically altered approaches to palaeoenvironmental reconstruction. This absolute dating method can be applied directly to the mainly organic peat matrix (either the extracted humic or humin fraction) and allows the independent dating of samples within the peat. The technique can now be applied to much smaller peat samples due to the development of Accelerator Mass Spectrometry (AMS) (Aitken 1990). Correction for fluctuations in ^{14}C levels through time (reconstructed using dendrochronology, uranium series dating or varve chronology: Lowe and Walker 1997), or calibration, enables the construction of age-depth models for peat profiles (Bronk Ramsey *et al.* 2001). Computer programmes such as OxCAL (Bronk Ramsey 2001) and CLAM (Blaaw 2010) have been developed to calibrate radiocarbon dates to ages BP or BC/AD, as well as allowing the construction of age depth models and the application of dates to individual samples from a core or profile. One of the key advantages of using this technique for palaeoenvironmental reconstruction is that it allows the detection of regional and local differences between palaeoenvironmental sequences to be detected, rather than relying on the assumption that vegetational changes occurred simultaneously across wide areas. As dating more recent deposits can be unreliable, dating markers such as spheroidal carbonaceous particles (SCPs) (fly-ash particles released by industrial processes developed during the Industrial Revolution [Rose *et al.*

1995; Rose and Appleby 2005]), or increases in pine pollen originating from late 18th and 19th century pine plantations (e.g. Long *et al.* 1999), can be useful in constraining age-depth models in the modern period. The detection of tephra within peat samples (either in layers detected by X-ray, or as tiny cryptotephra particles), can also provide a dating marker to constrain age-depth models, as chemical analyses can allow tephra particles to be traced to specific, independently dateable, volcanic eruptions (Einarsson 1986; Gehrels *et al.* 2008). In recent years, new radioisotopic dating methods have been developed, which allow the more precise dating of more modern sediments. Radionuclide dating techniques involve the application of models of the rate of supply and radioactive decay of radionuclides (e.g. ^{210}Pb, ^{241}Am, ^{137}Cs, ^{3}H) through time from the atmosphere to a fixed ground surface area (Appleby and Oldfield 1978; Appleby 2001; Le Roux and Marshall 2011). Often, a combination of a number of these techniques can lead to the most precise and accurate dating models of peat profiles (Lowe and Walker 1997).

2.3.3. Mire typology

2.3.3.1. Mire type definitions

The term peatland is used to refer to all landscapes where the dominant surface deposit is peat in excess of 0.4m in depth (Evans and Warburton 2007) (although this figure does vary between publications). Peatlands may be classified according to many different criteria, including their hydrology, nutrient status, surface vegetation or topographic position in the landscape (Charman 2002). They can also be classified by the conditions under which they formed: so that they are either *limnic* (forming through the terrestrialisation of lakes or watercourses); *terrestrial* (where peat is formed on land by paludification, often due to the restriction of drainage); or *telmatic* (where peat is formed under swampy, or semi-submerged conditions) (Burton and Hodgson 1987; Lowe and Walker 1997). The classification used often depends on the purpose of the study, as well as the country in which a study is based. In the UK, the distinction is usually made between bogs (ombrotrophic) and fens (minerotrophic). Bogs are rainwater fed, acidic, and nutrient poor, whilst fens are typically groundwater fed, circum-neutral, and are more nutrient-rich than bogs (Wheeler and Proctor 2000; Hughes and Heathwaite1995). The National Vegetation Classification (NVC) system may also be used to classify peatlands into different vegetation categories (Rodwell 1991). The separation of peatlands into soligenous, basin, valley, floodplain, raised, and blanket mires (see Table 2.4) represents a generic hydromorphological classification which can be broadly applied to most British upland mires (Hughes and Heathwaite 1995; Charman 2002).

This project focuses on valley and soligenous mires, which may be located at the top of combes, in the bottom of valley, or on valley sides, but all are fed by groundwater, surface run-off or springs, in addition to direct precipitation. Although valley and soligenous mires are formed in areas with groundwater supply, the amount of nutrients they receive from their water sources (their trophic status) can vary greatly (Charman 2002). Wheeler and Proctor (2000) classify acidic or nutrient poor mires as *poor* (or oligotrophic) *fens*, and nutrient- or base-rich mires as *rich* (or eutrophic) *fens.* However, nutrient status is more often a continuum, rather than a binary division, as the variety of topographical locations of valley and soligenous mires, means that the water sources that feed them will come from different locations. Therefore the chemistry of the peat is likely to vary between sites (i.e. sites in the bottom of valleys are likely to be more nutrient-rich than sites at the heads of combes).

2.3.3.2.. The importance of small upland mires to archaeological and palaeoenvironmental research

The small size and RSAP of valley, soligenous and spring mires, mean that vegetation reconstruction from these sites can provide more sensitive evidence of local-scale human impacts on past environments than samples from blanket peat (Sugita 1994). The variety of topographic locations in the upland landscape in which these mires are found, the varied dates of peat inception, and the possibility of rapid peat accumulation (providing potential for higher-resolution reconstructions) mean that these sites are a particularly valuable palaeoenvironmental resource. They may also have high potential for providing landscape context to nearby archaeological sites. Increasing interest in how past peoples inhabited different landscapes niches (e.g. woodlands and wetlands) and utilised resources within them (Edmonds 1999) has meant that local-scale impacts on the environment have become a focus of archaeological/palaeoenvironmental investigations (Edwards 1999; Davies and Tipping 2004; Fyfe et al. 2004). Although palynological studies from blanket peat have been used for decades to reconstruct palaeoenvironments, the large RSAP of these locations means that local vegetational changes cannot be detected (Sugita 1994; Evans and O'Connor 2005; Davies and Tipping 2004). Thus these reconstructions may underestimate the spatial diversity of small-scale human activity within the landscape (*ibid.*). To assess human impacts on the landscape on a particular location within a landscape, for example within a combe or around a particular momument, palaeoenvironmental sampling sites must be selected which "sense vegetation and land use history at scales matching the environment in question and research question" (Davies and Tipping 2004: 242). Therefore, if small-scale local impacts are of interest, small valley, spring, or basin mires (or perhaps isolated pockets of deeper peat within blanket peat areas) near to the site of interest should be selected due to their small RSAP (Davies and Tipping 2004; Fyfe et al. 2003). Analysis of results from a single core, or from multiple cores, can allow the detection of local scale land use: such as small areas of cultivation corresponding to small patches of suitable soils (Davies and Tipping 2004), or the possible maintenance of woodland in steep valley to be managed for fuel and fodder (Fyfe at al. 2003). The varied topographic position of soligenous and valley mire in particular (from the top of upland combes to valley bottoms around the upland fringes), means that palaeoenvironmental evidence from these sites can be used to compare land use at a period in the past across different landscape contexts within a region (e.g. Fyfe *et al.* 2003 in the Exe catchment).

2.4. Conservation and management

2.4.1. Threats to peatland environments

Peat accumulation and decomposition rates may be affected by physical damage to the peat matrix, or by alterations to the surface vegetation composition or hydrological regime (Hulme and Birnie 1997). The interaction of factors such as grazing, burning, peat cutting, climate and pollution therefore directly influence peat growth and condition. In general, threats to the palaeoenvironmental resource (and potential buried archaeology within peat) consist of factors which lower the water-table or cause erosion by streamflow. Lowering of water-tables leads to increased aeration of deeper levels within the peat, causing increased microbial activity and thus accelerated decay of organic material. While this means that palaeoenvironmental remains are likely to become degraded, it also means that the peat structure may be broken down and erosion by streamflow becomes more likely (Fyfe 2006; Holden *et al.* 2007).

Compared to the catotelm, which has low hydraulic conductivity and high bulk density, the acrotelm (particularly the fibrous upper part) allows "relatively free movement of water" (Hulme and Birnie 1997:163). Any reduction in the fibrous part of the acrotelm, for example due to changes in surface vegetation or increased decay rates at the surface, increases the overland flow. This can lead to erosion of the peat by streamflow, especially during periods of heavy rainfall (*ibid.*). Erosion by streamflow is often associated with drain construction, as peat is eroded from exposed peat sections (Fyfe 2006). Peat piping occurs when water table draw-down causes the desiccation and shrinkage of the peat surface. This leads to the formation of cracks in the peat surface, which expand into pipes due to seasonal freezing and drying, and begin to transmit water (Holden and Burt 2002;

Holden *et al.* 2006; Fyfe 2006). In periods of high rainfall, much water can flow through peat pipes and hence remove peat from the site. From their investigations in the Pennines, Holden and Burt (2002) found that pipeflow contributed around 10% to streamflow volume, increasing to 30% at times of high rainfall. Table 2.5 summarises a number of types of damage which can be caused to mires by a number of factors, discussed in the following sections.

2.4.1.1. Drainage

Drainage has often been undertaken to ‘improve’ peatland for grazing, by lowering the water-table and encouraging more suitable vegetation. After the Second World War, government subsidies for moorland drainage (or ‘gripping’) were introduced (Simmons 2003; Holden *et al.* 2007). While the focus of 19th century drainage was lowering water tables in lowland areas to improve their agricultural potential, it was only after the Second World War that moorland drainage (‘gripping’) began to take place in earnest in many regions due to government subsidies (Holden *et al.* 2007). The majority of moorland drainage took place in the 1960s and 70s and was explicitly aimed at improving grazing and removing hazards to stock in moorland areas (*ibid*.). An exception to this pattern is Exmoor, where large upland ‘improvement’ schemes were undertaken by a single landowning family (the Knights) from the mid-1800s (Orwin and Sellick 1970; Riley and Wilson-North 2001). Drainage, resulting in the lowering of the water table, leads to the desiccation of peat, decomposition of organic material, breakdown of peat structure, and formation of peat pipes (Holden and Burt 2002). These factors, coupled with the exposure of peat in channel sides, have caused increased erosion of peat by streamflow, and the formation of eroded gullies in many areas. Policies of ditch and gully blocking , or ‘mire restoration’ have been adopted in a number of moorland areas (DEFRA 2008; Lindsay 2010) to prevent sediment loss, reduce downstream flooding, and promote the regeneration of mire vegetation and carbon sequestration through accelerating peat accumulation (Evans 2005; ENPA 2008). The monitoring of the success of these projects is ongoing (DEFRA 2008; ENPA 2008; Lindsay 2010). Increasing water-table levels and reducing erosion by streamflow may halt the degradation of the palaeoenvironmental resource. However, it cannot reverse damage already caused, and ditch blocking techniques which involve extracting peat to form dams may cause disturbance to the peat stratigraphy. This means that the selection of mire restoration techniques must be carefully selected to avoid increased damage to the palaeoenvironmental resource within peat.

2.4.1.2. Overgrazing

High stocking density (sheep, cattle, or deer) can lead to increased degradation of upland peat. Common Agricultural Policy (CAP) subsidies in the 1970s, 80s and 90s, based on payments per head, led to increased livestock numbers on moorland areas (Holden *et al.* 2007) This included a 40% increase in ewe numbers in British Less Favoured Areas (LFAs) between 1976 and 1993. More cross-breeding also led to heavier animals (Simmons 2003). Sheep grazing usually leads to the formation of scars in the surface of peat (i.e. ‘sheep tracks), which can cause sediment to be eroded from the exposed surface. A number of changes in agricultural policy (see section 2.4.3) mean that stocking rates on moorland, particularly of sheep, have begun to be reduced over the last decade. However, livestock are still a cause of erosion, exacerbated by inappropriate positioning of feeders (Riley and Wilson-North 2004).

2.4.1.3. Vehicles

Vehicles such as quad bikes may create eroded trackways across mires, leading sediment to be eroded from exposed peat and along trackways. Damage may also be caused by mowing and bracken cutting, but this is likely to take place in areas peripheral to mires (Riley and Wilson-North 2004). Erosion may be a particular problem at access points or stream crossing points.

2.4.1.2. Burning/swaling

Heather moorlands provide good grazing for sheep, deer, and grouse. Traditionally, moorlands have been burned to manage heather and prevent the increase of species such as *Molinia* (Holden *et al.* 2007). Rotational burning therefore has taken place since the 19th century. The Heather and Grass Burning Code (MAFF 1994) allows burning only between particular dates to mitigate against the risk of wildfire and protect breeding bird species. Burning on mire sites, whether deliberate or accidental, may kill the root mat, so that the peat is no longer protected by vegetation cover (Anderson 1997). This could lead to increased erosion by wind or streamflow (Holden *et al.* 2007).

2.4.1.5. Afforestation

In the last century, 9% of peatlands in the UK have been planted with coniferous plantations, largely by commercial companies (Holden at al. 2007). Prior to planting sites are ploughed and drained. This destroys the upper layers of peat stratigraphy, lowers the water-table, causes increased microbial activity and shrinking and cracking of the peat, and leads to subsequent decomposition of organic remains. It seems likely that more mixed plantations may be planted in British uplands in coming years, to aid carbon sequestration (it is not yet clear if this would be viable on peatland sites, as peat is also a carbon sink), to reduce the rate of water run-off and hence prevent flooding downstream, or to improve landscape aesthetics and increase biodiversity (*ibid.*). This may have a detrimental effect on peatlands and thus on palaeoenvironmental remains. While it is unlikely that this would take place on blanket peat areas, small discrete mires could be engulfed within 're-wilding' exercises.

2.4.1.6. Peat cutting

Large-scale mechanised peat cutting has tended to take place on large lowland mires (e.g. Thorne Moors in South Yorkshire [Buckland *et al.* 1994], Winmarleigh Moss in Lancashire [Middleton *et al.* 1995]) and continues in many areas, notably in Ireland. However, small-scale peat cutting for domestic fuel, although rare in Britain today, was much more widespread in the past. Visible evidence of past peat cutting in upland landscapes often includes sharp changes in the level of peat which cut across contours, trackways, drains, baulks, and loading features (Ardron *et al.* 1997). In the South Pennines, aerial photograph and field surveys suggest that virtually all peripheral blanket peat areas were affected by cutting (*ibid.*). Peat cutting has a number of effects on the preservation of peatland: peat is physically removed, therefore potentially destroying archaeological remains and truncating the palaeoenvironmental record; surface vegetation may be removed, slowing or preventing re-colonistation by plants such as *Sphagnums* and the resumption of peat accumulation; exposed peat surfaces may become desiccated leading to erosion; and peat cuts and drainage ditches (to dry the peat and enable easier extraction) cause localised water-table draw-down and subsequent degradation of adjacent areas of uncut peat (*ibid.*). In upland areas, the predominance of small-scale domestic peat cutting meant that the top turves are were often replaced to cover cutover ground, allowing the regeneration of vegetation. However, water-table draw-down caused by historic peat cutting is still a threat to the condition of the palaeoenvironmental resource, despite the cessation of peat extraction.

2.4.1.7. Recreation

The high number of visitors to National Parks in Britain (and particularly upland areas such as Exmoor, Dartmoor, and the Peak District) means that there is high potential for recreational activities in these areas to cause damage to peatlands. The erosion of footpaths across peatland areas can lead to gully erosion, the surface of the peat is broken down, creating channels for surface water to run along after high rainfall events. Waterloggged footpaths are also made wider as walkers walk alongside them, expanding the eroded area. Since the introduction of the Countryside and Rights of Way Act (CRoW) (DEFRA 2000), which came into effect from 31st October 2005, large areas of moorland have been designated as Open Access Land. This may mean that trackway/footpath erosion may become a problem in areas where this was not previously an issue. The use of motor vehicles and bicycles, and horse riding are still confined to designated rights of way. The illegal use of motor vehicles for recreation on moorland is a cause of erosion away from these designated routes. Pony trekking, hunting, and 4x4-use, are also causes of erosion which are of particular concern on Exmoor (Riley and Wilson-North 2004).

2.4.1.8. Climate change

Climate change predictions for the UK (Hulme *et al*. 2002; Murphy *et al.* 2009) suggest trends towards rising temperatures, reduced summer rainfall, and an increasing number of high-rainfall events. Threats to peatlands therefore include: a reduction in the areas of peatland which are waterlogged and therefore actively accumulating peat; increased loss of peat through erosion (both erosion of small particles and peatslides) owing to drier peat and more intense storm events (Evans and Warburton 2007; Worrall *et al.* 2009); increased risk of wildfires (Holden *et al.* 2007); and shifts in patterns of vegetation from *Sphagnums* to vascular plants, causing peat accumulation to slow or stop (Lindsay 2010). As peatlands provide a key stratigraphic record of past climate change, and changing rates of peat accumulation in response to climate change, they provide an unrivalled resource for investigating the impact of past changes in climate on peat accumulation. However, few studies have yet to study recent trends in peat accumulation in a way which could shed light on the effects of instrumentally recorded climate change (e.g. over the last 50 years) on peatland systems (Lindsay 2010).

2.4.2. Moves towards sustainable upland management

Until recently, upland management policies have been shaped by the concept that upland areas are economically marginal. Uplands are defined as Less Favoured Areas (LFAs). These were designated under the 1947 Agriculture Act as areas in which farming is more difficult due to poor climate, poor soils, and difficult terrain (Simmons 2003). LFAs actually make up 51.4% of the total agricultural area of Great Britain, and the incomes of hill-farmers in these areas have traditionally been supported by payments related to their level of production (Hanley *et al*. 2006).

During the last century, hill-farming steadily intensified, encouraged by CAP production subsidies. Due to falling prices for livestock and other changes in support, by 2000 incomes from cattle and sheep in LFAs had fallen by 70% in 5 years (Hanley *et al.* 2006). Since reforms of the CAP in 1992, which decoupled payments from production, a number of subsidy schemes have been introduced to encourage farmers to maintain upland areas in good environmental condition. This includes safeguarding important habitats (such as blanket peat), and reducing erosion (Simmons 2003). The Single Payment Scheme pays a flat rate of subsidy according to land area with the proviso that land managers must be able to show that they are maintaining their land in Good Agricultural and Environmental Condition (GAEC) and complying with legal requirements known as Statutory Management Requirements (SMR's) (Farmer *et al.* 2007). This movement towards more sustainable upland farming built on earlier acts, such as the Wildlife and Countryside Act 1981 (which meant that National Parks could effectively pay farmers to use more environmentally sustainable practices) and the initiation of Biodiversity Action Plans by the Rio Convention in 1992 (Simmons 2003). Other subsidy schemes (such as Hill Farm

Allowance and Environmentally Sensitive Areas) are gradually being phased out and replaced by more holistic Stewardship Schemes (Hanley *et al.* 2006; DEFRA 2011). Entry these schemes (at either Higher-level or Entry-level) is dependent on the number of points that can be gained from implementing measures to maintain the land in good condition (e.g. lower stocking, larger field margins on arable land) (Lobley *et al.* 2006). A separate uplands stewardship scheme has recently been launched by DEFRA (2011) to provide an approach more appropriate to the concerns of farmers in upland areas.

These reforms are in line with the move away from production-linked support, and a refocusing of policy towards providing “public goods” (DEFRA 2006). This includes maintaining ecologically important habitats and landscape features that are valued by the general public, as well as ‘healthy’ peatlands, which act as carbon sinks and aid hydrological management (Hanley et al. 2006; Reed *et al.* 2009; Lindsay 2011). The current alignment of policy towards promoting environmentally sustainable farming practices and the provision of public goods in environmentally sensitive upland areas, may allow additional protection for upland peatlands from a number of threats, such as erosion due to overgrazing or water-table draw-down due to drainage. This may help to indirectly safeguard the condition of upland peatlands and palaeoenvironmental remains in future. However, highlighting mires with high palaeoenvironmental potential may allow the greater integration of heritage values, alongside other ‘public goods’, into upland stewardship schemes.

2.4.3. Statutory protection for peatlands

Legislation to protect archaeological sites was developed primarily with the designation of visible monuments, or sites which had already undergone excavation, in mind: i.e. The Ancient Monuments and Archaeological Areas Act (HMSO 1979). Although the scheduling of archaeological monuments may protect a particular site and the small area around it, there is little direct legislation to protect historic landscapes in a wider sense, or palaeoenvironmental sampling sites. This is of particular concern for sites where human impacts are *indirectly* evident as there are no artefacts, but which provide a repository of palaeoenvironmental remains (Buckland *et al.* 1994). English Heritage and local authorities currently have little power to protect sites with high palaeoenvironmental interest or potential. In fact, in many cases there is “no obligation upon conservation agencies to have regard for archaeology” in peatlands with no known material culture remains (Cox, 1995: 126). In effect this means that environmental impact assessment (EIA) or planning consent according to Planning and Policy Guidance 5 (PPS5 replaced Planning and Policy Guidance 16 [PPG16] in 2010: DCMS 2010) is not usually required for ecological conservation projects. Palaeoenvironmental sites sampled for research projects are often not recorded in local Historic Environment Records (HERs), particularly if no archaeological remains were discovered. Also, wetlands or peatlands protected under the Ramsar Convention (1971) tend to be much larger than the relatively small upland mire which provide a focus for this project (e.g. the Humber Estuary, which covers many thousands of hectares) (Coles 2001; Van de Noort *et al.* 2001). Although new guidelines for the protection of heritage under PPS5 (DCMS 2010) indicate that archaeological landscapes as a whole, and locations with heritage value (such as peatlands) should be considered ‘heritage assets’ and protected accordingly, this is difficult to put into practice without extensive resource assessment (see section 2.5.2.). Furthermore, recent widely publicised funding cuts to local heritage budgets (e.g. in the Fenland District Council area, and South Yorkshire) may affect the level of assessment of the impact of potential development on archaeological (and palaeoenvironmental) remains.

Peatland conservation, for example the designation of Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation (SACs), or National Nature Reserves (NNRs), is currently based on largely biological criteria: the diversity, naturalness, rarity, typicalness, position within an ecological or geographic unit, potential value, and intrinsic appeal are all factor that are assessed (Charman 1994; Coles 1995). Some areas which may be of interest to archaeology (particularly sites of palaeoenvironmental interest) are not encompassed within these criteria. This can mean that upland valley mires (Fyfe 2006), or sites which have been subject to peat cutting but preserve earlier deposits intact (Buckland et al 1994; Charman 1994), for example, are given little or no statutory protection. Although there is the possibility of designating individual mire sites as SSSIs, or Regionally Important Geological or Geomorphological Sites (RIGS), only sites which have undergone much investigation can be protected (Fyfe 2006). As few mire have been investigated, many potentially valuable locations may be excluded from this type of designation, and the collective value of small upland mires for illuminating the past of a particular locale may be overlooked. The small and scattered nature of upland valley, spring and soligenous mires means that they may not be detected through larger scale soil mapping (usually 1:50,000). The extent and potential of the resource is therefore difficult to define without extensive survey of upland areas (Fyfe 2006). This makes prioritising the protection of these sites or the development of mitigation strategies, in advance of this type of survey, problematic.

2.5. Assessment and valuation of archaeological and palaeoenvironmental resources

2.5.1. Condition assessment: definitions

Resource assessment of the palaeoenvironmental resource in upland peat involves the quantification of the extent and condition of peatlands as a whole within a fixed area, as well as of peat deposits of which these areas are composed. Throughout this project, the term ‘condition’ will be used in connection with mires, the peat matrix, palaeoenvironmental remains, and vegetation on the mire surface. Many publications tend to conflate the terms mire condition, peat condition, and vegetation condition, leading to confusion when switching between studies which focus, for example, on mire ecology, mire hydrology, or peatland palaeoenvironmental studies. Therefore some clarification of background to the use of the term ‘condition’ in different contexts, within wider literature and within this study, is necessary.

2.5.1.1. Mire condition

Mire condition is used here to refer to the visual assessment of the damage to a mire caused by management impacts such as peat cutting, drainage and the resultant loss of peat through erosion (see section 2.4.1. for a more comprehensive summary). It is assumed that these types of damage to the peat result in either physical loss of peat through erosion, or increased oxygenation of peat, resulting in accelerated decay of organic remains. Fyfe (2005) established a list of threats to mires which could be easily catalogued through walkover survey, including channel erosion, peat piping, trackway erosion and peat cutting. A greater number of threats, or more extensive visible damage to a mire, therefore indicates poorer mire condition.

2.5.1.2. Peat condition

Peat condition refers to the degree of humification (*humicity*), or level of decay, of the peat matrix. While this can be assessed visually from an extracted peat core or exposed sections, using the Troels-Smith (1955) system, it can also be quantified through photospectrometry (Blackford and Chambers 1993: see section 2.3.2.3). The condition of the peat matrix may reflect both past climate and human impacts on the peat. Assessment of peat condition may provide a proxy for the level of preservation of archaeological or palaeoenvironmental remains within the peat matrix. Although monitoring water-table levels or peat chemistry provides a method of assessing current *conditions* within the peat (and potential for continued peat growth and preservation of organic remains) (e.g. Brunning 2007); in this study, the use of the term ‘peat condition’ will be confined to the current physical state, or level of humification, of the peat matrix.

2.5.1.3. The condition of palaeoenvironmental remains

Assessing the condition of palaeoenvironmental remains involves extracting and identifying macrofossils or microfossils (e.g. pollen, testate amoebae, plant macrofossils, etc) fro the peat matrix and noting their condition (e.g. Cushing 1967; Jones *et al.* 2007). This type of assessment is particularly time-consuming and can only take place under controlled laboratory conditions. However, if a mire has the potential to preserve important palaeoenvironmental sequences, assessing the condition of remains in this way may be the only way to definitively assess their condition and potential for long-term survival (Jones *et al.* 2007).

2.5.1.4. Vegetation condition

Characteristic vegetation on peatland ranges from heather (*Calluna vulgaris*) to *Sphagnum* lawns, depending on the depth of peat, its pH status and its moisture content. Heather (*Calluna vulgaris)* grows well on the thinner peat and peaty soils whilst *Sphagnam* species are found in wetter, more acidic conditions. Other species found commonly found on peatlands, such as mosses e.g *Hypnum cupressiforme* and grasses e.g. Purple moor grass (*Molinia caerulea*), thrive in conditions of varying humidity and acidity (Marrs *et al.* 2004; Chambers *et al.* 2007). Mire vegetation is most often defined by its grasses, rushes, sedges and mosses. The National Vegetation Classification (NVC) lists 38 categories of mire vegetation from those dominated by *Sphagnum* species e.g. M2 *Sphagnum cuspidatum/fallax* bog pool to those dominated by Purple Moor Grass e.g. M25 *Molinia caerulea - Potenilla erecta* (Rodwell 1991). These classifications are based on proportions of the various plants in areas of homogenous vegetation. Blanket bog vegetation often comprises a mosaic of vegetation patterns varying with local hydrology and topography, from *Molinia* dominated areas to rush pastures and *Sphagnum* pools. Certain flowering plants, such as Bog Asphodel (*Narthecium ossifragum*), and Round-Leaved Sundew (*Drosera rotundifolia*) are seen as indicators of waterlogged and acid conditions; as are bryophytes (particularly *Sphagnums*) which have the ability to thrive in these environments. These species are therefore seen as good indicators of 'healthy' mire ecosystems (e.g. NVC M17 or M18) (Rodwell 1991; Jerram *et al.* 2001).

As well as using NVC designations to classify mire vegetation, Natural England (2006) have also produced Common Standards for Monitoring Guidance for Upland Habitiats, which lists key indicator species for both good and poor vegetation conditions. Specific vegetation condition indicators are identified for different mire habitat types, including blanket bog, valley bog, transition mire, ladder fen, quaking bog, and short sedge acidic fen habitats. These guidelines specify the percentage of a mire area which should be covered by a particular type of vegetation for the mire to be deemed to be in good or poor vegetational condition. Standardised guidelines for a number of different habitat types are particularly important for the field assessment of the condition of mire vegetation within SSSIs (e.g. Dayton and O'Hanrahan 2011), and areas of blanket bog, which are designated as important habitats in the UK and in many local biodiversity action plans (e.g. Jarvis 2000).

2.5.2. Resource assessment in peatlands

2.5.2.1. 'Known unknowns': problems of detection and assessment

Carver (1996, 52) identifies the paradox in the management of the historic environment; while "...the point of archaeology is to know more; the resource on which it depends is managed so as to favour what is already known". This is an even more acute problem for peatland archaeology, as the resource in question is, by its very nature, held within or sealed beneath peat deposits and therefore 'hidden' from view during walkover or aerial surveys. This has resulted in the often frustrating problem of having to argue for the historic environmental *potential*, rather than clearly defined and audited assets, within upland peat: what could be termed 'known unknowns'. Our inability to point to tangible archaeological remains has resulted in a situation whereby there is no system for consistent protection of peat on the basis of its Historic Environment value (as opposed to its biodiversity, geological or hydrological values). Although there have been attempts to catalogue known archaeological remains within peatlands (e.g. The Monuments at Risk in England's Wetlands Survey (MAREW): Van de Noort *et al.* 2002), the paucity of known wetland or peatland archaeological sites in upland areas, due to a lack chance discoveries during development projects (in contrast to lowland peatlands) or archaeological excavations, has made detailed resource assessment difficult (see section 2.2.2.1). If we consider palaeoenvironmental remains as a distinct category - aside from artefacts or structures beneath, within, or on peat - there have been few consistent surveys to assess the extent or nature of this resource either. Two major problems present themselves once we begin to think of the peatland palaeoenvironmental archive as a resource to be assessed: firstly, how do we detect and catalogue a resource which is not clearly visible, and secondly, how do we determine which mires contain the palaeoenvironmental remains that are most useful or important to archaeology?

2.5.2.2. Resource assessment methodologies

In this section, resource assessment methodologies for a selection of projects from across the UK will be discussed. Rather than providing a comprehensive review of archaeological resource assessment in the UK, the aim is to provide case studies of projects carrying out resource assessment in wetland, peatland, or upland environments, or landscapes at a broader scale.

English Heritage Wetlands Strategy

English Heritage (EH) has supported a long-term programme of work to research some of the largest areas of lowland wetlands in England. This resulted in 4 large-scale projects to identify and record the archaeological potential of: the Somerset levels (e.g. Coles and Coles 1982, 1996; Minnitt and Coles 1996); the East Anglian fens (e.g. Hall and Coles 1994; Crowson *et al.* 2000; Pryor 2001); the Humber wetlands (e.g. Van de Noort and Ellis 1995; 1997; 2000); and wetlands in North-West England (e.g. Middleton *et al.* 1995; 2001, Hodgkinson *et al*. 2001). An estimated 450,000 ha were studied in the field by these projects (Van de Noort *et al.* 2002). Although these surveys did not cover any upland areas, and largely used maps and historical documents to locate the larger wetland areas, which was the primary focus of the project, in most cases walkover survey was used to record the extent and/or condition of peat deposits (e.g. Middleton *et al* .1995). Field survey included extensive fieldwalking to record sites (usually earthwork in pasture land), finds, modern land-use, and condition and depth of surviving peat deposits. Archaeological features, extant peatlands (this was limited in some regions due to the lack of photos with suitable ground conditions/vegetation cover), and relict hydrological features were also identified and transcribed from aerial photographs. Palaeoecological techniques used included biostratigraphical surveys to determine development and condition of mires identified through desk-based and walkover survey, and the analysis of pollen and plant macrofossils from peat samples.

Other projects which have taken place as part of EH's wetlands strategy. These include Coles' (1995) *Wetland Management* volume, which reported the results of a survey of the wetland management practices used by nature conservation agencies, with the aim of drawing on these experiences in developing conservation strategies for the wetland archaeological resource. The Monuments at Risk in England's Wetlands (MAREW) survey (Van de Noort *et al.* 2002) was commissioned to provide a general picture of the condition of the wetland archaeological resource, and provide a benchmark against which future monitoring can take place. The desk-based survey aimed to address the effects of hydrological changes on archaeological and palaeoenvironmental remains in upland and lowland peatlands and alluvial lowlands, largely using the results of EH commissioned surveys, and Sites and Monuments Record (SMR) data in some upland regions where no comprehensive surveys had been undertaken (*ibid.*). The effects of government and non-government policies were also addressed and recommendations for further discussion were made. The areas of peatland identified in the uplands were found to be limited by the lack of previous investigation (with the exception of Dartmoor).

Oxford Archaeology North Upland Peat Survey

In recent years, Oxford Archaeology North (OAN 2003; Quartermaine *et al.* 2007) have attempted to address the problem of visibility of archaeological sites within upland deep peat areas by conducting large-scale landscape survey of transects within a number of upland areas in the north-west England. This project (full results are as yet unpublished) aims to use a variety of techniques to intensively survey these areas for potential archaeological/palaeoecological sites. These include field walking (looking for artefacts in ploughed areas and earthworks in undisturbed areas), and prospecting for erosion scars and earthworks in peat areas (using aerial photos, field walking and peat depth probing). The aim is to develop predictive models through GIS mapping for locating areas of high archaeological/palaeoenvironmental potential. It is hoped that this will enable the historic environment of upland peatland areas to be managed more effectively and mitigation strategies to be developed to prevent damage to potentially valuable, but poorly visible, sites. The results of this survey are as yet unpublished, so the success of the methods used cannot be commented on at this point.

Trent Valley Geoarchaeology

The Trent Valley Geoarchaeology project used a combination of airborne remote sensing and ground-based geophysical survey to map areas of high archaeological potential in the mid-Trent floodplain area (Carey *et al*. 2006; Howard *et al*. 2008; Challis *et al.* 2011). River confluences and avulsive river systems, where many palaeochannels are formed, have been a rich source of archaeological remains. In this region these include prehistoric to medieval settlement and ritual complexes buried by alluvium, preserved organic finds such as log boats, and deposited metalwork finds, as well as palaeoenvironmental sequences within palaeochannels. Quarrying and infrastructure developments, while posing a threat to these remains, have also led to the discovery of a number of archaeological sites. A GIS system was used to bring together traditional HER point data, geological mapping and borehole stratigraphic data, LiDAR topographic and intensity data, aerial photos, and GPR and resistivity surveys (calibrated with coring). A targeted programme of radiocarbon dating also enabled the ages of detected sediment deposits. This integrated approach to geoprospection, aimed to elucidate relationships between geomorphological landforms and the subsurface archaeological resource. Interpretive methods for LiDAR intensity data (or Near Infrared Radiation), which is routinely recorded in LiDAR surveys but rarely utilised by archaeological researchers, were developed, and used to highlight vegetation colour changes, organic content, and near-surface moisture content of soils and sediments. This meant that it could be used to pick out features such as cropmarks and palaeochannels (Challis *et al.*2011). Some of the other major outcomes of the project were to create a method or framework for rapid assessment of floodplain deposits for archaeological potential, as well as zoning the valley floor into areas of high and low archaeological potential (Howard *et al.* 2008). A similar project, combining geological, archaeological, and remote sensed data has also been carried out in the Till-Tweed catchment in North-east England (Passmore *et al.* 2006).

‘Wetland Vision’

‘Wetland Vision’ is a project developed jointly by The Environment Agency, the RSPB, English Heritage, and The Wildlife Trusts. It sets out a 50-year holistic/integrated vision for England’s freshwater wetlands, making recommendations about the location and extent of wetland restoration and creation, as well as well as encouraging the conservation of the palaeoenvironmental resource in wetlands (Hume 2008). Its output to date includes GIS maps of projected locations of wetlands, and priority areas for wetland conservation, and case studies of numerous wetlands from across England. For example, a map is included of “Historic wetland priority areas”, mapping areas with high archaeological and palaeoenvironmental potential, based on soil mapping and previous surveys (*ibid.*). However, the maps available are on a relatively low resolution (showing the whole of England on one map), as the data have been summarized in a “relatively coarse way” (*ibid*.: 15). Also, the maps are based on desk-based surveys of current knowledge of wetland areas, as no field survey was commissioned for the project. In most cases this only covers wetlands which have already been well researched and documented.

Historic Landscape Analysis/Characterisation

Another approach to valuing archaeological sites and landscapes and setting priorities for conservation without extensive field survey is Historic Landscape Analysis (Rippon 2004). This includes a number of desk based approaches to defining distinctive local patterns within the historic landscape. Although methodologies and categories vary, in general projects involve ascribing parcels of land to one of a number of predefined landscape types, according to interpretations of the main historical processes which contributed to their present characteristics (*ibid.*). These character types are now commonly mapped in a GIS system. English Heritage has funded a number of county-scale Historic Landscape

Characterisation projects, the results of which are used to inform landscape management, including assessing planning applications, being used to advise on agri-environmental schemes, and putting historic properties into their landscape setting to aid presentation and understanding (Clark 2004). For example, the results of HLC projects have been used to provide advice on the sensitivity of an area between London, Stansted, and Cambridge where extensive development was planned (*ibid.*) These mapping projects do not, however, attempt to give a value to types of landscape (although this may be inferred subjectively): more analysis is always required by 'an expert' to elicit 'value' from the different area designations.

2.5.3. Valuing the palaeoenvironmental resource

The value of small mires sites as a repository for palaeoenvironmental data which documents local scale human impacts on the environment, has been demonstrated in a number of regions (e.g. Exmoor [Fyfe et al. 2003] and Northern Scotland [Davies and Tipping 2004]). Due to the increased interest in the management of upland mires, for mire 'restoration' projects, and flood management (Holden *et al.* 2007), mitigation strategies need to be developed to protect these sites for future research, and to prioritise the monitoring of the sites with the greatest potential archaeological/palaeoenvironmental value/importance. This fits with the current emphasis on the sustainable management of the historic environment at both national and local levels (Fairclough 2006; Grenville 1999). Government and national bodies, such as English Heritage (DCMS 2008) and Natural England (2006a), have placed greater emphasis on cross-disciplinarity and integrated incentive programmes. Simple systems for communicating priorities for preservation or research between different organisations (who do not necessarily have a detailed understanding of each other's area of expertise) will therefore be necessary.

2.5.3.1. Archaeological approaches to valuing heritage 'assets'

The term 'value' itself can be interpreted in a number of different ways. Within a research and management context, valuation systems for archaeological/palaeoenvironmental sites may be based on (1) current research interests (Carver 1996; Ove Arup and Partners 1991); (2) the assessment of sites for their future research potential (e.g. Fyfe, 2006); or (3) the need to value sites currently under threat (e.g. from development) to allow action to preserve or record them (French 2004). There are many other ways in which sites and landscapes can be valued. For example, moorland landscapes may hold particular aesthetic values due to their openness, and perceived 'wildness' (Simmons 2003; Preece 2007), or mire sites may be valued for their specific vegetation (Blackshall *et al.* 2001). It would be impossible to consider all (possibly contradictory) views on the value of mire sites and moorland landscape in the development of archaeologically based value systems. Darvill (2001; 2005) suggests that the difference between what he terms 'value' and 'importance' systems, is key here: whilst individual sites are 'important' to archaeology, as a consequence of assessment or research by specialists with particular interests, 'value' represents the esteem which sites hold in the wider community, encompassing many different view of sites/landscapes. In this project, value is meant as an indication of the potential for individual peatland sites to serve future archaeological research or current archaeological research agendas: i.e. their 'importance' (*sensu* Darvill 2005) to archaeological/palaeoenvironmental interests/specialists.

In upland areas across the UK (including the Peak District, Dartmoor, the North York Moors, and Exmoor) spatially-extensive peatland restoration projects have been taking place over the last decade (Wheeler 1995; Anderson *et al.* 1997; Lunt *et al.* 2010), making the need for an assessment of the research potential, or 'value' of the palaeoenvironmental resource in upland peat a priority. A report by NE (2010) on carbon storage in England's peatlands suggests that there is greater scope for peatland restoration project at a landscape scale in upland areas, owing to lower land values and less severe levels of peat degradation then in lowland basin mires. Although the aims of restoration projects are often in harmony with archaeological interests (e.g. rewetting and maintenance of high water tables) (Coles 1995), they have highlighted a problem that archaeology increasingly faces: to protect archaeological 'assets' (DCMS 2010) we must be able to place 'values' upon them. For peatland restoration projects, it is relatively simple to rank sites in order of importance, using estimates of biodiversity value or potential for carbon capture due to the extent or volume of peat (Maltby 2010; Rawlins and Morris 2010). However, there is a tendency amongst archaeologists to resist ranking sites (whether archaeological or palaeoenvironmental) in terms of their importance to research. Mason (2008, 304) suggests that archaeologists and heritage professionals work within a 'conservation discourse', tending to regard cultural values as plural and heritage as 'priceless'. This is often opposed to the way in which 'economic discourse' reduces complexity to a single monetary value, with the result that decisions are made on the basis of market forces. There may also be anxiety that sites deemed 'less important' or 'more common' will be neglected by research, potentially creating skewed pictures of our past, or that such sites will be seen as unworthy of action to preserve or restore them. However, the fact that some archaeological sites (whether individual sites or types of sites) attract more research and conservation funding than others suggests that valuation and ranking is often carried out implicitly, although theoretical models or guidelines for best practice are rare (Mathers *et al.* 2005).

There is often a need for heritage professionals to work closely with other disciplines such as nature conservation. There are also agricultural subsidy schemes (or agri-environmental schemes: Hanley *et al.* 2006; Lobley *et al.* 2006; DEFRA 2011) which encourage the protection of archaeological sites. This creates a need to communicate heritage values clearly to non-specialists. Also, the view that historic landscapes rather than just individual sites should be protected may facilitate the need for a different type of cataloguing and valuation of these landscapes (Schaich *et al.* 2010). It is therefore pertinent to consider how the importance or value of archaeological sites and landscapes can be assessed, as well as working towards clear interdisciplinary communication of the resulting research agendas and systems of assessment. The translation of value systems between theory and practice can be problematic, and there will be many caveats associated with any system of archaeological 'valuation'. In order to avoid oversimplification of the historic environment as simply a source of tourist attractions, or as a provider of less tangible benefits such as enhancement of 'quality-of-life' (Grenville and Ritchie 2005), it is necessary to develop definitions of value that incorporate archaeological *research* values (Carver 1996). Furthermore, these values must be set within a clear frame of reference, such as national or regional archaeological research frameworks, so that their aims and standards are clear (Mathers *et al.* 2005; Deeben and Groenewould 2005). Finally, there are a number of problems associated with palaeoenvironmental sites in particular, such as: how can mires be detected? (see section 2.5.2.1.); how can the palaeoenvironmental potential of mires or peatland areas be assessed?; How could these assessments be translated into a 'valuation system'?

2.5.3.2. The ecosystem services approach to valuing peatlands

In a policy landscape of changing land management, climate-change mitigation, and assessment of the ecosystems services provided by different landscape types, ranking or grading 'environmental assets' is now commonplace (Costanza 2002; Maltby 2010). The development of ecosystem services assessment techniques has been driven by the need "to tackle unsustainable economic drivers of environmental degradation" and prevent the overuse of unvalued environmental assets (Cornell 2010:1). In the context of wetlands, ecosystem services include benefits to humans that the functioning of wetland ecosystems provide, including: nutrient cycling; preserving habitats of conservation importance; carbon sequestration and climate mitigation; flood risk management, recreation and tourism uses; and preserving archaeology and palaeoecological remains (NE 2006a). The Millennium Ecosystem Assessment (2005) highlighted the paucity of data as a major problem preventing the quantification of ecosystem services in economic terms. Whilst various tensions may exist between different stakeholder groups, it remains important that each of the different environmental assets can develop appropriate priorities and management structures that can be integrated into wider frameworks of holistic management of landscapes (Mooney *et al.* 2009; Reed *et al.* 2009).

Many of the objections to archaeological valuation systems (discussed in section 2.5.3.1) are embodied by the following question: can the complex, multiple, and qualitative values be translated into simple quantitative values? (Schaich *et al.* 2010). The emphasis in environmental management on an ecosystem services approach (Rawlins and Morris 2010; Maltby 2010) has led some to suggest that it is no longer a question of *whether*, but *how* historic environment values are determined and integrated into wider valuation systems (Mason 2008; Schaich *et al.* 2010). This change is particularly evident in peatland research, where a 'paradigm shift' in the attitudes of policy-makers and environmental managers towards accounting for the wider values of ecosystem functioning, has helped to shift research agendas from what peatlands *are*, to what they *do* (Maltby 2010, 249): i.e. what benefits can they provide. Bonn *et al.* (2009) divide these benefits or 'services' an ecosystem can provide into three categories: *provisioning* services, defined as what material good an environment is capable of producing, such as livestock, timber, or water; *regulating* services, defined as ways in which an ecosystem regulates external processes, for example regulating flood risk, water quality or carbon storage; and *cultural* services, defined as the opportunities ecosystems provide for leisure and recreation, as well as less tangible contributions to the cultural identity of a society, for example through art and literature. Although provisioning services are fairly simple to place a monetary value on, as the value of goods produced is regulated by market forces of supply and demand, regulating and cultural services are more difficult to value in this way.

Costanza *et al.* (1997) and Hawken *et al.* (1999) use the term ‘natural capital’ to identify all the products and services supplied by our environment. In an extreme approach to ecosystem valuation, they attempted to provide monetary a ‘value of Earth’. Shaw and Whyte (2008), in a study of the uplands of North West England, suggest that detailed historical and palaeoenvironmental studies should play a part in determining future land management policy, as they provide key insights into the processes which have driven environmental change through time. They suggest this is particularly important in upland areas, where (despite the fact that upland landscapes are often perceived as ‘natural’), landscapes have been shaped by human management over millennia. It is perhaps the need for in-depth interdisciplinary communication of complex concepts and objective between various and diverse stakeholder groups (Bateman *et al.* 2010), as well as some uncertainties as to the processes driving ecosystem function (Bonn *et al.* 2009), which makes the economic analysis of ecosystem services such a complex proposition.

2.6. Exmoor case study

2.6.1. Exmoor background: Introduction to the study area

Exmoor National Park was established in 1954. It covers an area of 686 km^2, two-thirds of which is in Somerset, and the remaining third of which is in Devon (Riley and Wilson-North 2001). More than half of Exmoor is over 300m OD, with higher ground formed by three ridges running roughly east to west. Slates and sandstones make up the underlying geology, and the park is particularly known for its grass and heather moorland plateaus and steep wooded valleys (Curtis 1971; Riley and Wilson-North 2001). While much land on the moorland fringe was improved for pasture and cultivation in the 19^{th} century, large tracts of moorland, from Challacombe Common and the Chains in the west, to Dunkery

Hill in the east is today used as rough pasture (ENPA 2007). Surveys of the extent of blanket peat within the National Park have been undertaken by Merryfield (1977) and Bowes (2006), as part of PhD and MSc projects respectively. Merryfield's (1977) survey indicates that the area covered by peat more than 60cm in depth is around 3.5km^2. This is supported by Bowes' (2006) survey, which estimated that around 4km^2 of her sampled area (24km^2) was covered by peat more than 50cm deep. Although Bowes' (2006) survey covered a smaller area than Merryfield's (1977) 65km^2 survey, the area surveyed was constrained by his results. A survey of valley, spring and soligenous mires was undertaken by Fyfe (2005) within two of the 'moorland units' (7 and 13) defined by the Moorlands at a Crossroads report, commissioned by the Exmoor Society (Landuse Consultants 2004). Figure 2.1 shows the location and extent of surveys carried out by Merryfield (1977), Fyfe (2005) and Bowes (2006).

As part of its 'Moorland Initiative', Exmoor National Park Authority won a development funding grant from the Heritage Lottery Fund (HLF). Part of the development work within this HLF funded Landscape Partnership is to delimit Areas of Exceptional Archaeological and Historical Importance (AEAHIs), in particular building on an earlier report (Landuse Consultants 2004) and incorporating palaeoenvironmental importance into the designation of areas (Fyfe and Adams 2008). Forty-eight Areas of Exceptional Archaeological and Historical Importance (AEAHIs) were subsequently revised to 37 areas, and have more recently been renamed Principal Archaeological Landscapes (PALS) (Riley and Wilson-North 2004; Fyfe and Adams 2008; Wilson-North 2011). These 37 areas are illustrated in figure 2.2, and described in a gazetteer showing the principle components of the archaeology of each area (table 2.6). The report by Fyfe and Adams (2008) also included guidance for monitoring the condition of identified earthwork, standing building, and palaeoenvironmental sites. This approach has provided a key mechanism for recognising the importance of heritage assets in upland management and draws heavily on the Regional Archaeological Research Framework (SWARF: Webster 2008).

2.6.2. The archaeology and palaeoenvironment of Exmoor

Owing to a lack of well-dated excavations of archaeological sites on Exmoor, the dating of sites has generally been based on monument typologies developed for the UK (Riley and Wilson-North 2001). In order to facilitate comparisons with other reviews of the archaeology of Exmoor, the chronology adopted in this section is that used in Riley and Wilson-North's (2001) survey for English Heritage. The date ranges used are: Late Upper Palaeolithic (15,000 to 10,000 BC), the Mesolithic (10,000-4000 BC), the Neolithic (4000-2000 BC), the Bronze Age (2000-700 BC), the Iron Age (700 BC-43 AD), the Romano-British period (AD 43-410), the medieval period (AD 410-1600), and the post-medieval to modern period (AD 1600-present). All radiocarbon dates used in this section have been calibrated to calendar years AD/BC using the Radiocarbon Calibration programme CALIB 5.0 (Stuiver and Reimer, 1993; Stuiver *et al*., 1998).

Our knowledge of the archaeology of Exmoor is largely based on standing archaeological remains, as excavations of sites are still limited in number. Riley and Wilson-North's (2001) survey for English Heritage comprises a study of both standing field monuments, archaeological finds, as well as the history of a number of standing buildings in the National Park. This survey builds on previous work by Grinsall (1970) and Quinell and Dunn (1992). In the following section, the key features of the archaeology of Exmoor will be summarised alongside the environmental history of the area. This will allow the a more holistic picture of Exmoor's landscape to be presented than could be achieved by describing archaeology and palaeoenvironment separately, and avoid the repetition of summaries (particularly of the archaeology) which can be found elsewhere. As the aim of this section is not to provide a comprehensive summary of the archaeology of Exmoor, but to outline the key changes in Exmoor's upland landscapes (encompassing both environment, land-use, and settlement pattern), some of the key archaeological remains which characterise each period (some of which are mentioned in the text) are summarised in table 2.7.

The earliest palaeoenvironmental work on Exmoor was undertaken by Merryfield and Moore (1974), and focussed on the human impact on peat inception at The Chains. Further work was undertaken on blanket peat sites adjacent to Bronze Age field systems at Hoar and Codsend Moors by Francis and Slater (1990; 1992). Due to their topographic setting on plateau and hilltops, blanket mires are in a favourable position to receive pollen from a wide area, making peat deposits from these areas suitable for analysing regional vegetation histories (Moore *et al.* 1984)*.* In 1995, Straker and Crabtree reviewed palaeoenvironmental investigations on Exmoor, and carried out further work in The Chains. Up to that point, palaeoenvironmental work focussed entirely on blanket peat formed in the last 3-4000 years (3 dated, and 4 undated sequences), representing what is assumed to be largely human-induced landscape change and peat initiation from the Late Neolithic through to the later Iron Age. From the late 1990s, palaeoenvironmental studies began to establish the palaeoenvironmental potential of small valley and spring mire sites in both upland and upland fringe environments (e.g. Fyfe 2000; Fyfe *et al*. 2003; 2003a; Rippon *et al.* 2006; Fyfe *et al.* 2008). The small pollen catchment area (RSAP) of these sites means that they are more suitable for projects which aim to assess 'human scale' impacts on the landscape. The varied processes which lead to the formation of these small mire sites mean that records for up to the last 10,000 years can be obtained in some cases, and in others, high resolution data may be obtained from fast-accumulating mires. The palaeoenvironmental archive amassed for Exmoor, particularly over the last decade, totals 38 reconstructed sequences, the majority of which focus on pollen analysis, and 23 of which have at least one radiocarbon dated sample (see table 2.8 and figure 2.3). The type of analyses carried out at each site depends on both the research question and the nature of available sediments. Although the majority of investigations (as described above) have focussed on pollen analysis from upland peat, changes in sea-level have been reconstructed using diatom and pollen analysis at coastal locations (Jennings *et al*. 2008), questions of woodland management have been addressed through studies of microscopic charcoal (Juleff 1997), and analyses of testate amoebae and plant macrofossils have been used to access patterns of past climate change (Chambers *et al.* 1999).

Late Upper Palaeoelithic (15,000-10,000 BC)

Other than a fragment of a handaxe - which, like many solitary finds of its type, lacks recorded context– there is no Palaeolithic evidence from Exmoor (Riley and Wilson-North 2001). Exbridge, to the south of the upland area, is the only palaeoenvironental sequence from the Exmoor region which covers the Late Upper Palaeolithic period. Here, the floodplain environment was dominated by cold-loving grassland and fen species (Fyfe *et al*., 2003), as would be expected in arctic-steppe conditions. Although there was unlikely to have been many trees locally under these climatic conditions, birch and pine were present in the wider landscape at this time although trees were unlikely to have been growing locally.

Mesolithic (10,000-4000 BC)

While there are no Early Mesolithic finds, there have been discoveries of a number of flint scatters comprising Late Mesolithic tool types, including narrow blade microliths (used in compound tools) and 7 maceheads (Riley and Wilson-North 2001). The distribution of these finds may reflect the work of several collectors, and most are without accurate recorded location (*ibid.*). At two sites in particular – Kentisbury Down and Hawcombe Head – extensive scatters of worked flint have been discovered. The largest assemblage, totalling hundreds of tools and flakes, at Hawkcombe Head may represent a flint working site where tools were made from flint pebbles from nearby Porlock Bay (Gardiner 2004). The location may indicate that hunter-gathers were making use of seasonally available resources from both the shore and marsh and the nearby upland forest.

The rapid increase in temperatures at the end of the Late-Glacial (Horsfield *et al.* 2008) led to a change in the vegetation on and around Exmoor in the Early Mesolithic. There is evidence for the development of pine and birch woodland in the Exebridge area (Fyfe *et al*., 2003), a pattern which would have been repeated across Exmoor. Migration of deciduous woodland from continental Europe (Birks 1989) marks the beginning of the Late Mesolithic, from 8,000 BC onwards. Sequences from Brightworthy and Exbridge (Fyfe *et al*. 2003), Long Breach and Gourte Mires (Fyfe *at al.* 2003a), Hoar Moor (Francis and Slater 1990), and Landacre Bridge (Badger 2000) indicate that mixed oak-hazel woodland was the dominant vegetation type, and that open ground was very limited. Peat development began at Comerslade shortly before from around 6500 BC (Fyfe *et al.* 2008). Although hazel macrofossils are visible in this profile, pollen analysis indicates that the species composition of woodland was diverse, with pine, alder, elm and birch pollen all present. Patterns of species cover varied across Exmoor, for example with: stands of pine woodland persisting throughout the period around Hoccombe Combe (Wessely 2002); the establishment of alder woodland to the south of the upland area at Exbridge and later (4450-4250 BC) at Brightworthy (Fyfe et al. 2003); and predominantly elm woodland near Halscombe Allotment (Carter 2002). Evidence of tree clearance, indicated by charcoal and reduced tree/increased plant species has been identified at Brightworthy around 6500 and 5000 cal BC. Also, evidence from Exebridge shows later Mesolithic woodland disturbance on the valley floor (Fyfe *et al.* 2003).

Neolithic (4000-2000 BC)

In contrast to other areas in Britain (and other areas of the south-west), a number of monument types seen to characterise the Neolithic, such as long mounds, megalithic tombs or causewayed enclosures, are not found on Exmoor. Although there are a number of scattered surface finds of stone tools of Neolithic types (such as polished stone axes, but again, often without recorded location), there is no evidence of Neolithic settlement sites on Exmoor (Riley and Wilson-North 2001). However, this is not uncommon in Britain, as Neolithic settlement sites are rare. An abundance of standing stones and stone settings, attributed to the late Neolithic and Early Bronze Age can be found on Exmoor. It is usually accepted these monuments, common to upland areas across Britain, were placed within an open, cleared, pastoral landscape (Simmons 2003). Blanket peat sequences, which begin during this period at a number of locations in Exmoor, have provided fertile ground for palaeoenvironmental research (Wilkinson and Straker 2008). Evidence from the Chains (Moore *et al*., 1984; Crabtree and Straker 1995) and Hoar Moor (Francis and Slater 1990) indicate largely open grassy landscapes, whilst small increases in grassland at the expense of woodland species such as elm at both Hoccombe Combe (Wessely, 2002) and Halscombe Allotment (Carter 2002), suggest woodland clearance in upland areas. Increases in charcoal concentrations in the profile from Long Breach in the Early Neolithic suggests that woodland in upland areas was cleared, or managed for grazing, by burning (Fyfe *et al*. 2003a). This supports the hypothesis that monuments were constructed in landscapes which were at least partially open. In contrast, evidence from mires in lower floodplain or alley locations, such as Landacre Bridge (Badger 2000) and Brightworthy (Fyfe *et al*. 2003) in the Barle valley show little disturbance of woodland, indicating that valleys may have remained dominated by mixed deciduous woodland.

Bronze Age (2000-700 BC)

The Bronze Age is often seen to represent a peak in human activity in the uplands of South-west Britain, with numerous stone setting and round barrows (monuments often categorised as 'ritual'), as well as settlement sites and field systems on both Bodmin Moor (Johnson and Rose 1994) and Dartmoor (e.g. Fleming 1988), as well as Exmoor. While standing stones and stone settings are often dated typologically to the Late Neolithic and Early Bronze Age, settlement sites and field systems were constructed from the Bronze Age onwards. Although none of the known field systems on Exmoor (e.g. Hoar Moor and Codsend Moor: Riley 2009) have been excavated, a number of similar sites have been excavated on Dartmoor (Balaam *et al.* 1982; Fleming 1988; Johnston 2005; Fyfe *et al.* 2008a). The ring cairn at Shallowmead and the burial cairn at Barton Down provide some of the few radiocarbon dated contexts from Bronze Age Exmoor, and date from 1500-900BC (Quinell 1997). The lack of dateable pottery from other excavated barrows in Exmoor (except the Early Bronze Age beaker from the Culbone Cist) means that few can be securely dated (Riley and Wilson-North 2001). A program of excavations is currently underway on stone settings at Lanacombe to try to shed more light on the date of erection, technologies of construction, and possible significance in the landscape of these monuments, as well as to obtain organic material to date their construction (Gillings *et al.* 2010).

Eight palaeoenvironmental sequences on Exmoor include a radiocarbon date that falls within the Bronze Age (Brightworthy Farm, Halscombe Allotment, The Chains, Moles Chamber, Gourte Mires, Long Breach, Comerslade, and North Twitchen Springs). During this period there is evidence of further expansion of grassland and reduction in woodland in high upland areas, for example from blanket peat sequences at The Chains and Hoar Moor (Merryfield and Moore 1974; Francis and Slater 1990) and from smaller spring mires at the heads of combes, such as Hoccombe Combe (Wessely 2002), where there are also a number of nearby clearance cairns. Most of the assemblages have a significant numbers of *Plantago lanceolata* grains, indicating pastoral land use. However, the lack of cereal pollen taxa may partially be a result of the fact that cereal species are self-pollinating and therefore cereal pollen is poorly dispersed. Pollen sequences from smaller mires at the uplands fringes, such as Gourte Mires and Long Breach (Fyfe *et al*., 2003a) indicate more spatially varied vegatation patterns: within a small geographical area, there appear to have been patches of heath, grazing land, as well as areas of woodland concentrated in the valleys and the tops of some combes. By the end of the Bronze Age, woodland may only have persisted in the river valleys and steeper combes (*ibid.*). A shift from alder carr to sedge-dominated vegetation on the Brightworthy floodplain suggests a period of increased alluviation, possibly as a result of increased upland erosion due to woodland clearance, grazing, and possibly cultivation (Fyfe *et al.* 2003).

Iron Age and Romano-British Period (700 BC – AD 410)

The transition from Bronze Age to Iron Age is often associated with climatic deterioration (Roberts 1998; Van Geel and Renssen 1998) and retreat from high moorland areas in Britain (Simmons 2003; Dark 2006). Human induced soil degradation and climatic changes noted from peat stratigraphy (indicating a colder and wetter climate) are often cited as the cause for the abandonment of upland field systems in the UK (Caseldine 1999; Barnatt 1999; Simmons 2003; Amesbury *et al.* 2008). Archaeological investigation of the Iron Age in the Southwest England has focussed on hillforts (Fitzpatrick *et al.* 2008). The visibility of the Bronze Age settlement evidence in the uplands has also tended to overshadow the little that is known about settlement patterns in the Iron Age beyond hillfort sites*.* A decline in upland settlement is not apparent from the archaeological and palaeoenvironmental record from Exmoor. For example, there are a number of enclosed settlements and hillforts, including Wind Hill, the Myrtleberrys, Sweetworthy, Bury Castle, Shoulsbury Castle, Bat’s Castle, and Gallox Hill (Riley and

Wilson-North, 2001). However, the lack of excavation at these sites means that the information they provide about upland settlement in the Iron Age is limited.

Palaeoenvironmental sequences from this Iron and Romano-British period indicate continued openness in the landscape. For example, evidence from the Chains in the high moorland suggests that agricultural use of these areas was continuous from the prehistoric to the modern period (Merryfield and Moore 1974; Moore *et al*. 1984; Crabtree and Straker 1995). However, peat inception at Codsend Moor may be an indicator of the effects of changing climate, to which local communities had to adapt (Francis and Slater 1992). This general pattern contrasts with that on Dartmoor and Bodmin Moor, where there is evidence of woodland regeneration and scrub regeneration (Caseldine 1999; Gearey *et al.* 2000) indicating a decline in agricultural use of the uplands at the end of the Bronze Age. In the mid- to late-Iron Age, dramatic woodland clearance, and an increase in species-rich grassland (typical of rich grazing land), is seen across Exmoor, for example in sequences from Moles Chamber (Fyfe 2000), Gourte Mires and Long Breach (Fyfe *et al.* 2003a). However, high percentage of arboreal pollen at Ansteys Combe thoughout this period suggests that woodland persisted in steeper sided valley contexts, perhaps managed for fuel or timber (Fyfe et al. 2003a). The general expansion of woodland clearance throughout this period may reflect an expanding population or agricultural intensification, which included technological advances that allowed heavier soils to be cultivated. Archaeological Evidence of iron working from Sherracombe Ford (Juleff 1997), and mineral extraction (although difficult to date) at Roman Lode (Riley and Wilson-North 2001) suggests that woodland may have also been cleared to provide charcoal for mineral smelting.

Although the Roman invasion seems to have had little discernable effect on the settlement pattern in Exmoor, it is clear from a number of sites that Exmoor's coastal location and mineral resources were perceived as valuable (Riley and Wilson-North

2001). A number of chance finds, such as Roman coins and a lamp indicate that there was interaction with the other more Romanised areas, or with Roman soldiers. Two fortlets on the coast at Martinhoe and Old Burrow have been identified as Roman lookout posts, and Roman and native finds (including Roman coins dating to the 1st century AD) were discovered during excavations at these sites (*ibid.*). However, palaeoenvironmental evidence does not show significant changes from the Iron Age to the Romano-British period, suggesting that the Roman invasion did not significantly alter land-use practices in upland Exmoor (Fyfe and Rippon, 2004).

Medieval period (AD 410-1600)

There is little surviving archaeological evidence on Exmoor from the Early Medieval period (Riley and Wilson-North 2001). This period is often referred to as the 'Viking' or 'Anglo-Saxon' period in other areas of the country, due to an influx of settlers from Denmark and Germany, inferred from historical evidence and distinctive finds (particularly grave goods). However, as there is no real archaeological evidence of similar activity in Exmoor, these labels are considered inappropriate. As is common from this period in Britain, little settlement evidence survives, and it is likely that the population lived in dispersed farmsteads. Although the Royal Forest of Exmoor existed before the Norman Conquest, the Norman Kings extended its area and introduced Forest Law. By the 13th century, the forest encompassed much of the upland area, representing a central area of unenclosed land surrounded by villages and their commons, to which stock from the surrounding region was brought for summer grazing (Riley and Wilson-North 2001). The settlement pattern in the later medieval period on Exmoor echoes a familiar pattern seen elsewhere in Britain, with dispersed farmsteads, hamlets, villages, and some towns, with their associated open fields. Some earthwork evidence of abandoned settlements remain (e.g. at Badgworthy), but it is likely that most settlement evidence has disappeared beneath more recent structures in villages (*ibid.*). The majority of palaeoenvironmental sequences cover this period and indicate expanses of damp grassland with heath vegetation at higher altitudes. Around the southern fringes of Exmoor (Molland Common, Long Breach, and Gourte Mires), there is evidence for an expension of arable cultivation into the upland by around AD 1100 (Fyfe *et al*., 2003a). Rippon *et al.* (2006) suggest that this may represent part of a system of crop rotation. Earthworks representing the remains of extensive field systems have been identified at Molland Common, Withypool Common, and Winsford Hill (Riley and Wilson-North 2001), possibly indicating a reorganisation of the landscape during this period. Although it is assumed that deserted medieval villages and relict field systems represent a retreat from marginal land in the wake of the Black Death (Postan 1972; Dyer 1989), palaeoenvironmental evidence suggests continued agricultural use of Exmoor's upland area throughout this period.

Post-medieval to modern period (AD 1600-present)

Although many palaeoenviornmental sequences from Exmoor preserve deposits from the 17th century onwards, pollen analysts have not tended focus on this period, and therefore few high-resolution sequences covering this period have been generated. Difficulties calibrating radiocarbon dates from recent centuries may also be a factor in discouraging analysts from looking at post-medieval samples. The period between 1590 and 1850, known as the Little Ice Age, saw a drop in average temperature of 1 degree Celsius (Roberts 1998). However, this does not seem have had a great impact on agriculture in the South-west uplands, as palaeoenvironmental evidence suggests that landscapes of predominantly open grazed grassland and heathland persist from the medieval into the modern period (e.g. Fyfe *et al.* 2003a).

In the mid-nineteenth century, the Knight family purchased large areas of central Exmoor, and began a widespread programme of agricultural improvement (Orwin and Sellick 1970). Although, to some extent, their schemes had limited long-term success (many of the farmsteads were abandoned and land-use reverted to rough grazing), some key changes have been noted from palaeoenvironmental sequences, for example: rises in pine (and sometimes oak) pollen in the late 18th and early 19th centuries in southern Exmoor (Fyfe *at al.* 2003a) indicates the establishment of plantations; and at Hoar Moor, levels of grass pollen increase significantly in the 19th century as land was enclosed and improved for grazing (Francis and Slater 1990). Palynological studies of palaeosols buried by the construction of the Pinkery Canal in the 1830s on Exmoor by Crabtree and Maltby (1975) provide an insight into the moorland vegetation before the Knight family's intensive programme of moorland reclamation took place. Chambers *et al.* (1999) also undertook research into the antiquity of current vegetation pattern on Exmoor's central moorlands, in order to inform nature conservation and land management policy: finding periodic fluctuations in the dominant vegetation between grasses (likely to be *Molinia caerulea*, or purple moor grass) and heather (*Calluna vulgaris*).

2.7. Summary

This chapter has highlighted the importance of the palaeoenvironmental resource preserved in valley, spring, and soligenous mires on Exmoor to future archaeological/palaeoenvironmental research. It has also outlined a number of threats to these sites, the problems with assessing their archaeological or palaeoenvironmental potential, and obstacles to conserving them. Methodological approaches taken by a number of different projects to monitoring preservation conditions and palaeoenvironmental preservation, as well as resource assessment, have also been discussed.

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter reviews the methodological approaches taken to meet the objectives of the project (section 1.3) and details the procedures followed in the field and the laboratory, and in analysing the resulting data.

3.2. Spatially-extensive survey

3.2.1. Introduction

In 2005 Exmoor National Park Authority commissioned survey of the palaeoenvironmental potential of parts of the moorland (Fyfe 2005). This was prompted by the establishment of the value of small upland mires to preserve detailed local palaeoenvironmental records (e.g. Fyfe *et al.* 2003; Rippon *et al.* 2006), and clear tangible damage to a number of these sites across Exmoor (Fyfe 2006). The 2005 survey covered 31.6 km^2, and piloted methods subsequently further developed for this survey are discussed in this chapter. This section describes the desk-based and field methodologies followed during the spatially-extensive survey. The key questions the development of this survey aimed to address were: Can mires be identified from desk-based assessment? What is the extent of small mires on Exmoor (number, size, depth)? What is the current condition of the peat matrix? Is the condition of the peat under threat, and what do these threats consist of?

3.2.2. Defining the survey area

The survey of the extent and condition of mires took place within Exmoor's 'Moorland Units' (figure 3.1). These areas have been defined for management purposes within Exmoor National Park, and represent a combination of the Section 3 moor and heath (defined under Section 3 of the Wildlife and Countryside (Amendment) Act 1985: HMSO

1985) and DEFRA's Moorland Line (Less Favoured Areas of predominantly upland vegetation used for rough grazing) (Landuse Consultants 2004). Within these areas, the survey took place only with areas defined as access land by the Countryside and Rights of Way Act (CRoW: DEFRA 2000).

3.2.3. Identification of mires: Desk-based approach

A number of datasets were compiled facilitate the identification of potential mires locations within the survey area, to guide field survey. These included: previous peat depth surveys carried out by Merryfield (1977) and Bowes (2006: see figure 2.1); summaries of palaeoenvironmental research from Exmoor (all investigated sites listed in ENPA HER: see figure 2.3.); Ordnance Survey 1:10000 scale maps; a 50m resolution digital elevation model (DEM) for the National Park; and spot peat depth measurements from the Moorland Restoration and Improvement project (MIRE: ENPA 2008). The value of other datasets that might provide less direct indicators of potential mire location was also explored. These included three series' of air photographs (APs) including: 1946-48 black and white verticals; 1977 false colour infer-red verticals; and 2003 25cm resolution colour verticals, which were used to try to pinpoint typical mire vegetation patterns. Other ecological data collated included areas designated as Sites of Special Scientific Interest (SSSIs), vegetation survey data showing key indicator species of mire vegetation (*Drosera rotundifolia* [round-leaved sundew] and *Narthecium ossifragum* [bog asphodel]), areas of identified fen/flush vegetation, and some areas of National Vegetation Community (NVC) classification provided by Somerset Environmental Records Centre and ENPA ecology team. Soil mapping at 1:50,000 scale was also consulted, and for larger mires provided a guide for the possible extent of peat.

Using these datasets, potential mires were identified within an area targeted for a pilot field survey in May 2008. These were areas which exhibited a number of topographic, hydrological, vegetational or other morphological features identified from the datasets compiled in the project GIS (see above). Targetted areas had a one or a number of features including: topographic locations around combes or valleys (avoiding targeting blanket peat areas on the hill crests); were around or near watercourses marked on OS mapping, such as springs and small streams; had drainage ditches, peat cutting, or mire vegetation (such as *Juncus effusus* or *Eriophorum* species) which could be identified from APs; ecological records highlighted mire indicator species (see above); or were mapped as peat on soil mapping (this was only applicable to the larger mire systems due to the scale of mapping).

Initial comparisons were made between the Fyfe (2005) survey of valley, spring and soligenous mires and surveys carried out by Merryfield (1977) and Bowes (2006) of blanket peat. It was found that the blanket peat surveys rarely identified smaller valley, spring and soligenous mires, as a consequence of the sampling interval between depth measurements in their gridded approach, and their explicit focus on larger areas of blanket peat. While in some cases this meant that areas found to have deep peat were re-surveyed at a higher resolution, in other cases, gaps in these surveys, for example around the heads of combes, were targeted for field survey. At this stage no areas were eliminated from the survey due to steep topography (e.g. coastal areas), which would normally preclude the development of peat, as very small mires are known to form in the head of some steep combes. All sites exhibiting one or more of the features mentioned above were initially highlighted for field survey. Potential mire sites were marked on OS maps in the project GIS, and transferred to paper maps for use in the field.

3.2.4. Field survey methodology

A pilot project, drawing on the techniques developed by Fyfe (2005) was carried out in May 2008. While the majority of field survey methodologies were in place by this time (and are described here), other elements of the survey methodology were refined and standardised during this period, and are described in section 4.2.1. As well as focussing on one moorland unit (unit 12: see figure 3.1), the pilot survey (and early weeks of survey) also examined areas which were targeted for survey, as they exhibited a number of features mentioned above, but were thought less likely to have mires. For example, in very steep coastal areas it was thought that the topography might preclude the formation of peat. A number of these areas were therefore visited early in the survey to allow some familiarisation with different types of terrain, and to assess whether these areas could be surveyed more rapidly due to the relative lack of mires compared to more central areas of Exmoor.

Once locations identified through the desk-based study as possible mires were located on the ground, peat depths were taken using a narrow gouge auger to define the extent of the mire. The locations of these points were recorded with a hand-held GPS (with a horizontal accuracy of 5 metres or less). At one or more of these locations within the mire (up to 5 or 6 locations in very large mires) a peat core was removed with the auger and described using the Troels-Smith system (1955): peat condition, colour (*nigror* or darkness), and humification was recorded using both an average and range (e.g. 2 and 1-3). Peat type (*Sphagnum*, sedge, wood, or SH: very humified peat whose components can be recognised) was also recorded at each location. A $1m^2$ quadrat was then used to record the percentages of different vegetation species at each sampling location. A number of vegetation keys and reference books were used as an aid to plant and bryophyte identification (e.g. Phillips and Grant 1980; Hubbard 1992; Rose 2006). Visual assessment and peat depth survey also allowed the mire type (combe head, valley, spring, soligenous/slope, or flush) to be recorded.

Alongside peat condition, the overall condition of the mire was assessed: this was based on the extent of visible damage or threats to the peat matrix observed through walkover survey, and was deemed important to provide an audit of the current state of the potential palaeoenvironmental archive. A number of pre-established threats were developed through the pilot study in 2005 (Fyfe 2005; 2006; see table 2.5). The number and extent of these threats to the peat matrix were recorded, including damage causing physical peat loss and aeration/drying and cracking of the peat, leading to decay. To allow further monitoring to be carried out at any time of the year, only threats which would be clearly visible at all times of the year were noted. Indicators of damage, such as the sound of running water in peat pipes beneath the peat, which would be more obvious in winter than summer, were therefore excluded from assessment. The condition of each mire, based on these threats, was assessed at one or more locations (depending on the size of the mire), and assigned a condition score from 1 (pristine mire) to 5 (very damaged mire). A key was developed during the pilot survey in May 2008, setting out a standardised and replicable system for mire condition assessment, and ensuring consistency in survey results, and is described in section 4.3.1.

3.2.5. Data analysis

The results of the walkover survey were loaded into the project GIS. Mire polygons were defined using peat depth data. Where the peat condition was assessed at more than one location within a mire, average values were assigned to the mire polygon. Vegetation condition for each mire was assigned as either in good, bad, or mixed condition. This assessment was based on the number of indicator species of good mire vegetation condition, and the presence or absence of species indicative of unfavourable vegetation condition defined by the Natural England Common Standards for Monitoring Guidance for Upland Habitiats (Natural England 2006) across all vegetation quadrats recorded within each mire. This includes indicator species for valley bog, transition mire, ladder fen, quaking bog, and short sedge acidic fen habitats. This data was then used alongside other datasets, such as the proximity of mires to sites designated as archaeologically important, to develop a system for assessing the importance or value of mires as palaeoevironmental resources. The development of this valuation system is outlined in chapter 7 (section 7.4 2).

A number of statistical tests were used to analyse the significance of any correlation or covariance between datasets. Parametric tests, including Pearson's correlation and One Way Analysis of Variance (ANOVA) were used for continuous data (including peat depth, mire elevation, and mire area) (Shaw and Wheeler 1994). ANOVA (and Kruskal-Wallis) tests could be carried out to compare groups comprising different numbers of variables: for example, analysing covariance between the peat depths or elevations of different mire types. This allowed the effect of a discrete variables (or classifications), such as mire condition (recorded on a 1 to 5 scale) or peat condition (recorded on a 0-4 scale [Troes-Smith 1955]), or continuous variables to be analysed (as long as the data was normally distributed). Although parametric tests are considered more powerful, non-parametric Spearman's Rank Correlation was used to analyse the correlation between ordinal and nominal datasets, such as mire and peat condition, mire type, and vegetation condition (*ibid.*).

3.3. Site-based intensive survey

3.3.1. Introduction

The aim of the site-based intensive survey was to look at the effect of various types of damage to mires (including drainage ditches and peat cutting) on water-table levels within the peat, and the effect of this recorded water-table draw-down on the condition of palaeoenvironmental remains within the peat matrix. A number of methods were also trialled to analyse current decay rates within the peat.

3.3.2. Water-table monitoring

3.3.2.1. Site selection

The selection of three monitoring sites was based on Fyfe's (2005) pilot survey, the results of which included peat depth and mire condition data within moorland unit 7 and 13. Selection criteria included: the visibility of a variety of damage type to the mire (e.g. drainage ditches, peat cutting, peat piping), with peat in between these damage features; the accessibility of these sites for water-table monitoring; and the proximity of these mires to each other, to facilitate monitoring and so that the mires were subject to precipitation conditions.

3.3.2.2. Topographic and peat depth survey

Preliminary peat depth survey was carried out with a narrow gauge auger, to roughly determine the extent of the mires. This was followed by a gridded peat depth survey at 10m intervals across each mire. The locations of the peat depth measurements and spot-heights at each of these points was recorded using a Trimble RTK Differential GPS system, using both a fixed base station and rover unit, to minimise the horizontal and vertical positional errors. This data was post-processed to further reduce these errors to around 1-2cm horizontally, and 5-15cm vertically. The surface topographic survey data was, however, superseded by higher-resolution LiDAR data, collected in 2010.

3.3.2.3. Dipwell insertion and monitoring

Following peat depth surveys across the mires, dipwell locations were selected, with the aim of creating transects of dipwells across perceived damage gradients and through central, or deeper, sections of the mires. Water-table levels could then be monitored in relation to mapped damage features, to observe the effects of mire drainage and peat cutting on water-table levels at incremental distances away from these features.

Dipwell construction is illustrated in figure 3.2. 40mm plastic piping was selected for dipwell construction, as it was felt that a narrower pipe may cause water to be forced upwards under pressure, resulting in false water-table readings (Charman *pers. comm*.). Two lines of 5mm holes at were drilled along opposite sides of the pipes at 20mm intervals along their entire below-peat length. This allowed free entry of water into the pipe. These holes did not extend above the ground surface, so that water running over the surface of the peat could not enter the pipe. Also, the dipwells were sheathed in a fine nylon mesh, which allowed the free entry of water, but prevented the holes in the piping from clogging with sediment. The bottom of the dipwells were sealed and capped, to prevent water entering through the base. Previous peat depth survey meant that the depth of the peat was known prior to dipwell insertion. This allowed dipwells to be inserted to a depth which was within a few centimetres of the base of the peat. It was decided that dipwells should not extend below the peat, or come into contact with underlying sediments, as these may have had different hydrological properties to the peat. If underlying sediments, for example, were less permeable then peat (with lower hydrological conductivity), water could potentially travel along the top of this layer, and be forced up into a dipwell if it provided a channel of lower resistance (Charman *pers. comm*.). This could lead to a falsely high water-table reading.

During the monitoring period (28th February 2008 to 9th March 2010), dipwell readings were taken every week during the summer months (April to October), whilst water-table levels were likely to be low or fluctuating. Fortnightly readings were taken over the winter months (October to April), during which time water-table levels were likely to be higher and more stable due to antecedent moisture storage (Branfireun and Roulet 1998; Charman 2002). Readings were always taken at a similar time of day (between 11am and

2pm) to minimise the effect of diurnal water-table variation caused by evapotranspiration (Charman 2002). Readings were taken by measuring the depth of the water-table from the lip of the dipwell, using a dipwell meter (an electronic device which emits a beeping noise once its sensors come into contact with water, completing a circuit), and subtracting from this the height of the lip of the dipwell above the peat surface. This calculation was carried out to account for any movement of the dipwell in relation to the surface of the peat, because of peat shrinkage or swelling (Charman 2002; Lindsay 2010). As the dipwells were not tied in any way to the base of the peat, but were essentially 'free floating' within the peat matrix, any movement of the peat surface would be likely to also shift the dipwells. Thus the relationship between the surface of the peat and the dipwell was likely to remain fairly constant. Lindsay (2010) suggests that measuring water-table levels in relation to the peat surface actually provides an underestimate of the area of the mire affected by water-table draw-down, as it does not take account of surface subsidence, caused by the consolidation and shrinkage of surface layers as water escapes from the peat. However, as the depth of samples taken from cores extracted from the sites are always related to the surface of the peat, relating water-table levels to the peat surface allowed cross-referencing between these two dataset. This was considered important, as it allowed the key research question of what impact water-table draw-down has on the condition of the palaeoenvironmental resource, to be addressed. Furthermore, the fact that the peat matrix was fairly dense/compact across the mires, with no identified floating vegetation 'mats' or schwingmoor-like areas, meant that it was unlikely that the surface of the peat would move in a substantial or measureable way (differential GPS vertical accuracy was unlikely to be sufficient to detect any changes) due to water-table fluctuation (Charman 2002).

3.3.2.4. Data analysis

Initial processing of the water-table data involved producing water-table 'zones' for each dipwell. Three zones were defined: the first represented the areas of the peat which were constantly above the water-table (i.e. dipwells readings were always below this level during the monitoring period); the second, zones of fluctuating water-table, representing the range of water-table variation during the monitoring period; and the third, areas of the peat which were constantly saturated with water, or below the lowest water-table reading take during the monitoring period.

Daily rainfall data was obtained for Winsford Weather Station (BNG SS906347) for the monitoring period, and the preceding 50 years from the British Atmospheric Data Centre (BADC) from the Met Office MIDAS Land Surface Stations dataset. This station was chosen as it was within 12km of the sampling sites and had continuous daily precipitation readings for the whole of the monitoring period (28/02/2008-09/03/2010) and also from 02/02/1973 to the present. Daily precipitation data from the last 35 years (during which there is available, continuous daily precipitation data) was plotted as a line graph and compared to data during the monitoring period, to determine whether or not precipitation during the monitoring period conformed to typical patterns for preceding years: comparable patterns in precipitation would suggest that water-table readings from the dipwells may be similar to water-table levels over at least the last 35 years. Past water-table levels were then modelled for the last 35 years. To do this, linear regression was run between rainfall readings from Winsford weather station averaged over different numbers of days preceding dates of dipwell readings, and dipwell readings from the selected locations. The equation of the line with the highest R^2-value was selected to apply to the daily precipitation data from the last 35 years. This produced modelled water-table levels for all dipwells for every day from 02/02/1973 until 02/02/2008.

3.3.3. Core sampling

3.3.3.1. Coring location selection

The selection of coring locations was based on the first 3 months of water-table monitoring data. From each of the three mires a control location was selected, in close proximity to (no more than 2m away from) a dipwell which showed continuously high water-table readings. One or two test/experimental locations were also selected from each mire, in close proximity to dipwells with either continuously low or highly fluctuating water-table readings. The test locations were likely to be in proximity to mapped damage features, whilst the control locations were likely to be in the centre of the mires, near dipwells which were the furthest from visible damage features. Cores could not be taken directly adjacent to the dipwells, as this may have altered water-table readings.

3.3.3.2. Coring methodology

Cores were recovered from seven selected coring locations using a Russian-type corer (Jowsey 1965). Preliminary core stratigraphy was recorded in the field and refined in the lab, using the Troels-Smith system for sediment description (Troels-Smith 1955; Aaby and Berglund 1986). Cores were then wrapped and stored in refrigerated units for the duration of the project.

3.3.4. Assessing current decay rates

The presence of pollen in deposits where few other organic remains are preserved (e.g. many archaeological contexts), indicates that pollen is particularly robust and resistant to decay through oxidation. Results of experiments assessing the damage and loss of pollen over a 20 year period by Havinga (1984) demonstrated that there was no appreciable loss of pollen. This suggests that experiments to look at the loss of pollen over the duration of this study (2-3- years) would not be effective. However, monitoring decay rates during the project would be useful as an indicator of which areas of the peat matrix organics are likely to decay, and where there may be loss or damage to organics or pollen over the coming decades. Furthermore, the benefit of carrying out experiments into decay rates over the monitoring period is that, unlike the study of damage to pollen remains or peat humification, results are not influenced by events contemporary with or post-dating peat formation (i.e. human impact or climate change).

It would be expected that redox (Eh) readings in sections of the peat matrix which are constantly above the water-table, or subject to fluctuating water levels, and therefore more often oxygenated, would have more positive Eh readings (Urquhart and Gore 1972, Caple 1996, Charman 2002, Holden *et al.* 2006a, Lillie and Smith 2009). Although *in situ* redox and pH monitoring (as carried out, for example, by Vorenhout *et al*. 2004, Lillie *et al.* 2007) was not possible, Eh and pH were assessed using portable hand-held meters. To take readings, these electrodes were inserted directly into the peat at various depths in all extracted cores in the field, and a sample of the cores in the lab. Electrodes were calibrated using buffer solutions between sets of readings. Readings in the lab were taken using the same calibrated probes within 2-3 days of the extraction of the core, as well as within 1 month. During this time, the cores were sealed in LDPE plastic wrap (cling film) and protective plastic sleeve, and refrigerated below 5^{o}C.

A number of studies have investigated decay rates through recording the loss in mass or organic remains placed into *in situ* soils or sediments, or into lab-based experiments which artificially recreate particular environmental conditions (e.g. Lillie and Smith 2007; Bragazza *et al.* 2007). Unbleached woven cotton strips were chosen as the experimental substrate for this study in preference to plant material (as was used by Bragazza *et al*. 2007). This was because it was felt that standardising the plant material inserted into each experimental sample may be difficult, and it has been shown different types of plant material (particularly between different plant species) may decay at different rates (*ibid.*). Also, if was felt that bags of organic material would be difficult to bury in the peat without disturbance of the peat profile. Monitoring of the decay of cotton strips has been used in a number of previous studies have use the decay of cotton strips as a proxy for the decay of other organic materials such as wood, as cotton and all plant material is composed of cellulose. A number of studies presented in Harrison *et al.* (1988) test the impact of exposure various conditions within soils and sediments or increased microbial activity cotton strip material. Although many of these studies (e.g. Smith and Maw 1988) used the reduction in tensile strength of the cotton strip material resulting from this exposure as a proxy for rate of decay, mass loss after exposure was chosen as a more straightforward method for assessing rates of decay for this study.

Unbleached, woven cotton strip fabric was cut into 15cm lengths and each end hemmed to prevent the loss of fibres through fraying. The weight of each of these strips was noted. Untreated pine stakes were cut to the depth of the peat at the seven coring locations (LK2, LK4, SH7, SH8, SH10, B15, and B19), with the addition of an extra 20cm, which would allow the stakes to protrude above the surface of the peat. The strips were then stapled to the stakes (using galvanised staples), so that each strip was contiguous with the next, along the length of each stake (see figure 3.3). All the stakes were then inserted into the peat within 1m of the corresponding dipwell, with top of the uppermost cotton strip level with the peat surface. Duplicate stakes were inserted at B15 and B19, and removed after 3 months to check that decay had not already become too advanced, making it unlikely that the stakes could be removed without loss of material. After 6 months (30/07/2009-14/04/2010) all the stakes were removed from the peat and sealed into waterproof plastic sleeves. The cotton strips were removed from the stakes within 4 hours, rinsed throrughly in deionised water to removed peat residue, and dried at 100^{o}C overnight, before being weighed. The resulting weight, for each strip was then deducted from the initial weight before insertion into the peat, allowing the percentage mass lost over the 6 month period to be calculated. The resulting figure for each strip was then treated as a proxy for decay rate of organic remains at a particular depth in the peat matrix at different coring locations: i.e. the higher the percentage of the original mass lost the more rapid the rate of decay.

3.3.5. Laboratory methodologies

3.3.5.1. Dating methods

Chronological control on the archived cores was developed using samples submitted to the Chrono 14C centre (University of Belfast) for radiocarbon assay. Three cores were chosen for dating: one from each mire. Four samples were selected from each of these cores. The locations of cores and samples were chosen for different reasons, which will be outlined in chapter 5. All dates were calibrated to calendar years BP and AD/BC using the CALIB version 6.0 Radiocarbon Calibration programme and calibration curve Intcal09 (Stuiver and Reimer 1993; Reimer *et al*. 2009). Spheriodal carbonaceous particles (SCPs) were also counted and take-off and peak features were dated according to datasets compiled for south and central England by Rose et al. (1995) and Rose and Appleby (2005). Age depth models were constructed using cubic spline interpolation between dates using the programme CLAM (Blaauw 2010).

3.3.5.2. Peat humification

Peat humification calculation was carried out using a method based on Blackford and Chambers (1993). Samples of 2cm thickness (the centre of the samples was used as the depth measurement for the samples in further analyses) were weighed, oven-dried at 100^{o}C for 12 hours and ground with a pestle and mortar. 0.2g of each sample were placed into 100ml of 8% NaOH solution and simmered for 1 hour. These solutions are diluted to make up 200ml, and 50ml of the resulting solution was filtered through

Whatman No.1 grade filtration papers. The resulting solutions were again toppoed-up to 100ml. A small volume of the solution was pipetteed into a cuvette and percentage light transmission was measured using a spectrophotometer. Transmission at 540nm was measured 3 times and the mean calculated. These values were corrected for loss on ignition (LOI) using the formula: Corrected % transmission = % transmission/(1/LOI expressed as a proportion) (Payne and Blackford 2008). Some of the more minerogenic sediments (with low LOI) at the base of some of the cores were excluded from further calculations because of very high corrected values (*ibid.*). In the following statistical analyses, percentage transmission values are used rather than using a residual of this value as a direct proxy for humification. As peat humification increases as a function of age (Payne and Blackford 2008; Chambers et al. 2011), alongside other factors affecting preservation (which these analyses aimed to study), the percentage transmission values were also linearly detrended.

Peat humification (or humicity) was also recorded visually using the Troels-Smith (1955) system: the humification of the peat is recorded on a 0 to 4 scale, where peat scoring 0 is not humified (consisting of undecayed plant material), and peat scoring 4 is very humified (plant material is so decayed that the peat appears homogenous).

3.3.5.3. Pollen analysis

1 cm^3 sub-samples of the seven archived cores were taken for pollen analysis, initially at 8 cm resolution, with higher resolution sampling (every 2cm) in the top 10cm of each core. Samples were prepared using standard procedures (see Moore *et al*. 1991): An exotic marker (*Lycopodium*) tablet was added to facilitate calculation of pollen and charcoal concentrations (Stockmarr 1971). Non-pollen organics were removed using an acetolysis digestion and the remaining material was mounted on slides in silicone oil for identification. A minimum of 300 land pollen grains (including Cyperaceae) were

identified from each level, using a light microscope at 400× magnification. Grains were identified using the keys in Moore *et al*. (1991) and type slide collections at the Universities of Plymouth and Exeter. Identification was standardized to the taxonomy proposed by Bennett (1994). Charcoal fragments were counted from each pollen sample in two size classes (<50 microns, >50 microns) and are expressed as concentrations (number of charcoal fragments per cm^3).

Following condition categories established by Delcourt and Delcourt (1980), and used by Jones *et al.* (2007), each grain was assigned to one of eleven condition categories based on 5 basic categories defined by Cushing (1967: undamaged, corroded, degraded, broken, and crumpled), and described in table 3.1. The approach taken to analysing pollen condition in this study differed from that outlined by Jones *et al.* (2007) in a two ways: Firstly, all 300 grains in each sample was assigned to a condition category (rather than a sub-sample of 100). Secondly, each grain was only assigned one condition category from which it was seen to suffer most extensively. This meant that each grain was only recorded once. This was necessary as a number of studies have indicated that pollen are differentially susceptible to different types of damage due to differences in the structure and chemical composition of their exines (e.g. Havinga 1984). If the impact of water-table draw-down (and potentially past climate and human impact) on the condition of pollen remains within peat is to be analysed, the skewing effect of changes in the pollen assemblage (due to changing vegetation communities in the environment contemporary with peat formation) must be excluded. To do this, the susceptibility of each taxon to different types of damage (corrosion, degradation, breakage, and crumpling) was assessed. This allowed changes in the extent or type of damage through the cores caused by changes in taphonomic conditions (the focus of the study), rather than by changes in dominant taxa, to be isolated. The methodologies applied for analysing this data, including the calculation of 'susceptibility ratings' for different damage types for each taxa, and the calculation of damage scores, are described in section 3.3.6.3.

The approach taken differs from that used by Jones et al. (2007) and Delcourt and Delcourt (1980), who often recorded one grain in each damage classification, but *did not* record the taxa and damage type *together*. This approach would not allow calculations to be made as to the susceptibility of each taxon to damage. The approach to counting grains also differs from that of Lowe (1982) and Tweddle (2000), who recorded grains in only one condition category, but if more than one type of damage was seen, the damage category was assigned using a hierarchical system proposed by Cushing (1967): In this system, damage types were placed in an arbitrary order (corroded, degraded, broken, and crumpled), and if more than one damage type was visible on a grain, its damage type was assigned according to this order. For example if a grain was both crumpled and corroded, it was recorded as corroded. The problem with this hierarchical system is that it gives increased weighting in the final dataset to damage types higher in this order: corrosion over degradation; degradation over breakage, etc. The approach used in this study, of recording the damage type which appeared the most extensive was thought to be necessary to allow the number of grains and the extent of damage to grains to be more fully assessed. Despite the fact that it might make the results less comparable with those from other studies (described above).

3.3.5.4. Testate amoebae

2 cm^3 sub-samples of the seven archived cores were taken for testate analysis at 8 cm intervals. Testate amoeba preparation was modified from approaches outlined in Charman *et al.* (2000) and Booth *et al.* (2010). A number of preparation methods were trialled (see table 3.2), and resulting testate concentrations compared. The samples were then passed through 300 and 15 µm sieves, to remove coarse and very small particles. The material retained on the 15 µm sieve was then washed into tubes and centrifuged at 3000rpm for 5 minutes. Following this, water is decanted and samples are transferred to

vials. One the samples have settled, more water was pipette off. Small vials of glycerol were prepared and a sub-sample was added at the ratio 1:3 (sample:glycerol). This mixture was then mounted on slides for counting at 200× magnification (switching to 400× when a more detailed view was necessary for taxon identification).

Identification was based on the key in Charman *et al.* (2000), after training using modern samples from the site (prepared using the method outlined above). Each test counted was also recorded in one of five condition categories (OK/no visible damage, corroded, degraded, broken, or crumpled).

3.3.6. Data analysis

3.3.6.1. Presentation of stratigraphic data

All cores were zoned using stratigraphicallly constrained cluster analysis in Tilia (Tilia version 1.5.12: Grimm 2011). This produced both Local Pollen Assemblage Zones (lpaz) and Local Pollen Preservation Zones (LPPZ). Local Pollen Assemblge Zones (lpaz) were created from running stratigraphically constrained cluster analysis on pollen taxa summary data (excluding spores and pollen condition data). Local Pollen Preservation Zones (LPPZ: following Tweddle and Edwards 2010) were created by carrying out the same process using taxon-weighted damage scores (corrosion, degradation, breakage, and crumpling scores) and excluding pollen taxa summary data. Applying the taxon-weighting to the damage scores should allow the LPPZ to be independent of changes in pollen taxa through the cores. Each core is therefore presented as two zoned stratigraphic diagrams (produced in C2 version 1.5: Juggins 2007) with accompanying tables of descriptions of the zones.

3.3.6.2. Biostratigraphic correlation between dated and undated cores

It has not been possible to date all seven of the cores examined within this project due to the cost involved. Four radiocarbon dates were taken from three cores: one from each mire (section 3.3.5.1.). Whilst it is possible to correlate sequences from different cores by depth, it is unlikely that peat any given depth in two cores was formed at the same date: even cores from the same mire may have different dates of peat inception and rates of peat accumulation. Estimating ages of undated cores thus requires a biostratigaphical approach: While each core was zoned separately using stratigaphically constrained cluster analysis (see above), producing local pollen zones (lpaz), the aim in using a biostratigraphical approach was to produce overarching regional pollen zones (RPZ) which could be applied to all the cores. This would allow the examination of vegetation and pollen condition changes across all cores through time, facilitating analysis of the importance of past events and current conditions on the condition of the palaeoenvironmental resource within the peat matrix at the intensive study sites. The first step was to outline the RPZ using the dated cores: All dated samples were entered together into Tilia (Grimm 2011) and sorted by date. Stratigraphically constrained cluster analysis was then carried out on this dataset, excluding spores and aquatics from the analysis, as these are most likely to show highly localised changes. This produced RPZ 1-6, with which the dated core from each site (LK2, SH8, and B15) was zoned separately in C2. On a site-by-site basis, the key stratigrahic changes in taxa through each RPZ in the dated cores were used to allocate RPZ boundaries (and therefore approximate dates) to the undated cores.

There are a number of problems with this approach: Firstly, changes in herbaceous and aquatic taxa can be highly localised, meaning that similarities between mires may be misleading. Despite the removal of spores and aquatic taxa from the cluster analysis, this may still lead to some uncertainties around zone boundaries in undated cores. Secondly, the low resolution of radiocarbon dating in the dated cores (only 4 dates from each core) may mean that there is a fairly high level of uncertainty around the dates of sample depth from the dated cores (error boundaries are quantified in chapter 5).

3.3.6.3. Calculation of pollen preservation indices

The technique of assigning each pollen grain identified to one of 11 condition categories (see table 3.1) generates a substantial dataset, as each grain within each sample is assigned to a taxon as well as a condition category: this amounts to over 900 ‘pseudospecies’ when taxa and condition category are concatenated (e.g. *Alnus* condition 1, *Alnus* condition 2,....*Alnus* condition 11, *Betula* condition 1, *Betula* condition 2...etc). The volume of data makes the visual assessment of patterns impossible, as the diagrams produced are prohibitively long and the patterning of the data very complex. To allow trends in damage both within and between cores to be analysed, damage scores (or indices) were generated (Jones *et al*. 2007): these allowed damage trends to be plotted for each core and allowed comparison with other cores and environmental variables.

Damage scores were generated for overall damage, including corroded, degraded, broken, and crumpled gains, as well as for each of these damage types individually: i.e. an overall damage score, as well as a corrosion score, degradation score, breakage score, and crumpling score was calculated for each sample. This was deemed to be necessary as different types of damage to grains are known to be caused by different processes (see section 2.3.2.2). Assessing the prevalence of different types of damage in relation to modern water-table draw-down and past climate reconstructions, as well as comparing damage types between cores, allowed more detailed analysis of the processes causing damage to pollen grains.

To generate simple damage scores, each type of damage is given a score depending on its extent (more damaged = higher score: see table 3.1). For each sample, the total number of grains in each damage category is calculated, and each figure multiplied by its corresponding damage score (e.g. 30 grains in condition 9 'broken' = 30×3 = 90). These scores are then added together to produce one figure. This figure is divided by total number of grains counted in the sample to give a single damage score for each sample. This method is based on that described in Jones *et al.* (2007), with slight modifications to scoring to make scores comparable in a more straightforward way (so that the final crumpling and breakage scores or indexes, as they term them, do not have to be divided by a constant).

$$\textbf{Damage score} = \frac{\textbf{total damage score for sample}}{\textbf{number of grains in sample}}$$

This method, however, does not take into account the fact that different pollen taxa may be differently susceptible to damage (i.e. some grains may be weaker/more robust than others: Havinga 1984; Jones *et al.* 2007; Twiddle and Bunting 2010) and therefore changes in pollen assemblage in samples through the cores may have an effect on the damage scores for individual samples. The next stage of data analysis therefore involved calculating damage scores weighted by the taxa present in each sample, taking into account the robustness of each taxa and susceptibility to different types of damage: The first step is to calculate a 'susceptibility rating' for each taxon found across the cores: the more susceptible grains from that taxon are to damage, the higher the rating. This is essentially an average damage score for an individual taxon, and is calculated by summing the frequency of grains in each damage category from all the cores, and multiplying each frequency by its corresponding damage score (e.g. [30 *Betula* grains in category 2 = 30×1] + [10 *Betula* grains in category 3 = 10×2] etc....). These scores are then added to give one figure, which is then divided by total number of grains from that taxon in all the cores (overall count).

$$\textbf{Susceptibility rating} = \frac{\textbf{Overall score for a taxon}}{\textbf{Number of grains of taxon present in sample}}$$

A number of other researchers, notably Havinga (1984) and more recently Lebreton *et al*. (2010), have ranked pollen taxa according to their susceptibility to damage. However, these ranked lists do not always correspond between publications, only include a limited number of taxa, usually only discuss one type of damage, or conflate types of damage which are separated by the system used in this study (see sections 2.3.2.2 and 3.3.5.3). For example, Havinga (1984), Lebreton et al. (2010), and Twiddle and Bunting (2010) analyse the susceptibility of grains to corrosion and degradation, whilst susceptibility to breakage and crumpling is addressed by Campbell (1991; 1994; 1999) and Holloway (1989). A number of other studies do not address in detail the differential susceptibility of pollen taxa to different types of damage (e.g. Wilmshurst and McGlone 2005; Jones *et al*. 2007; Tweddle and Edwards 2010), or present the results of these analyses in a way which this data can be extracted and used to create 'susceptibility ratings'. As a result of the lack of comparability between studies, and the lack of observational data from field studies (Tweddle and Edwards 2010) as opposed to lab-based experiments in controlled conditions (some of which state the lack of correspondence between their results and field studies: e.g. Lebreton *et al.* 2010), it was decided to develop the methods described above for creating susceptibility ratings for each taxa to each type of damage. This method carries with it a number of potential problems, such as: the potential that some taxa may occur preferentially in samples which are more damaged resulting in an elevated susceptibility rating; the possibility that some taxa may be particularly damaged in these mires due to site-specific processes; and the fact that the same data is used to create susceptibility rating as the ratings are applied to in further calculations. However, it was felt that a consistent method must be developed to assess all damage types, and to allow the condition of pollen to be compared within and between cores to answer one of the key question of the project: whether or not water-table draw-down affects the condition of pollen grains within the peat.

Using the susceptibility rating, taxon-weighted damage scores can then be calculated for each sample. Firstly the total damage score for each taxon (e.g. *Betula* or *taxon X*) in a sample is calculated (as for raw damage scores). This is multiplied by the 'susceptibility rating' for this taxon (see above), and the result is divided by the number of grains of that taxon in the sample. For example:

$$\textbf{Damage score for } \textbf{\textit{taxonX}} = \frac{\textbf{total score for } \textbf{\textit{taxonX}} \textbf{ in sample} \times \textbf{\textit{taxonX}} \textbf{ 'susceptibility rating'}}{\textbf{Number of } \textbf{\textit{taxonX}} \textbf{ grains in sample}}$$

The resulting scores for each taxon are added together and divided by the number of different taxa present in the sample, to produce the taxon-weighted (TW) damage score.

$$\textbf{Taxon-weighted damage score} = \Sigma \frac{\textbf{damage scores for taxa}}{\textbf{number of taxa in sample}}$$

Taxon-weighted scores for each type of damage (corrosion, degradation, breakage, crumpling) can also be produced by calculating a damage score for on the selected damage type (e.g. corrosion) and a susceptibility rating for each taxon for this damage type. The same equations can then be used, substituting 'damage score' for 'corrosion score', etc.

In their analyses of pollen condition, Jones *et al.* (2007) grouped corrosion and degradation scores into a biochemical damage index; and breakage and crumpling scores into mechanical damage. Whilst a number of investigations (both in controlled lab conditions and in the field) have taken place into the causes of damage to pollen grains (see section 2.3.2.2), none have proved definitive on the causes of different types of damage to pollen grains. For this reason, it was decided to analyse the four types of damage separately, rather than amalgamating them into mechanical or chemical damage.

3.3.6.4. Other approaches to assessing pollen preservation

Bunting and Tipping (2000) developed a method for assessing the extent of damage to pollen assemblages, by testing results for each sample against a number of criteria which are indicative of poor preservation conditions (see table 3.3). In their analyses, samples which fulfilled one or more of the criteria, were rejected, as results from these samples were likely to have been skewed by taphonomic processes, and thus no longer reflected the living vegetation assemblage a predictable (or 'modelable') way. In this case, the tests are used to assess whether or not samples in zones of the peat matrix consistently above the water-table, or in zones of fluctuating water-table, had more biased or poorly preserved pollen assemblages.

3.3.6.5. Statistical analyses

To analyse statistically any relationships between pollen damage scores and environmental variables such as peat humification, water-table zone, and testate concentration a number of techniques were employed. Correlation analysis (using Pearson's Correlation Coefficient) was carried out to test the statistical significance of any relationships between continuous variables including pollen damage scores, pollen concentration, water-table residence time, peat humification (expressed as % transmission), testate amoeba concentration, and the percentage of robust grains. These analyses were carried out both for the overall dataset of 158 samples, as well as for each core individually. One way analysis of variance (ANOVA) was used to assess whether categorical variables such as water-table zone, the mire, core or RPZ a sample came from, or whether a sample fell within wet- or dry-shifts of climate reconstructions

(Charman *et al* 2006; Amesbury *et al.* 2008), had a statistically significant effect on continuous variables including pollen damage scores and peat humification (Shaw and Wheeler 1994). Principle Components Analysis (PCA) and Detrended Correspondance Analysis (DCA) were also carried out using PC-Ord5 on pollen damage data. These are ordination methods which involve scoring samples on the basis of their similarity to each other across multiple variables (Maddy and Brew 1995). Whilst damage scores were used as the first matrix, and basis for the ordination calculations, the second matrix included categorical data such as which mire, core a sample came from, or which RPZ or water-table zone a sample fell within. It also included continuous data, such as the depth of each sample. The selection of an ordination method (PCA or DCA) depended on the distribution of the data (and whether or not it had been normalised, as DCA cannot be run on variables with negative numbers), was based on Maddy and Brew (1995), and is explained in relation to the raw data in chapter 6. Ordination plots were used to visualise any patterning in the distribution of the data, and clarify relationships between pollen damage and peat humification, water-table level, past events, or mire-specific processes.

3.4. Summary

The methodologies described in this chapter were developed to suit the aims of the research and to achieve the project objectives (see section 1.3), covering both the spatially-extensive and site-based elements of the project. Field methodologies for the identification and assessment of mires were outlined; as were monitoring, sampling and data collection procedures, and methods for analysing the resulting data.

CHAPTER 4: RESULTS OF SPATIALLY-EXTENSIVE SURVEY

4.1. Introduction

This chapter outlines the standardised methodologies, developed through initial pilot survey, for assessing the extent and condition of the palaeoenvironmental resource on Exmoor, as well as presenting the results of the spatially-extensive survey.

4.2. Extent of the palaeoenvironmental resource

4.2.1. Developing methodologies for assessing the extent of the resource

Initial desk-based survey for potential mire locations (see methodology section 3.2.3) highlighted a number of areas within the study area which could be eliminated from the walkover survey, as they fulfilled none of the selection criteria (see section 3.2.3). These included areas with no watercourses marked on OS maps or visible on APs, and areas located centrally on upland plateaus, which earlier surveys (Merryfield 1977; Bowes 2006) indicated had significant depth of blanket peat. As well as highlighting areas of high-potential for the presence of mires, the desk-based survey also highlighted areas which, while not being eliminated from the survey for the reasons stated above, were thought to be less likely to facilitate peat formation: these included areas with particularly steep gradients, for example steep combes in the coastal moorland units.

The pilot walkover survey, which took place in May 2008 had three main purposes: to assess the effectiveness of desk-based selection of potential mires; to trial the sampling methodology to allow the remainder of the survey to be scheduled; and to develop a standardised mire condition key and recording methodology to facilitate the replicability of the study. While the overall effectiveness of the desk-based assessment method will be discussed in section 4.2.2, the targeting of the pilot survey on a variety of different areas (central moorland, larger river valleys, high moorland combes, and coastal areas), allowed decisions to be made about targeting and scheduling the remainder of the survey. Walkover survey of the coastal areas, indicated that the very steep gradients in these areas seemed to preclude peat depth formation, even in the head of combes. The open access area on the coast is also often confined to the immediate area around the South West Coast Path, limiting the area for survey to the heads of steep coastal combes or inlets. The decision was therefore made to confine the survey of coastal areas only to those locations highlighted for desk-based assessment which were most safely and easily accessible. It was also assumed that in timetabling the survey of these areas, survey would be rapid and often without the need for sediment/soil probing, and so little time was allocated to these areas. Recorded depth coverage in these areas is consequently patchy, and they are not specifically illustrated in peat depth distribution maps (figures 4.2-4.4).

The description of mire types was developed during the pilot survey in May 2008, and was based on a combination of their morphology, hydrology, and topographic position, and mire descriptions from a number of sources including Charman (2002) and descriptions used by Fyfe (2005) for small mires on Exmoor (see figure 4.1 and table 2.4). For example valley and combe head mires were classified due to their topographic position, whilst flush or spring mires were classified due to their hydrology. The term ‘combe head mire’, whilst not commonly used in the literature (Wheeler [1995] refers to this type of mire as a valleyhead wetland or headwater fen), has been used to describe mires which form at the tops of combes or small valleys where the gradient is lower than the slopes above and below, and a small basin-like mire forms above the clear beginning of a watercourse. This therefore distinguishes these mires, on topographic grounds, from valley mires which form in the bottom of combes/valleys. The topographic position also means that combe head mires are often physically separated from areas of blanket peat, as well as having differing hydrological status, i.e. they are partially groundwater-fed, rather than entirely rainwater-fed. It was found that mire types were often difficult to distinguish clearly, as variation appeared to be fairly continuous. The use of compound terms was often necessary to adequately describe mire morphology, hydrology and topographic position: for example, a mire could begin in a small basin-like feature at the head of a combe, and extend around the side of a combe (therefore termed combe head/soligenous) or extend down into the bottom of the combe (combe head/valley); or a mire could form around a spring creating a small flush (spring/flush) on a hillside or form a larger mire across a more gentle slope (spring/soligenous).

4.2.2. Distribution of mires

In total, 119 mires were identified in a survey area of $153km^2$ (figures 4.2 to 4.4), varying widely in size from $20m^2$ to $160000m^2$ ($0.16km^2$/16ha), and covering a total area of around $2km^2$. The following results do not include the results from Fyfe's (2005) survey (moorland units 7 and 13: see figure 3.1), as some elements of mire recording differed from this survey. Around 75% of the mires defined were found at elevations between 350 and 450 metres (above Ordnance Datum: see figure 4.5). The majority of mires are found the central and western areas of Exmoor's moorland (figure 4.3), with fewer in lower southern and eastern areas, and none in coastal areas. During the pilot survey in May 2008 no peat was discovered in units 1, 2, 3, 20, or 21 (see figure 3.1), and whilst some probing was attempted, it was found that the sediment/soil was so shallow that probing was often unnecessary. Around 80% of mires surveyed were either combe head mires or valley mires (figure 4.6). While there appears to be a difference in the size of mires of different type, with more larger valley and soligenous mires (figure 4.7), this is not a statistically significant difference ($F=1.21$, $P=0.289$ using the more robust parametric ANOVA test: table 4.1). This is due to the fact that 78% of mires are below 2 hectares (2 ha = $20{,}000m^2$), with a mean area of 1.7 ha (figure 4.8), and the majority of much larger outliers are valley and soligenous mires (figure 4.7). This may be due to the tendency of mires in the bottom and slopes of valleys to be longer and therefore cover a larger area. Alternatively, this may be because mire type definitions take into consideration mire area: i.e. mires were often described as soligenous mires rather than flushes due to their larger size.

Although there is not a statistically significant correlation between peat depth and mire type, peat depth is positively correlated with mire area (Pearson's P=0.000: see table 4.1 and figure 4.9). The depth value used for these calculations was the deepest peat recorded in the mire, rather than an averaged depth value. However, as all mires were defined using a number of peat depth measurements, and many depth measurements were taken in areas which were not subsequently defined as mires (e.g. on shallow peaty soils or alluvium), calculations were also carried out to identify correlations between peat depth (over 1000 measurements) and other variables: It was found that peat depth shows a positive correlation with elevation (R=0.105, Pearson's P=0.001: table 4.1 and Figure 4.10).

Many elements of the desk-based survey proved useful for identifying mires: the Ordnance Survey map data showing contours (and therefore gradient) and watercourses at 1:10,000 scale was invaluable in highlighting potential mire locations, many of which proved to have a significant depth of peat. The general distribution of mires (as well as mire depth distributions) proved to have a similar overall distribution across the moorland as blanket peat areas outlined by peat depth surveys by Merryfield (1977) and Bowes (2006) (figures 4.2-4.4), with the majority of mires and deeper peat focussed around central and western areas of Exmoor and away from the coasts. However, these surveys were not found to be useful for identifying individual mires: In many cases, this was because of the explicit focus of the Merryfield (1977) and Bowes' (2006) surveys on blanket peat. This meant that survey was largely confined to hilltops or plateaus, rather than continuing into combe heads, or the slopes or base of valleys: areas which were focussed on in this survey. In other cases, the broad gridded approach taken by Merryfield (1977) and Bowes (2006) (e.g. Bowes [*ibid.*] took measurements every 100m), meant that smaller mires - which were detected through the more targeted approach taken by this survey - were missed (see figure 4.11).

Analysis of the aerial photographs was helpful to some extent in identifying potential mires, as they could be used to pick out drainage features and vegetation changes (for example areas of green 'flush' surrounded by darker green rushes, or areas of *Eriophorum* sp. within expanses of *Molinia caerulea* or *Calluna vulgaris*). However, many of these *potential* areas yielded little or no peat, but rather were often areas of peaty soil (less then 40cm of peaty material: Natural England 2010). In fact, it was found that it is almost impossible to identify areas of peat on Exmoor from aerial photography alone. This seems to be a result of the similarities between the appearance of dry heath and mire vegetation on aerial photos, and even on infra-red imagery. In addition to this, the presence of drainage ditches on moorland does not always appear to be a useful indicator of the presence of peat as the drains frequently extend into areas of shallow peaty soil. Overall, the desk-based survey identified around 300 potential mire locations. Walkover survey and peat depth probing (totalling over 1000 depth measurements) at all these locations allowed 119 mires to be defined in terms of extent and depth. It also demonstrated that desk-based survey overestimated the number of mires in the 153km^2 survey area by approximately 250%. This therefore suggests that a combination of desk-based and walkover survey was the most effective way to identify mires with the datasets available at the time of the project.

4.3. Condition survey of mires identified through spatially-extensive survey

4.3.1. Developing methodologies for assessing the condition of the resource

The aims of the condition survey, which took place alongside the survey of the extent of mires on Exmoor, were to provide a baseline condition survey with replicable standards of assessment, and to assess various proxies for peat condition, such as mire condition, vegetation condition, and peat depth. To fulfil the first of these aims, a mire condition key was developed as part of the pilot study (May 2008) (figure 4.12). Central moorland areas at both high and lower elevations and with a variety of gradients (unit 12: figure 3.1), as well as coastal areas (units 2 and 3: figure 3.1) were targeted as part of the pilot study to allow the observation of a number of different types of mires in various stages of damage. This meant that condition categories were developed which would adequately cover a wide range of threats to the integrity of the peat matrix (including only those which would be visible in all seasons: see section 3.2.4), and describe the full range of potential mire states.

Most types of damage to the mire or peat matrix meant that there were visible signs of active erosion. In these cases mires were designated as in ‘declining’ condition, due to the continued physical loss of the palaeoenvironmental resource though sediment erosion. However, historic peat cutting scars and drainage ditches without visible signs of sediment loss through erosion (and therefore often with vegetation growing on the base and sides), if found without other signs of active erosions, were categorised as in ‘stable’ condition. A caveat to this classification of mires as either in ‘stable’ or ‘declining’ condition, is that it does not take into account that continued water-table draw-down due to peat cutting or drainage may be causing damage to the palaeoenvironmental resource (e.g. increased peat humification or declining pollen condition), despite a lack of active erosion. The relatively transparent standards used in this baseline survey mean that the condition of the palaeoenvironmental resource could be reassessed at various points in the future to the same standards with basic training of assessors.

4.3.2. The condition of the resource defined through spatially-extensive survey

The results from the field-based condition survey are summarised in figures 4.13-19. Mire condition scores were normally distributed with 61% of mires in condition 2 or 3 (condition score mean = 2.7: figure 4.13). The three mires in condition 5 (very poor condition with many/extensive threats to the peat matrix), are in the western/central section of the survey area (figure 4.14). However, this may be due to the fact that this area has the highest density of mires overall. Visual assessment in the field of the degree of peat humification (on a 0-4 scale using the Troels-Smith [1955] system) showed a similar normal distribution to mire condition (figure 4.15). Peat condition shows more clear spatial patterning than mire condition, with more extremes of peat humification (mire with peat in condition 0 and condition 4) appearing in the more densely covered central/western section of the survey area. Other areas (i.e. though south or east) have no mires in either condition 0 or 4 (figure 4.14).

The most common threat to the peat matrix in mires (contributing to a higher mire condition score) was channel erosion, with over 70% of mires showing signs of channel erosion. This ranged from extensive channel down-cutting, exposing sections up to one metre deep, to vegetation and particulate loss along the base of ditches. Trackway erosion (the result of both unmarked footpaths and animal tracks) also affected 53% of mires, but no other threat affected more than 50% of mires (see figure 4.16). There were only 9 (7.5%) mires defined as being in ‘stable’ (as opposed to ‘declining’) condition (figure 4.12), due to their lack of visible active sediment erosion (see above). Of the mires currently in ‘stable’ condition, there was no visible damage to the peat matrix at 6 mires, and evidence of historic peat cutting and/or drainage ditches was visible at the other 3. Of the various damage/threats types defined through the survey, channel erosion, collapsed section and peat piping are the most prevalent and have fairly even distributions across the mires defined through the survey (figure 4.17). There is a higher concentration of mires where peat cutting and vegetated drainage ditches (where no active erosion was visible) were observed in the west of the survey area. There were also very few mires to the south of the survey area where animal poaching was recorded, with most examples observed in the northern moorland area.

One of the major aims in assessing both mire and peat condition, alongside a number of other variables (including vegetation condition, mire area, and mire elevation), was to evaluate potential effectiveness of using different variables as a proxy for peat or mire condition. To fulfil this aim, correlations and covariance analysis between a number of variables was carried out. Spearman's rank correlation analysis indicated that there was little correlation between mire and peat condition (coefficient=0.06: table 4.1); suggesting that poor mire condition and extensive visible threats to the peat matrix do not necessarily mean that the peat matrix itself will be very humified. There was no statistically significant correlation between mire type and mire condition or peat condition. Neither was there significant correlation between mire area and mire condition or peat condition (table 4.1), showing that particular mire types or particular sizes of mire are not more likely to have more visible threats or more humified peat. It was found that neither mire condition ($F=0.97$, $P=0.465$ ANOVA) or peat condition ($F=1.41$, $P=0.21$ ANOVA) co-varied with elevation: so although there are a greater number of mires at higher elevations (see section 4.2.2), these do not have statistically less visible damage to mires or less humified peat. Covariance analysis indicates that while there is no significant relationship between mire condition and peat depth (at a significance level of 0.05), there is a significant relationship between peat condition and peat depth ($F=7.64$, $P=0.006$ ANOVA: table 4.1). This demonstrate that deeper peat tends to be less humified than shallower peat. Figure

4.18 indicates that this trend is only true for peat in condition category 1 or above (on the Troels-Smith [1955] humification scale).

Over 50% of the mires identified had vegetation which was in poor condition, 30% in good condition, and 18% in 'mixed' condition (see methodology section 3.2.5). Vegetation condition was positively correlated with mire area (F=34.48, P=0.000 ANOVA: table 4.1), indicating that vegetation tends to be in a better condition in larger mires (figure 4.19). It might be expected that mires with poor vegetation condition would also have more humified peat and more signs of physical damage to the peat matrix. However, the Spearman's rank correlation coefficient was close to 0 for both comparisons of vegetation and peat condition, and vegetation and mire condition. This suggests that vegetation condition is not a good indicator of the condition of the peat matrix beneath, and also that damage to mires, particularly peat channel erosion, may not be a clear causal factor for poor vegetation condition. However, the patchy nature of vegetation cover within some mires may mask wider patterns, which a more comprehensive vegetation survey would clarify.

4.4. Summary

This chapter has presented the results of the spatially-extensive survey. The results indicate that Ordnance Survey contour and watercourse mapping were particularly useful in identifying mire sites through desk-based survey. Analysis of mire vegetation or drainage ditches from aerial photos identified many areas which yielded little or no peat. The extent of mires defined here has gone beyond that of previous peat depth surveys, defining many previously undetected small mires in and around valleys. The survey found that deeper peat tended to be found in larger mires at higher elevations, and that deeper peat was more likely to be less humified. The results also suggest that there are few viable alternatives to walkover survey or coring for assessing the condition of the palaeoenvironmental resource. Extensive visible damage to the mire surface (poor mire condition) does not mean that the peat matrix will also be in poor condition. Vegetation condition was not found to be a good proxy for either mire or peat condition.

CHAPTER 5: RESULTS OF INTENSIVE SURVEY AND LABORATORY ASSESSMENT OF THE CONDITION OF THE PALAEOENVIONMENTAL RESOURCE

5.1. Introduction

This chapter presents the results of the site-based intensive survey and laboratory assessment of the palaeoenvironmental resource from the three selected monitoring/sampling sites. This includes: descriptions of the mires and dipwell locations; selection criteria for coring locations; core descriptions; humification analyses; stratigraphic changes in microfossil assemblages and condition; and the assessment of current decay rates.

5.2. Descriptions of mires

5.2.1. Monitoring mire selection

Selection of mires for intensive monitoring was based on a number of factors including: Fyfe's (2005) survey of moorland units 7 and 13 (see figures 2.1 and 3.1); the need to select mires in close proximity to each other to reduce the spatial variability of weather conditions between mires; and the historic and archaeological context of the mires. It was necessary to use Fyfe's (2005) survey to quickly select monitoring sites, as this allowed water-table monitoring to commence within the first 6 months of the project. This means that water-table data could be collected over a two year period, and initial monitoring data could be used to select coring sites. Three mires were selected which were in close proximity to each other (within a $3km^2$ area), to allow dipwell monitoring to be undertaken from all three at a similar time on the same day, and so that each mire would be subject to as similar precipitation and climatic conditions as possible (figure 5.1). Mires of a similar size were also selected in an attempt to control variability between sites. Initial walkover survey to aid mire selection, allowed the identification of a variety of damage features at each site, including drainage ditches, peat cutting, channel erosion, and peat piping. These features all have potential to cause water-table draw-down and therefore damage to the palaeoenvironmental resource through drying and oxygenation of the peat matrix.

The selection of the monitoring sites was influenced by the historical and archaeological context of the mires, in terms of past human impact on the mires themselves and their landscape setting. The area in which the mires are located (see figure 5.1) was chosen for three major reasons: firstly the area around Larkbarrow has been designated an Area of Exceptional Archaeological and Historical Importance (Riley and Wilson-North 2004, Fyfe and Adams 2008) with a number of extant earthwork features as well as recorded finds. Secondly, the areas was subject to early moorland agricultural improvement in the mid-nineteenth century, indicating that the mires selected may have been subject to drainage and damage through peat cutting for over 100 years (Orwin and Sellick 1970; Riley and Wilson-North 2004, Fyfe and Adams 2008). Thirdly, the selected mires are within a Site of Special Scientific Interest (SSSI), and represent the types of locations which may be targeted in future for peatland restoration schemes.

The earliest archaeological evidence from the areas immediately surrounding the mires is a number of Mesolithic flints discovered to the north of Larkbarrow mire (to the east of Larkbarrow Farm). These flints were discovered as chance finds (McDonald, Wilson-North, Fyfe *pers comm*.), motivating an excavation of the area immediately adjacent to the farmstead in May 2008. During this excavation scatters of flint were found through test-pitting, but no other clearly defined archaeological features were discovered. There is also evidence inhabitation in the Neolithic and Bronze Age: with tumuli to the North, at Kittuck, and to the South near Larkbarrow Corner; and two standing stones and a stone setting between Kittuck and Three Combes Foot (Jamieson 2003, see figure 5.2). Monument typology on Exmoor suggests that these date to the Early Bronze Age (Riley and Wilson-North 2001, Jamieson 2003). The most visible archaeological remains in the area are those of the 19th century farmstead (Larkbarrow), with its associated field systems, network of gutters and drainage ditches, and evidence of peat cutting. The farmstead and associated improvement was begun in the mid-nineteenth century by John Knight, who purchased a large area of the former Royal Forest in 1820, and continued by his son, Fredrick Knight. The first recorded tenant at Larkbarrow took up residence in 1846 and the second and final left in 1852 (Orwin and Sellick 1970). The area was used during the Second World War as a firing range, a fact attested to by numerous shell holes around the farmstead, and a number of slit trenches in the surrounding area (Jamieson 2003).

Aerial photos (from the 1940s onwards), extant walls and earthworks, and documentary evidence (Orwin and Sellick 1970, Riley and Wilson-North 2001) suggest that peat cutting and drainage of the mires selected for monitoring are likely to have their origin in this broad scheme of agricultural improvements carried out from the mid-nineteenth century. Visible damage to the mires was likely to have begun between 150 and 60 years ago (between documented dates of agricultural improvement and visible evidence of drainage ditches from APs). This early scheme of upland improvement took place in central Exmoor almost a century earlier then the large-scale drainage or ‘gripping’ of many upland areas in the UK, which was particularly focussed in the 1960s and 70s (Holden *et al.* 2007). The likely long duration of damage to the mires, which can be dated to with a limited period of agricultural use of the sites (and for which 1940’s aerial photos provide a *terminus ante quem*), maximises the potential for detecting damage to the palaeoenvironmental resource at these mires.

5.2.2. Larkbarrow

The valley mire at Larkbarrow is approximately 100 by 200 metres in size to the south of the ruined 19th century Larkbarrow Farm (see figure 5.3). There is evidence of peat cutting on the western side of the mire, which is on a small, domestic scale and is likely to have been carried out to supply the farm with fuel. There is an eroding drainage ditch on its western border, and shallow vegetated (not currently eroding) artificial drainage on its eastern edge. Peat depth survey was carried out to define the mire area, and determine the most appropriate locations for dipwells. A gridded approach was taken with depths approximately 10m apart. In the overcut area to the western side of the mire, the peat is fairly shallow, not reaching more than 1m (figure 5.3). The survey showed that the mire had only one basin, with a maximium depth of 1.89m.

The vegetation is dominated *by Molinia caerulea*, with patches of *Juncus effusus* in the centre and western edges of the mire. The overcut eastern section of the mire is still dominated by *Molinia*, but also has a significant percentage of *Erica tetralix* and *Eriophorum veginatum*. The small area (around 2-5m wide) bordering the stream forming the western boundary of the mire is dominated by *Sphagnums*, particularly *Sphagnum fallax* and *Sphagnum papillosum*.

The dipwells were positioned in a transect across the mire, passing through the deepest section. As the aim was to monitor the affect of observed damage features on the watertable level within peat (so that this could be related to any recorded damage to the palaeoenvironmental resource), the transect passed from the shallow overcut western area of the mire (where LK1 is located), with one dipwell 1-2m from the edge of the peat cut (LK2), and into the deepest part of the mire, furthest from visible damage (LK3, LK4, LK5). The final dipwell in the transect (LK6) was placed 5m from the artificial (but not currently eroding) drainage ditch marking the eastern extent of the mire. Depth measurements to the east of this ditch showed the sediment to be shallow peaty soil rather than peat. Table 5.1 gives further details of the dipwell locations in terms of peat depth.

5.2.3. Swap Hill

The soligenous mire at Swap Hill is approximately 300 by 300 metres in size. Extensive artificial drainage is visible on the ground, from LiDAR data, and from aerial photographs from the 1940s (see figure 5.4). Some of these drains are not actively eroding, but others are deep (down to the base of the peat), suffering from extensive erosion and collapsing peat sections. Three transects of peat depths at 10m intervals were recorded. These indicated that there are two sub-basins, with a shallower section in the centre. The western sub-basin had a maximum depth of 1.4m, while the eastern sub-basin was deeper, reaching a maximum depth of 2.98m (the deepest peat in the three mires selected for monitoring).

The vegetation is dominated by *Molinia caerulea*, with large patches of *Juncus effuses* bordering the mire to the west and east, and with patches in the central, shallower area of the mire. The section of the mire to the west of the ditch around which dipwells SH7-9 were positioned has a higher concentration of *Erica tetralix* to the rest of the mire, perhaps as the peat surface is relatively dry in this area. A slightly raised area of the mire between the shallow central area and the area of deeper peat to the east is dominated by *Carex nigra*, rather than *Molinia caerulea*. *Sphagnums* are rare on the mire and are limited to small patches of *Sphagnum fallax* and *Sphagnum papillosum* in the central depressed area.

Dipwells were sited on the basis of both the depth of peat and locations of damage features. SH8 and SH9 were placed immediately on either side (within 2m) of a large eroding drainage ditch, with some collapsing peat sections. SH7 was placed 10m to the west of SH8, to monitor the distance at which the water-table level was affected by a large drainage feature. SH10, SH11, and SH12 were placed in a short transect in the deepest area of the mire. SH12 was placed within 2m of a small drainage ditch, with SH11 placed 10m to the west of the drainage ditch, and SH10 a further 20m away. Table 5.1 gives further details of the dipwell location in terms of peat depth.

5.2.4. Beckham

The mire at Beckham is a spring mire with some characteristics of a soligenous mire (it is fairly large and on a shallow slope), and measures approximately 100 by 200m (see figure 5.5). As at Swap Hill, a number of drainage ditches are visible from both LiDAR and vertical aerial photos. The ditch to the north-east of the mire is vegetated and shallow, while that to the south-west is deep and undergoing erosion. There is evidence of peat piping and collapsed peat piping at the site, north-west of the dipwell transect, indicating that actions to drain the site in the past have led to drying and cracking of the peat. A gridded approach was taken to peat depth survey, with a sampling interval of approximately 10m. The deepest peat was found to be 1.93m near the centre of the mire. The vegetation is dominated by *Molinia caerulea*, with a large patch of *Juncus effuses* along the shallow depression between dipwells B19 and B18. *Potentilla* is also common towards the centre and east of the mire.

The dipwells at Beckham were arranged in a transect between two clear damage features: the deeper, eroding, drainage ditch marking the south-west extent of the mire, and the shallower, vegetated, ditch at the north-east extent. They passed through the deepest part of the mire at intervals of approximately 15m. Dipwell B19 was within 1m of the deep drainage ditch, in peat just over 1m deep. Dipwell B18 was placed in one of the deepest areas of peat in the mire, in a shallow depression, which becomes a down-cutting drainage ditch 5-10m further to the north-west. The peat becomes shallower and then increases in depth again before dipwell B17. Dipwells B16 and B15 are placed in the deep and fairly flat, central area of the mire, and are furthest from any damage or threats to the peat matrix. By B14, the peat depth has begun to decrease, and continues to do so up to the shallow ditch by which B13 is placed. At this point there is 75cm of peat. Table 5.1 gives further details of the dipwell locations in terms of peat depth.

5.3. Water-table monitoring

5.3.1. Meteorological data

Daily rainfall data was obtained from the nearest Met Office weather station at Winsford (BNG SS 906347), 12 km to the Southeast of the monitoring sites. Data was available from 01/01/1958 to 01/06/2010, with continuous daily measurements from 02/02/1973. This data daily precipitation data is displayed in figure 5.6a. The monitoring period (28/02/2008-09/03/2010) shows similar precipitation levels to the preceding years, with peaks of high rainfall within the same range as those recorded over the last 50 years. Figure 5.6b shows the same data plotted for the last decade (01/01/1999-09/03/2010). The 30-day moving average shows that precipitation levels over this period are generally higher in winter than in summer, although the raw daily rainfall data show a number of peaks during the summer period, reflecting storm events. The 30-day moving average for the monitoring period, in common with data from the previous decade, shows high rainfall during the winter, peaking around December to January. However, there are also high peaks in precipitation during the summer. In contrast to the majority of years during the decade (particularly 2003, 2004, and 2006), the raw rainfall data for the monitoring period shows higher peaks in the summer than the winter, demonstrating frequent and high-intensity storm events between April and October in 2008 and 2009. This suggests that while rainfall levels for the monitoring period are demonstrably within the same range as those from the previous 50 years, there was a greater amplitude and frequency of high rainfall or storm events during the summer months compared to the last decade.

5.3.2. Dipwell water-table monitoring

Water-table monitoring was undertaken at all dipwells, at weekly/fortnightly intervals , over the two year monitoring period (28/02/08-09/03/10). There are a number of patterns which are clear from the data. Firstly, all dipwells show broadly similar patterns of water-table variation. This suggests that water-table levels in all dipwells are responding to the same external influence. Periods of high/low rainfall show corresponding peaks/dips in water-table levels, suggesting that precipitation is a major driver of water-table levels within the peat. Secondly, seasonality is clear in both the precipitation and water-table data: water-table levels are, on average, lower in summer than in winter. The amplitude of variation is also higher in summer then in winter, with lower water-tables increasing a lot in response to individual high-rainfall storm events. Finally, the water-table level, and amplitude of water-table variation, varied according to the proximity of dipwells to damage features (see table 5.1 and figures 5.7 and 5.8): Dipwells which were very close to large damage features (SH8 and SH9) had consistently low water-table levels, showing that the proximity of the ditch caused any rainwater or groundwater to drain quickly through the top c. 50cm of the peat. Dipwells near less extensive damage features (LK2, SH12, B13, B18, B19) had water-table levels which were highly fluctuating: peaking in response to periods of high rainfall and dropping rapidly afterwards to a lower levels (lower in the summer then the winter). This shows that while water does appear to immediately drain out of the peat in these areas due to drainage features, it is retained for a period of time after high rainfall events or if precipitation is fairly continuous over a number of days (demonstrated by higher winter water-table levels). The dipwells which were the furthest from damage features, and often in the central or deepest areas of the mires (LK4, LK5, SH10, SH11, B15, B16) show continuously high water-table levels throughout the year. Although the water-table at these dipwells clearly increases in response to high rainfall events and decreases in response to very low rainfall over a number of days or weeks, the amplitude of fluctuation is low, and water-table levels rarely fall more than 10cm below the peat surface. At most of these locations, high rainfall events cause a few centimetres of standing water above the surface of the peat, as the peat becomes saturated. The dipwells which are intermediate to these extremes show intermediate average water-table levels and amplitude of water-table fluctuation. Figure 5.7 (mire cross-sections) shows a cross section of each mire with the highest and lowest water-table level at each dipwell location.

5.3.3. Modelling the relationship between water-table and precipitation

Whilst water-table monitoring for the project could only be carried out over a relatively short period, it is long-term trends in the level of the water-table in the study sites which are most likely to control microfossil preservation humification at different levels within the peat matrix. This means that longer-term trends, rather than short-term ‘noise’ should provide the focus of our investigations. Continuous daily precipitation readings were available from the Winsford weather station for the last 35 years (from 02/02/1973), allowing modelled water-table levels for this period to be generated using the method described in section 3.3.2.4. Linear regression was run between rainfall readings averaged over different numbers of days preceding the dates of dipwell readings, and dipwell readings from the selected locations. Regression between dipwells readings and rainfall averaged over 4 days prior to the reading produced the highest R^2-value for the majority of dipwells. The equation of this line was therefore selected to apply to the daily precipitation data, to model water-table levels at each dipwell location over the last 35 years

A number of flaws were found in this approach, the most important of which was the inability for this approach to model either very dry or drought conditions (where there was no rainfall for over 4 days), or when there was events with unusually high rainfall during the monitoring period. It was therefore decided, that due to these problems, this modelling approach was unreliable. Plotting rainfall levels (and average rainfall) over the last 35 years (see figure 5.9), shows that the average daily rainfall during these years has varied little (is always between 3 and 5 cm). Also, despite a number of years with very high outlying readings, the means and interquartile ranges of the readings during 2008 and 2009 are similar to those over the last 35 years. This suggests that here is a clear justification for using recorded water-table readings from the 2-year monitoring period (as well as water-table zones and residence times generated from these), rather than 35-year modelled levels, for the following analyses of the condition of palaeoenvironmental remains.

5.4. Coring location selection

The first 3 months of dipwell readings (March to May 2008) were used to aid the selection of coring locations. At least two coring locations were chosen within each mire, to allow quantification of the extent of damage to the palaeoenvironmental resource (the peat matrix and microfossils within it) caused by water-table draw down. These included both a location near to a recorded damage feature (either drainage ditch or peat cut) where recorded water-table levels had been low, and a control location, further from damage features, where the water-table had been consistently high. At Larkbarrow, coring locations within 2m of dipwells LK2 (low, fluctuating water-table) and LK4 (consistently high water-table) were chosen. At Beckham, coring locations within 2m of B19 (low, fluctuating water-table) and B15 (consistently high water-table) were chosen. At Swap Hill, three coring locations were chosen, to representing locations within the mire with consistently low water-table (within 2m of dipwell SH8), low but fluctuating water-table (within 2m of dipwell SH7), and consistently high water-table (within 2m dipwell SH10 as the experimental control). Coring locations could not be immediately adjacent to the dipwells, due to the risk of influencing water-table levels through coring, or the risk of damage to the upper levels of the peat cores because of trampling caused by repeated visits to the site to take dipwell readings. Figure 5.10 shows boxplots of water-table readings from all locations, with those locations selected for coring highlighted. Figure 5.11 shows water-table residence curves calculated from water-table readings from dipwell locations selected for core extraction. These illustrate the proportion of time the water-table was at a particular depth in the peat profile (or above this depth). The selected coring locations can be clearly grouped into three types: Those with consistently low water-table (SH8); those with low water-table but with a large amplitude of fluctuation (LK2, SH7, and B19); and those with consistently high water-table (control locations LK4, SH10, and B15). In the following text, cores will be referred to with the same codes as the dipwells by which they were extracted.

5.5. Core chronologies

Due to budgetary constraints, it was not possible to develop independent chronologies based on radiocarbon dates for all seven cores. The decision was taken to date four samples from three cores: one from each mire. The selection of a core for dating at each site took place after pollen had been counted from all cores and was based on the comparison of taxa summary diagrams within each mire (the condition of the pollen/peat was not a factor in core selection). The core selected for dating from each mire was the one which was believed to have the earliest peat inception, based on patterns on patterns of vegetation change inferred from summary pollen diagrams (see figures 5.12-18 and table 5.2). At Beckham, core B15 clearly dated from an earlier period, with a higher percentage of arboreal taxa at the base which were not present at the base of B19. Palaeoenvironmental studies across Exmoor indicate that wooded landscapes existed on Exmoor from the Mesolithic, with the percentage of arboreal pollen beginning to decrease between the Neolithic and Late Iron Age in almost all recorded pollen sequences, as woodland clearance led to increasingly open upland landscapes (Fyfe and Adams 2011). B15, was also over a metre deeper then B19, making it the obvious choice for dating. At Larkbarrow and Swap Hill, two of the cores at each mire showed similar patterns of taxa change: LK2 and LK4; and SH7 and SH8. The decision was therefore taken to date the deepest core, with the larger number of pollen samples, and thus showing a more resolved pattern of vegetation change. As it was not the primary aim of the study to date particular changes in taxa, and the core lithologies showed no marked transitions or hiatuses (see table 5.3), the depths sampled for dating from each core were distributed evenly throughout the profile.

Radiocarbon results from the three dated cores (LK2, SH8, and B15) are detailed in table 5.4. All dates have been calibrated to calendar years BP and AD/BC using the CALIB version 6.0 Radiocarbon Calibration programme and the Intcal09 calibration curve (Stuiver and Reimer, 1993; Reimer *et al*., 2009). Those which lie within a single stratigraphic sequence show no age reversals and there do not appear to be any contamination issues or errors within the dated samples. Spheroidal carbonaceous particles (SCPs) were counted from samples prepared for pollen analysis, and their concentrations calculated using *Lycopodium* (exotic spore) concentration. The SCP concentrations (figures 5.12-18) provided additional dateable markers: SCP take-off and peak. The dating of the samples in which these feature occurred was based on dates from the south and central region from Rose *et al.* (1995) and Rose and Appleby (2005). While the take-off was present in all the cores and dated to 90 BP[2] (±25), only LK2 showed a peak (and subsequent decline) in SCPs, dated to -20 BP (±5). Age-depth relationships for each sequence have been generated with CLAM (Blaaw 2010) using a cubic spline model (figure 5.19), and are presented as a secondary (Cal age BP) axis on the pollen diagrams (figures 5.12-18).

[2] All references to ages BP from this point refer to calibrated years BP (cal BP) unless otherwise stated.

The age-depth models indicate peat has accumulated at the locations of all the dated cores until the present (or very recently). Initially, all the cubic-spline age depth models projected peat accumulation into the future. This meant that it was necessary to add the year the cores were extracted (-58 BP) as a marker to constrain the models. This suggests that although it is likely that peat is still accumulating, or was accumulating until recently, the rate of peat accumulation has slowed since the last dated sample: 90 BP (±25) at SH8 and B15, and -20 BP (±5) at LK2. The earliest peat inception was at SH8 at 6478-6388 cal BP (4528-4438 BC), with B15 at 5609-4545 cal BP (3659-2595 BC), and LK2 at 3746-3609 cal BP (1796-1659 BC). As the lowest sample for dating from B15 was taken, in error, at 145cm (dated to 3466-3382 cal BP/1516-1432BC), rather than the basal peat depth of 178cm, the basal depth of the core was projected back from the radiocarbon dated samples using a cubic spline model, giving the date of 5101-4545 cal BP (3151-2595BC). The wide error boundaries of this basal date (over 600 years) make it clear that this date is both less precise and less accurate than the basal dates of LK2 and SH8. Both LK2 and B15 show fairly steady peat accumulation up to the present (or recent past), while SH8 shows fairly slow accumulation between the base of the peat to 4413-4237 cal BP (2463-2287BC) after which accumulation is more rapid until 3716-3584 cal BP (1766-1634BC). From around this time, peat accumulation is slower and steadier until the present or recent past.

5.6. Biostratigraphic changes

5.6.1. Lithology

5.6.1.1. Visual descriptions

Core descriptions based on the Troels-Smith system (Troels-Smith 1955; Aaby and Berglund 1986) are shown in table 5.3. The majority of the seven cores are dominated by sedge peat with few inclusions. LK2, SH7, SH8, and B15 all have sedge/wood peat in basal layers (dating from between around 3500 and 6500 cal BP). This indicates the presence of some trees growing on the mires between these dates. The defined layers are all fairly homogeneous, showing little stratification. There are no very marked changes in the composition of the peat, which could suggest hiatuses in peat accumulation or the commencement of soil formation. There are also no clear non-peat layers (e.g. layers of in-washed sediment), although fine sediment in-wash cannot be ruled out, particularly within the more humified layers of peat, where the composition of the peat is less clear. There are some clear boundaries between layers, but these do not mark large changes in peat humification. All cores appear to have more humified peat near the surface. Observed/visual humification (or *humicity*) is compared between cores in section 5.6.2.

5.6.1.2. Loss on Ignition

Loss on ignition results show a high organic content throughout the peat profiles at all coring locations (figure 5.12-18). Except for in the basal 10-35cm of the cores, the percentage organic content does not fall below 70%. This supports descriptions in the lithology that all layers, except basal layers at LK2 and B15 (where% organics falls below 30%), are peat (peat must be more than 65% organic: Clymo 1983). The sharp fall in organic content towards the base of all the cores suggests that coring has captured peat inception, or the early stages of peat formation at cores, except potentially LK4, where the % of organic matter seems to fluctuate towards the base. At all of the cores there is a slight reduction in the percentage organic content in the top 10-30cm of the profiles. Only at B19 is there a slight increase in the percentage organic content in the sample nearest the surface. This result appears anomalous, and may be accounted for by experimental error, such as the inclusion of modern plant remains from the surface of the peat: very little sediment was recovered at the top of B19, due to drying out of the upper levels of the peat. This reduction in organic content near to the surface of the peat may indicate increased decay in the upper levels of the peat at all locations. This drop in organics is more pronounced at SH8, SH7, and LK4, where a decline begins deeper in the peat profiles (around 35cm), but appears to be much more rapid at SH10, where the percentage organic material decreases by 10% in the top 10cm of the profile. Although the decline in organic matter begins deeper in the profile and is more pronounced at locations with lower water-table levels (SH7, SH8, and B19), it is not confined to these cores. Decline in the percentage organic material near the surface of all the cores (even if slight, as at LK2), may indicate worsening peat preservation conditions across all the mires, which may be due reduced summer water-table levels or to increasing summer temperatures (UKCP09: Murphy *et al.* 2009). This could indicate that peat accumulation rates are beginning to slow across the mires, that decay of organic matter near the surface is accelerating, or that soils formation may be beginning.

5.6.2. Peat humification

Peat humification was recorded using two different methods in each of the cores: using the Troels-Smith system (Troels-Smith 1955, Aaby and Berglund 1986) and by measuring the percentage transmission of light through a solution produced from a peat sample (see section 3.3.5.2). If water–table draw-down is causing accelerated decay in peat within zones of the profile which are always above the water-table, or subject to fluctuating water-table, we would expect higher humification (lower % transmission) readings in these zones (i.e. towards the top of cores LK2, SH7, SH8, and B19). However, it was also expected that this pattern would be overlain with the influence of past climate as the peat was forming, with more humified peat forming warmer and drier periods, and low rates of decay causing less humified peat to form in colder and wetter periods (Blackford and Chambers 1993, Charman 2002, Chambers *et al.* 2011).

Visual assessment showed that the most humified peat was at the tops of cores with consistently low or fluctuating water-table levels (condition 4 at SH7, SH8, and B19: see figure 5.21). There are marked differences between visually assessed humification in the cores at Swap Hill, with peat at SH8 and SH7 appearing more humified than that at SH10 throughout the cores. It is possible that these differences could be attributed to modern water-table draw-down, as peat from SH8 becomes less humified (and readings closer to that of SH10), in the bottom 80-90cm of the core. The data from Beckham also show higher visual humification in the top 30-40cm of B19 than in B15, and more similar readings at lower levels. At Larkbarrow, the pattern of humification is unexpectedly very similar between the cores, in the top 70cm. This indicates that humification is also a reflection of wider processes (i.e. climate change) than local-scale change in water-table level. Below 70cm, the differences in humification between LK2 and LK4 may in fact reflect the same climate events, as differing rates of peat accumulation in the cores may cause miss-matches in the data when it is plotted against depth rather than time. However, as only LK2 was C^{14} dated this comparison is very difficult to make accurately.

The measurement of humification by percentage transmission shows some similarities to visual assessment of peat humification (see figures 5.12-18, and 5.21-22), although, as percentage transmission is plotted, the trends in fact appear opposite (as % transmission increases, inferred humification decreases). However, there are two clear noticeable differences between the two datasets: firstly, % transmission readings indicate that there is little difference in the level of humification between peat which was always saturated with that which was subject to low or fluctuating water-table levels (see figure 5.22). Secondly, humification measurements (by % transmission) are in fact high in the top 5-20cm in all cores (figure 5.12-18, and 5.22). Linear detrending was therefore carried out to remove a trend towards greater humification in older peat deposits (although humification is fastest in the acrotelm, it does continue, but at a slower rate in the catotelm: Belyea and Clymo 2001, Chambers et al. 2011). However, percentage transmission readings still indicate that peat humification is higher nearer the surface of the peat. In fact, there is a net increase in percentage transmission (humification decreased) in all cores over the top 20-40cm. Amesbury *et al*. (2008) suggest that % transmission readings may be erratic in the upper levels of cores, as humification increases as a function of time since initial formation of the peat layer. These results suggest that this trend is not linear, and so is not entirely removed by linear detrending. There is, however, a small decrease in % transmission (increase in humification) in the top 10cm of the cores at the sites with the lowest water-table readings. This suggests that decay may in fact be accelerating due to reduced water-table levels and oxygenation of the peat in these locations: as at these sites, the more rapid decay in peat appears to have overcome the overall trend towards lower humification in more recently formed peat.

It is difficult to explain why visual humification and humification recorded through % transmission appear to give such different readings near the top of the cores. It may be because the preparation of the solution for % transmission uses homogenised and ground peat samples, whereas the Troels-Smith (1955) method allows visual distinction to be made between a general peat matrix which appears very humified, and potentially larger pieces of vegetative matter, which have not yet begun to decay, because peat has only recently begun to form. This may explain the distinction between readings at the top of cores (particularly SH8), where recently formed peat very near the surface, is very dry, causing small elements in the peat matrix to decay quickly, but leaving larger pieces of vegetation less decayed due to the short time since peat formation.

Although we would expect peat humification to be higher when the climate is warmer/drier, and lower in wetter/colder periods, when percentage transmission readings from the three dated cores (LK2, SH8, and B15) were plotted against climate reconstructions (Charman *et al.,* 2006, Amesbury *et al*. 2008: see figure 5.22), there was little correspondence between % transmission readings and wet- and dry-shifts.

Comparison of humification patterns between the three dated cores through time showed some common trends (e.g. low humification between around 1200 and 500 cal BP), in addition to elevated % transmission readings at the tops of the cores. However, it is surprising that these correlations are not stronger, given the close proximity of the coring locations and the fact that, at present, water-table levels at all three mires behave similarly in response to precipitation. This could potentially be explained by the low resolution sampling and dating of the cores. Further statistical analyses of the comparisons between humification and climate reconstruction are presented in chapter 6.

5.6.3. Pollen stratigraphy

5.6.3.1. Local pollen assemblage zones

Pollen taxa percentage diagrams for each sequence are shown in figures 12-18. Values for individual land pollen taxa are presented as percentage of total land pollen (TLP) and values for aquatics and spores have been calculated as a percentage of TLP plus aquatics and spores. Zonation into local pollen assemblage zones (*lpaz*) has been carried out separately for each sequence using stratigraphically constrained cluster analysis in Tilia (Grimm 2011). Zonation of each sequence is described in Table 5.2.

5.6.3.2. Biostratigraphic correlation between dated and undated cores

The procedure for creating Regional Pollen Zones (RPZ) and their application is described in section 3.3.6.2. Biostratigraphic changes within RPZs are described in table 5.5, and the application of these zones to undated cores is illustrated in figure 5.23. The entire recorded timeline, from the earliest peat inception until the most recent peat accumulation (shown by age-depth modelling to be the present or very recent past) was divided into 6 RPZs: Only SH8 has samples in RPZ1 (6500-5200 cal BP), which is dominated by arboreal taxa, particularly *Betula* and *Corylus*. RPZ2 (5200-4050 cal BP) has samples from LK4, SH7, SH8 and B15, and shows an increase in *Alnus* and Cyperaceae, with continued dominanace by arboreal taxa. RPZ3 (4050-3250 cal BP) comprises samples from all cores except B19, and shows a similar pattern to RPZ3, with *Alnus* further increasing and an increase in Poaceae towards the top of the zone. RPZ4, 5, and 6 have samples from all cores. Poaceae is dominant in RPZ4 (3250-1920 cal BP), and there is a marked increase in charcoal. Cyperaceae increases towards the top of the zone. Similarly dominated by Poaceae, RPZ5 (1920-550 cal BP) has high concentrations of charcoal and shows an increase in herbaceous taxa. RPZ6 has a peak in *Calluna vulgaris* at the base followed by an increase in Poaceae towards the surface. Charcoal is lower at the base of this zone and increases towards the surface.

Overall, peat inception is earliest at SH8, in the late Mesolithic. Until the Middle Bronze Age, the regional vegetation is dominated by arboreal taxa, with a transition *Corylus* and *Betula* to a higher percentage of *Alnus*, and some local increases in Cyperaceae. From this time, the assemblage indicates a much more open landscape with Poaceae and charcoal concentration increasing rapidly at the majority of locations. There are local fluctuations in Cyperaceae, but Poaceae remains high until the late medieval period, when *Calluna vulgaris* increases suddenly and Poaceae decreases. From this time until the present, Poaceae increases once again, replacing *Calluna vulgaris* as the dominant taxon.

Figures 5.24-25 show Principle Components Analysis (PCA) scores for pollen taxa assemblages categorised by zone and plotted alongside taxa. Figure 5.24 shows all samples from all cores plotted together and categorised by zone, and figures 5.24 and 5.25 show the results of PCA carried out separately on individual cores. For the majority of cores (LK2, LK4, SH77, SH8, B15) 'depth' plots along axis 1, indicating that for these cores, depth (or time) provides the main controller of species change: i.e. pollen taxa assemblages look different through time. The fact that this is the major trend across all cores is shown when PCA is carried out on the pollen summary (taxa) data for all samples from all cores, is demonstrated by the fact that 'depth' plots along axis 1, and the patterning of taxa seen in each zone is similar to that seen in individual cores. Only at SH10 and B19 is depth represented more closely by axis 2, suggesting that there is more fluctuation in taxa (with similar samples at different points in the cores) than the other cores. The inferred dating of these cores indicate that the likely reason for this is that peat inception at these sites was more recent than the other sites. This means there are low levels of arboreal taxa throughout SH10 and B19, but also higher resolution records from these cores then other cores (particularly SH10 which is a longer sequence than any other, with 36 samples) and therefore more fluctuation in taxa is visible. Overall, the PCA plots show that similar patterns of vegetation change occurred in each core through time. This serves to test the effectiveness of the Regional Pollen Zonation, with the similar distribution of taxa and samples within zones justifying the approach.

The benefit of using a regional zoning approach is that it allows rough dates to be assigned to samples from undated cores, providing a larger dataset from which to make comparisons of changes through time. The approach will particularly be used for the analysis of changes in pollen condition scores through time in the next chapter (chapter 6). Although there are a number of problems with the approach (described in section 3.3.6.2.), it is justified, as small local changes in taxa are not the focus of the study (the fairly low-resolution sampling was not designed to pick up detailed local vegetation change). The zoning of cores into RPZ, despite its drawbacks, allowed broad changes in pollen condition through time to be visualised and analysed. Ages of individual samples were not inferred from biostratigraphic correlation between cores, rather, the approach was a means to an end: it was a necessary step in the attempt to disentangle past human impacts and climatic change from current processes as causal factors in variation in the condition of the palaeoenvironmental resource.

5.6.3.3. Pollen condition

Three aspects of the pollen condition results will be discussed in this section: The differential susceptibility of pollen grains of different taxa to different types of damage; an assessment of whether condition scores are affected by changes in pollen taxon assemblages through the cores; and assessment of how damage scores vary between cores and through time. This final aspect will be discussed further in relation to water-table variation and climate reconstructions in chapter 6.

The method used for calculating ‘susceptibility ratings’ (which indicate how likely each pollen taxon is to suffer from different types of damage) is presented in section 3.3.6.3, and graphs showing ratings for all taxa representing more than 0.1% of the total pollen assemblage (all pollen grains counted from all seven cores) are shown in figure 5.26. These graphs illustrate that within the total pollen assemblage taxa were differentially susceptible to different types of damage: *Pinus, Succisa, Fraxinus*, and Cyperaceae were the most commonly or extensively damaged taxa. This is likely to be due either due to their large size, or thin walls. While grains of many taxa were susceptible to crumpling (with many taxa having grains which were commonly or extensively crumpled), only a few taxa (*Pinus* and *Succisa*) were susceptible to breakage. Overall, not many taxa were susceptible to degradation, with Poaceae showing the highest degradation susceptibility rating. Arboreal taxa, and particularly *Alnus*, *Corylus*, and *Betula*, are most susceptible to corrosion. There are relatively few taxa which are particularly susceptible to corrosion. These results indicate that thickness of the exine is not the only cause of differential preservation (or damage to) pollen grains. This is supported by Birks and Birks (1980) who state that that decay susceptibility is not directly correlated with the percentage of sporopollenin in pollen grain walls. Havinga’s (1984) long-term preservation experiments, and a number of neotaphonomic experiments (e.g. Twiddle and Bunting 2010), also demonstrate that under varying conditions or chemical treatments, or in different substrates (e.g. carex peat or sandy soil), the most damaged taxa varies and is therefore not always the taxa with the thinnest grain walls. Susceptibility rating also take into account the fact that particular types of damage may be more clearly visible on one taxa than another: e.g. *Corylus* grains appear particularly susceptible to corrosion, but this high susceptibility may partly be attributed their lack of surface texture. It is difficult to see whether or not more textured grains, such as *Salix*, or irregularly textures grains such as *Quercus*, are corroded. A particular problem with using susceptibility ratings is that they were calculated with the same data they were used to assess. This was due to the fact that no other studies have used the same condition categories to this study and kept a consistent record of which taxa suffered from particular types of damage (see section 3.3.6.3. and 2.3.2.2). However, it is reasonable to argue that the large assemblage size, comprising over 60,000 grains from a variety of preservation conditions (well preserved to humified peat) provides a large enough dataset of which to calculate these scores.

'Raw' damage scores, which assume that all grains are equally susceptible to different types of damage and do not take account of the possibility that variation in pollen assemblages through the cores (because the cores cover different time periods or reflect very local vegetation change), could mask variation in pollen condition through time or by depth (Jones *et al.* 2007). Generating taxon-weighted (TW) damage scores (as well as taxon-weighted corrosion, degradation, breakage, and crumpling scores) using the method outlined in section 3.3.5.3, should allow samples with different vegetation patterns to be compared (both within and between cores). It was important to assess whether applying taxon-weighting to damage scores is necessary: i.e. are pollen damage scores actually affected by taxa change through time? To do this, the covariance of Raw and TW damage scores between different samples was examined. Comparing the results of ANOVA using TW and Raw damage scores showed that in cores where vegetation patterns were very similar through the cores (LK2 and LK4), applying a taxon-weighting to the damage scores made little difference to the results. The same result was seen when the covariance of Raw and TW overall damage scores was assessed in cores with very different vegetation patterns (ANOVA was run on samples from SH7 and SH10 as well as samples from all cores together). However, when damage scores were broken down into separate damage type categories (corrosion, degradation, breakage, and crumpling scores), applying taxon-weighting to the scores gave very different results to comparing raw scores: for example, breakage and crumpling scores co-vary when raw scores are used, but show different distributions when TW scores are used. This suggests that the differences in vegetation patterns skew the results of statistical analyses using raw damage scores. Applying TW damage scores is therefore important in comparing damage between samples in which pollen taxa assemblages are different[3].

There are problems with generating TW damage scores: the most obvious (demonstrated in figure 5.27) is that corrosion and degradation scores are effectively 'downweighted' by the calculation, as fewer grains in the total assemblage were corroded or degraded, or grains were less extensively damaged in these ways. This amplifies an interesting result, that crumpling is the most common type of damage in the dataset as a whole, followed by breakage, and corrosion and degradation score are far lower (figure 5.27). However, it makes statistical analyses between datasets with different orders of magnitude difficult. To solve this problem, once the overall trends had been noted (i.e. the prevalence of crumpling as a type of damage in the dataset), all damage scores were normalised (figure 5.29-5.36). This allowed comparisons of the *relative* fluctuations between different types of damage to be compared within cores through time, as well as between cores. Patterns were much easier to observe, and statistical analyses and visualisation of the data through ordination could be carried out with normalised data.

[3] From this point, all damage scores (overall damage, corrosion, degradation, breakage and crumpling scores) used in statistical analyses are taxon-weighted (TW) unless otherwise stated.

Initial visual analysis of the stratigraphically plotted data (figures 5.12-18) indicates that overall damage scores show no clear correspondence with monitored water-table level (figure 5.28). There is only a clear trend towards higher damage scores in more recently formed peat at B19, although damage scores are in general higher in the top 10-20cm of most of the cores (with the exception of LK4). Damage scores do seem higher in the cores with lower water-table levels during the monitoring period (LK2, SH7, SH8, B19) than those with higher water-table levels (LK4, SH10, B15). However, this is not consistent throughout the cores at any mire. This may be because the cores are compared by depth, rather than age, and peat may not have accumulated at the same rate at each core (in fact the Regional Pollen Zonation demonstrated this: see section 5.6.3.2.). When overall damage scores are compared by age (cal BP) through the dated cores (LK2, SH8, and B19), there are clear corresponding patterns between the cores (figure 5.28). For example, all three dated cores show low damage scores between around 400 and 900 cal BP, and higher scores between 1000 and 3000 cal BP. There is some correlation between damage scores and reconstructed shifts in climate (Charman *et al.* 2006, Amesbury *et al.* 2008): in wetter/colder periods, damage scores are generally lower, and in drier/warmer periods they are higher. The statistical validity of these patterns will be explored further in chapter 6.

Following Tweddle and Edwards (2010), stratigraphically constrained cluster analysis was carried out on the normalised TW damage scores to produce Local Pollen Preservation Zones (LPPZ) for each core individually. Zonation of the cores into LPPZ is shown in figures 5.29-35, and is described in table 5.6. Although the prevalence of crumpling scores is clear in the dataset as a whole (as noted above: see figure 5.27), the observed patterns of normalised corrosion, degradation, breakage, and crumpling scores are complex and very difficult to analyse visually from simple stratigraphic diagrams (figure 5.29-36). Disentangling the effects of recent water-table draw down, from the effects of climate and human impact through time, as well as from individual mire formation processes at the three mires, is particularly problematic. Therefore the pollen condition results are described and assessed in more detail, and compared to other datasets (e.g. peat humification, water-table residence time, pollen concentration) with the aid of various statistical and visualisation methods, in chapter 6.

5.6.4. Testate amoebae

The literature on testate amoeba preparation describes a number of different preparation techniques, and Charman *et al.* (2000) demonstrate that different preparation methods may affect the assemblages recovered from peat samples. A number of preparation methodologies were therefore trialled (see table 3.2) and resulting testate concentrations were compared. It was found that treatment with alkaline solutions (5 or 10% KOH) resulted in markedly lower concentrations of tests, as did boiling the samples in deionised water for different periods between 2 and 10 minutes. Instead, samples were added to 50-100ml deionised water in a beaker, and gently heated (without boiling) for 20 minutes, to disaggregate the peat (method G: Table 3.2). Two exotic marker tablets were added to each sample to facilitate calculation of testate concentration. The samples were stirred occasionally to aid disaggregation and disperse the *Lycopodium* spores. However, concentrations of testate amoebae were still found to be very low in the majority of samples, suggesting poor preservation conditions in the mires (see figure 5.37). Because of the low numbers of amoebae in many samples, the counting methodology employed involved counting testates until 50 *Lycopodium* spores had been counted. This meant that a very long time was not spent on samples with very low concentrations of amoebae. Taxa assemblages are presented as raw count data in figures 5.38-44 rather than percentage data, as it was felt that this gave a clearer picture of the assemblages and the number of testate amoebae found: some samples had very low counts comprising a single taxon, meaning that a count of three of four amoebae could otherwise appear as 100%. Amoeba concentration is also presented alongside the raw taxa count data.

Across all cores (except B15) the concentration of amoebae is much higher near the surface (within the top 5-20cm), than throughout the rest of the core. This supports the conclusion that preservation conditions are fairly poor within the peat matrix at most coring locations. The counts of amoebae were not sufficient to run bog surface-wetness transfer functions on the data. The fact that the mires used in the investigation were partially groundwater-fed (minerotrophic) whilst all bog surface-wetness transfer functions have been constructed from data from ombrotrophic mires, would mean that the results of such analysis may have been questionable/unreliable even if there had been sufficient concentrations of amoebae (Payne 2011).

Zonation of the records was carried out separately for each sequence, to create Local Testate Zones (LTZ), based on both change in taxa and concentration of amoebae. Zonation of the sequences is described in table 5.7, and illustrated in figures 5.29-35 and 5.38-44. Although transfer functions were not used, LTZ are also coloured in these figures to indicate the degree of surface wetness indicated by the testate amoeba assemblages present (red=dry, yellow=intermediate, blue=wet). Information on the environmental niches (with regard to surface wetness/water-table level) for each taxon encountered is detailed in table 5.7. The results indicate that the mire surface at SH8, SH10, B15, B19 has been drier in recent years than in the past. This is shown by a greater dominance of hygrophilous taxa in more recent samples (table 5.8).

Plotting detrended correspondence analysis (DCA) scores, shows that hygrophilous taxa (such as *Arcella discoides, Centropyxis cassis* and *Difflugia lanceolata*) plot towards the right of axis 1, and at the extremes of axis 2, whilst xerophilous (dry-loving) and intermediate taxa (such as *Nebela militaris*, *Hyalosphenia subflava*, and *Assulina muscorum*) tend to plot towards the left of axis 1 and the centre of axis 2 (figures 5.45). Samples from cores with higher water-tables today (LK4 SH10, and B15) tend to plot towards the hygrophilous taxa, whilst samples from the cores with lower water-tables today (LK2, SH7, SH8, and B19) largely group around the xerophilous taxa. This suggests that similar differences in water-table may have existed in the past as exist today. Due to the low amoeba concentrations, and evidently poor preservation conditions, it is difficult to say whether the assemblages of amoeba preserved in the samples are directly reflective of the taxa present in the environment when the peat was forming, or is more a reflection of differential preservation of more/less robust taxa. However, while taxa diversity within samples is relatively low, the diversity of taxa identified across all the cores may suggest that preservation conditions have not caused the preferential preservation of only limited taxa, and therefore taxa assemblages may have some interpretive value (despite low concentrations).

Testate amoebae concentrations from the three dated cores (LK2, SH8 and B15) were also compared with climate reconstructions from Amesbury *et al.* (2008: for south-west England), and Charman *et al.* (2006: for Northern Britain), constructed from testate amoebae inferred surface-wetness transfer functions and peat humification. The results show that there is limited correlation between testate amoeba concentration from this investigation and the wet- and dry-shifts reconstructed by the Amesbury *et al.* (2008) and Charman *et al.* (2006) (figure 5.46). Categorising samples using Regional Pollen Zones (to allow broadly contemporary samples from across all the cores to be grouped) produces a DCA plot (Figure 5.45) which shows that samples from RPZ 3 and 4 (1920-4050 cal BP) have a similar distribution to hygrophilous taxa, whilst those from RPZ1 (-60-550 cal BP) group more tightly towards xerophilous taxa and those with intermediate niches. This suggests that mire surface wetness was higher during the period 1920-4050BP than in the last 600 years. This shift to drier mire surface conditions, particularly in RPZ1 may be indicative of water-table draw-down caused by peat drainage and cutting, it may also be augmented by a shift to a drier, warmer climate over the last 300 years (shown by Amesbury *et al.* 2008: figure 5.46). The pattern of wetter surface conditions in RPZ 3 and 4, however, does not accord with the patterns of wet and dry shifts illustrated in figure 5.46. This may be due to the skewing of results by a number of factors including: low numbers of identified amoebae, particularly in deeper samples; potential differential preservation of different taxa; and the conjunction of data from different cores (potentially with varying water-table levels through time) in one DCA plot.

5.7. Assessing current decay processes

Assessing contemporary decay rates within the peat matix was deemed important as an indicator of the rate of change, or decay or organic matter, within the peat. This could provide an indicator of potential preservation levels of microfossils and organic remains within the peat matrix, highlighting spatial locations across the mires, or zones within the peat matrix, which are likely to suffer from losses to the palaeoenvironmental resource in future. Two methods were trialled, namely measurement of redox potential and pH, and deployment and recovery of cotton strips to directly measure losses of organic material between coring locations and within peat profiles. This would allow the potential effects of water-table draw-down on the long-term preservation of the palaeoenvironmental resource to be assessed. A number of studies suggest that we would expect to see higher redox potential readings in zones of the peat matrix which are no longer waterlogged, or only seasonally waterlogged. For example monitoring projects at the Sweet Track, Starr Carr and Flag Fen have demonstrated that the removal of saturation and high redox values lead to poor preservation of organic remains, whilst waterlogged conditions and negative redox values indicate a reducing environment and more favourable conditions for the preservation of organic remians (Caple and Dungworth 1998; Brunning *et al.* 2000; Lillie *et al.* 2007).

pH and redox (Eh) monitoring was carried out in both the field (figures 5.47 and 5.48) and in the lab (figure 5.49) using hand-held probes inserted directly into the peat matrix. Lab readings were taken both within 2-3 days of core extraction and 1 month afterwards (figures 5.49). The results of field testing show all redox readings (from all cores from three depths in the top 1m of the peat) to be greater than 0mV. Redox measurements taken in the lab from three selected cores (B15, SH7, and SH8) were also largely greater then 0mV, with the exception of some measurements from B15. Although Corfield (1996) reported redox readings of between -200 and +400mV for anaerobic environments, Caple and Dungworth (1998) suggested that optimum conditions for preservation of organic remains within the buried environment would be maintained if the redox values are between -400 and -100mV. Lillie *et al.* (2007) placed redox readings into four categories to enable comparison between studies: Oxidised = >+400mV; Moderately reduced = +100 to +400mV; Reduced = -100 to +100mV; and Highly reduced = -300 to -100mV. Using these categories, all readings from Swap Hill (field and lab) fall into the oxidised and moderately reduced categories, regardless of the location of reading relative to water-table levels. Readings from Larkbarrow and Beckham are more variable, ranging from reduced to moderately reduced (see figure 5.47). From the field readings, all cores showed a tendency towards higher (more positive) redox conditions towards the surface of the peat. All cores at Larkbarrow and Swap Hill showed similar redox conditions at 1m below the surface, but the cores with low water-table levels (LK2, SH7, and SH8) showed greater increases in redox readings towards the surface of the peat in the zone of the profiles constantly or seasonally above the water-table then the ‘control’ cores (LK4 and SH10 where water-table levels were continuously high). This conforms to the expected results (see above). Figure 5.48 indicates that the combination of field pH and Eh readings mean that the peat matrix is within expected boundaries for waterlogged sediments, and that conditions within the peat are likely to be conducive to long-term preservation of pollen, and other organic remains which are not destroyed by the acidic environment (e.g. plant remains and wood, but not bones or molluscs) (Corfield 2007).

Redox readings taken within 2-3 days of the extraction of the core in the lab in cores B15, SH7, and SH8 show moderately reduced to oxidised conditions (>+250mV) in all cores (see figure 5.49). The readings seem fairly stable throughout the cores in all cases, with little clear trend with depth. At B15 and SH8, the readings are also higher than those taken in the field. This may suggest that, despite wrapping and refrigerating the cores, the conditions within the peat became more reduced, and more homogenous throughout the cores during transport and storage. Redox readings taken a few weeks later were much more variable and erratic between readings within the core, and the maximum and minimum readings were also much more variable (figure 5.49). This increased variability (when compared to earlier field and lab readings) suggests that the storage conditions of the cores, or possible the temperature in the lab during testing were having some effect on the readings. This indicates that lab readings using hand-held probes, either within a few days or a month of coring, may not be effective. pH readings taken in the field showed an decrease in pH towards the surface of the peat. Readings were lower (between pH 3.5 and 4.5) and showed less variability between cores at Swap Hill, than at Larkbarrow (beween 4 and 6) or Beckham (between 4 and 5.5). pH readings at LK2 were lower (more acidic) than at LK4, whilst B15 showed lower readings than B19.

Overall, the results of lab testing suggest that this method may not be effective, despite attempts to seal and refrigerate cores. It was also found that both field and lab readings would often not settle to allow a firm measurement to be taken. This could be caused by a number of factors including: the fibrous nature of the peat, variations in temperature between the atmosphere and the cores, or variability in the moisture of the peat at different depths within a core. In the case of the field testing, the readings may also have begun to alter rapidly due to the exposure of the peat cores to oxygen. When *in situ* pH or redox monitoring probes are inserted into the peat matrix, it may also take some time for readings to stabilise. However, as the probes were not left in situ within the sediment, but testing was carried out core extraction, this was not possible.

5.7.1. Cotton strip analysis

Cotton strips were inserted into the peat matrix within 1m of dipwells lK2, LK4, SH7, SH8, SH10, B15 and B19 for 6 months (30/07/09 – 14/03/10). Strips were stapled contiguously along wooden stakes. The percentage weight loss of the cotton strips between insertion and removal was higher in the majority of cores nearer the surface of the peat (figure 5.50). This indicates a higher rate of decay of organic matter near the surface of the peat, potentially owing to oxygenation of the upper layers of the peat matrix resulting from water-table draw-down. This is particularly demonstrated at SH8 and B19, where water table draw-down was much greater and more consistent over the monitoring period (due to their proximity to drainage ditches). As a result, the % weight loss was much higher in the sections of the core which were permanently dry indicating a more rapid rate of decay in organic remains. Decay rates were not consistent throughout the 'dry' zone, with weight loss being highest in strips nearer to the surface. The results from LK2, SH7, and B15 all appear similar at the tops of the cores, with a slight increase in weight loss (and by inference decay rates) near the surface of the peat. This may be due to the tendency for decay rates to be higher in the acrotelm (upper layers of peat) than in the catotelm (Belyea and Clmo 2001, Chambers *et al.* 2011). Results from LK2 and LK4 are more difficult to explain and differ from those at Swap Hill and Beckham. Decay rate seems to increase at LK4 from the base to the surface of the peat at a fairly steady rate, whilst the highest rates of decay at LK2 are towards the base of the peat.

These results indicate that oxygenation due to water-table draw-down is a significant cause of the decay of organic remains within the peat, particularly in sections of the core which are permanently dry. This is supported by results of a similar experiment carried out by Doyle and Dowding (1990), the results of which indicated that decay rates were more rapid the upper 'oxic' zones of peat profiles and in *Sphagnum* hummocks, which were most often dry and therefore oxygenated. The benefit of this type of experiment is that current processes within the peat are monitored, without the overlaying, and often confounding, effects of past processes (such as climate change and human impact) on the data. Whilst the results in preceding sections indicate that pollen is fairly resistant to damage, even in peat which is consistently above the water-table, the cotton strip analysis suggests that other organic remains (e.g. potential archaeological finds or structures) may be at risk of accelerated decay in this environment. While pollen (and to some extent testate amoebae) may not be good proxies for the condition of other more fragile organic remains in peat drying due to water-table draw-down, water-table monitoring may be useful for indicating zones in which preservation of these more fragile organics may be threatened.

5.8. Summary

This chapter has presented the results of the intensive survey and laboratory assessment of the condition of the palaeoenvironmental resource. Three mires were selected for water-table monitoring and coring because: they were close together and therefore subject to similar weather conditions; they are located in areas of archaeological and ecological interest; they have suffered from different types of damage to the peat matrix (drainage, peat cutting) with clear ‘damage gradients’ across the mires; and the visible damage was likely to be longstanding (occurred between 60 and 150 years ago), and therefore more likely to have had an impact on the palaeoenvironmental resource.

Precipitation over the two year monitoring period was seen to be similar to that over the last 35 years of continuous recording (although with increased intensity in summer rainfall). Dipwell readings were seen to reflect patterns of rainfall, the position of dipwells relative to damage features controlling the magnitude and amplitude of the water-table response to events: i.e. dipwells near to larger damage features had consistently low water-table levels, near to smaller damage features (or further away from large features) the amplitude of readings was high. The dipwells furthest from damage features had the consistently high water-table levels. It was concluded that dipwell readings and precipitation data cannot be used in a straightforward way to model past water-table levels, as periods of unusually high rainfall or drought cannot be effectively modelled. Dipwell data was used to select at least two coring locations from each mire: identifying one or two 'test' locations where water-table levels were low or with a large amplitude of fluctuation, and a 'control' location, where water-table levels were continuously high.

Seven cores were taken and sampled for pollen and SCP, humification, loss on ignition, and testate amoeba analysis. Both the taxa and condition of each identified pollen grain was recorded. Three cores (one from each mire) were selected for radiocarbon dating. All cores were zoned individually by both taxa change (producing local pollen assemblage zones) and by pollen damage scores (producing Local Pollen Preservation Zones). Correlation of biostratigraphic changes (arboreal, shrub and herb pollen taxa change) were used to correlate between dated and undated cores, producing overarching Regional Pollen Zones. These indicated a general change from a wooded to more open regional landscape during the Bronze Age, and were a useful tool to allow broad changes through time to be examined, the results of which will be explored in more detail in chapter 6.

Analysis of pollen condition data indicated that some taxa were more susceptible to different types of damage than others. Using taxon-weighted (TW) damage scores (generated using 'susceptibility ratings') allowed comparisons between samples at different depths, as well as comparisons through time. However, variation in pollen condition was not straightforward to interpret from visual assessment of stratigraphic plots, and is likely to represent a combination of the effects of water-table draw-down and climate change and human impact over more extended periods. In common with pollen condition analysis, the results of humification analysis were not straightforward to interpret, as they did not seem to simply reflect monitored water-table. Rather they are also likely to reflect the overlapping effects of a number of factors. There did, however, appear to be little visual correlation between testate amoeba- and humification-inferred climate reconstructions from ombrotrophic mires (Charman *et al.* 2006, Amesbury *et al.* 2008) and recorded humification results. A fall in the percentage of organic remains in the top 10-35cm of all the cores (although generally beginning deeper in the profiles and dropping further at coring locations with lower water-table levels) may indicate worsening peat preservation conditions across all the mires, which may be caused by reduced water-table levels as a result of increasing summer temperatures, increasing water loss by evaporation (Murphy *et al.* 2009).

The aim of testate amoeba analysis was to attempt the reconstruction of local surface wetness (or water-table level) in the past (throughout the time peat was forming), facilitating attempts to identify potential causes for variation in pollen condition through the cores. However, testate amoeba preservation was found to be too poor to attempt full analysis through the cores and model past surface wetness using transfer functions. Comparison of testate amoeba concentration remains to other indicators of palaeoenvironmental condition may be useful (as testate amoeba may be a more sensitive indicator of the level of preservation of other organic remains than pollen), but differential preservation may partly be a function of the robustness of differing testate taxa found in different samples. Despite low amoeba counts Local Testate Zones (LTZ) were produced to allow some inferences about local surface wetness through time to be made.

Assessment of current decay rates found ‘cotton strip’ analysis to be the only effective method of monitoring current decay rates, and their relation to water-table levels, without the ‘background noise’ of past climate and/or human impact. Current trends in the deterioration of the palaeoenvironmental resource can be accessed through experimental techniques in a way which is not possible by using palaeoenvironmental proxies such as pollen condition and peat humification, as past climate and human impact play no part in forming the results. However, short-term experiments are more prone to experimental error and anomalous results if not repeated many times, as they are more sensitive to short-term processes, as opposed to the longer term processes which have altered pollen and peat condition.

CHAPTER 6: THE IMPACT OF WATER TABLE DRAW-DOWN ON THE PALAEOENVIRONMENTAL RESOURCE

6.1. Introduction

In this chapter trends in the condition of palaeoenvironmental remains will be explored both within and between cores, and in relation to a number of environmental variables. The aim is to disentangle various potential causes of change in the condition of palaeoenvironmental remains within the seven sampled cores: This includes the condition of pollen remains, as well as the condition of the peat matrix (peat humification), and by inference, potential buried organic remains. Variation in the condition of palaeoenvironmental remains may be due to a number of factors. Firstly, variation may be due to modern water-table levels. Secondly, variation may be due to mire-specific peat formation processes, with similar patterns of pollen condition and peat humification seen within each mire, which vary significantly from those recorded at the other mires. Thirdly, variation may be due to past events contemporary with peat formation, or subsequent to peat formation but before the modern impacts on the mires causing the measured water-table draw-down. These 'events' may be attributed to climate change or human impact. The potential contribution of these factors will be analysed with the aid of climate reconstructions from other studies (Charman *et al*. 2006 and Amesbury *et al*. 2008), as well as using the changes in pollen taxa to infer potential human impact.

Alongside pollen taxa assemblage and pollen damage scores (including overall damage score as well as corrosion, degradation, breakage, and crumpling scores), a number of other environmental variables were recorded for each sample. These included: values for percentage transmission (humification) and percentage of robust grains; pollen and testate amoeba concentration values; and a water-table residence time value. Each sample was also assigned to an RPZ and one of three water-table zones (**1.** constantly above the water-table, **2.** in a zone of fluctuating water-table, or **3.** constantly below the water-table), as well as being assigned to wet- or dry-shifts according to two climate reconstructions (Charman *et al*. 2006 and Amesbury *et al*. 2008). In this chapter, correlation/covariance between environmental variables and pollen condition is used to analyse to what extent the factors mentioned above (water-table variation, mire-specific taphonomic processes, and past climate-change and human impact) contribute to variation in pollen condition within and between cores.

In terms of variation in pollen condition due to water-table variation, it is hypothesised that damage to pollen will be greater in samples which are constantly, or most often, above the water-table. Previous studies of pollen condition indicate that pollen from samples which are continuously or seasonally above the water-table are likely to suffer from increased damage. It is suggested that increased corrosion or degradation to the pollen grains in these zones is caused by increased rates of oxidation reactions, as well as elevated bacterial and fungal action to due aerobic conditions (Delcourt and Delcourt 1980, Havinga 1984, Jones *et al.* 2007). Repeated wetting and drying may also be a cause of corrosion (Holloway 1989). Campbell (1991), and Campbell and Campbell (1994) also suggest that exposure to cyles of wet and dry conditions may lead to increased breakage and crumpling of pollen grains, resulting from swelling and shrinking of grains and associated weakening of the exine structure. This suggests that crumpling and breakage scores may also be higher in samples which are constantly above the water-table (and thus are wet during and after rainfall events) or in zones of fluctuating water-table. Crumpling and breakage of pollen grains is also caused by physical compaction (Lowe 1982, Jones et al. 2007), which may occur more readily in more humified peat due to increased bulk density (Charman 2002). Thus, samples from peat which has become dried out due to low water-table levels may also suffer from increased crumpling and breakage of grains.

6.2. Relationships between peat and pollen condition and environmental variables

6.2.1. Is pollen condition poor enough to make assemblages biased/unreliable in samples which are above the water-table?

The tests outlined by Bunting and Tipping (2000: see section 3.3.6.4) were used to assess whether samples which were consistently above the water-table were more damaged then those which were consistently below the water-table (table 6.1). These tests check the reliability of a pollen assemblage for vegetation reconstruction, allowing the elimination samples in which the assemblage has been biased due to damage. It was found that the majority of samples from the 7 cores did not fulfil any of the criteria outlined in the tests (i.e. 'passed' the tests): this meant that no samples from LK2, LK4, or B15 were biased due to taphonomic damage to the pollen grains. Only 21 of the 258 samples from the seven cores met one or more of the criteria indicating an unreliable or unrepresentative assemblage (i.e. 'failed' one or more test) (see table 6.1). Samples from SH7 and SH8 met the criteria due to high levels of Pteropsida (monolete) undiff. One sample from SH7 and the majority of samples fulfilled the criteria to have 35% or more corroded or degraded grains, and the remainder of samples from B19, and 3 samples from SH10 were particularly difficult to count and produced counts of less than 300 grains. In SH7 and SH8, the majority of these 'damaged' or 'biased' samples were focussed at the base of the core, in areas of the peat matrix constantly below the water-table. This is contrary to our hypothesis that more damaged pollen would be found in areas of the peat matrix constantly or periodically above the water-table. This may suggest one of two things: either that palaeoenvironmental remains are in poorer condition at the base of the peat due to unfavourable environmental conditions when the peat at those levels was forming; or that this pattern may reflect contemporary vegetation (i.e. very high levels of Pteropsida when the peat was forming). In B19 and SH10, the unreliable or damaged samples were largely focussed at the tops of the cores, within areas of the matrix constantly or periodically above the water-table. This suggests that water-table draw-down, coupled with other mire-specific parameters, may increase corrosion or degradation. However, this may also be due to a predominance of grains of taxa susceptible to corrosion/degradation within these upper samples (something which taxon-weighted damage scores attempts to overcome: see section 3.3.6.3). In a number of samples from the upper sections of cores SH10 and B19, plant macrofossils were broken down into small fragments which were not entirely removed through sieving, thus making pollen counting difficult as pollen grains are obscured. This may indicate that drying out of peat due to water-table draw-down may also affect the condition of plant macrofossils (causing their breakdown).

6.2.2. Are there relationships between areas of peat which are above the water-table and levels of damage to the palaeoenvironmental resource?

Although we would expect higher overall pollen damage scores in samples taken from sections of the core which are either permanently or seasonally above the water-table, there is no clear visual relationship (see figure 5.28). Patterns of corrosion, degradation, breakage, and crumpling scores appear complex and are difficult to interpret visually (see figure 5.29-36). However, in all cores, there are peaks (increase and decrease) in crumpling and breakage scores in the top 20-30cm of the core, followed by a rise in corrosion and degradation scores towards the peat surface. This is most pronounced in LK2 and SH7, and could be due to drying out of the upper layers of peat, causing increased compaction (and therefore crumpling an breakage of grains: Lowe 1982, Jones *et al.* 2007) and increased oxidation and microbial action very near the peat surface (therefore increased corrosion and degradation of grains: Havinga 1984, Jones *et al.* 2007, Tweddle and Edwards 2010; Twiddle and Bunting 2010). Although Radiocarbon dates cannot accurately pinpoint the age of these upper samples, age-depth modelling and SCP profiles suggest that they have formed over the last 100 years.

Visual description of the humification through the cores using the Troels-Smith system (Troels-Smith 1955, Aaby and Berglund 1986) indicates that all cores appear to have more humified peat near the top of the cores, with cores from locations with low water-table levels (particularly SH7, SH8 and B19) showing an increase in humification beginning deeper in the profile than cores from locations with high water-table levels (see figure 5.21). The results of humification testing through % light transmission show more complex results, indicating an overlap of a number of trends at the top of the cores (figure 5.22). Despite general trend towards decreased humification at the tops of cores, the top readings at SH7, SH8 and B19 show increased humification, suggesting an accelerated rate of decay near the surface at these locations where the water-table is particularly low. This may suggest that peat near the surface is more affected by water-table draw-down, even in cores where large sections of the profile are always dry (such as SH8, where the top 62cm of the core was permanently above the water-table during the monitoring period). This appears to be supported by the results from the cotton strip analysis, which shows a higher percentage loss of organic matter (higher decay rates) in section of the peat at SH8 and B19 in particular, that are permanently dry. Also, loss on ignition results indicate that the percentage of organic material decreases towards the surface of the peat at all locations, but begins lower in the profiles of those cores which are subject to lower water-table levels (see figure 5.20). These results also indicate that the high decay rates in these ‘dry’ zones increase nearer to the surface of the peat. This may be due to increased oxidation and microbial action nearer to the surface once peat deposits become dried out and oxygenated.

Statistical analyses, particularly analysis of variance (ANOVA), were used to further analyse the complex datasets. Analysis of the covariance (using ANOVA) between samples from sections of all the cores which were consistently above the water-table (‘dry’ samples) and those which were always below the water-table (‘wet’ or saturated samples) indicated that crumpling scores were significantly higher in samples from dry sections of the cores, and corrosion scores lower. Although 'wet' and 'dry' samples were shown to have similar mean % transmission measurements, the much larger range of values within the dry samples shows that there are differences between wetter and drier samples within cores. The larger range of % transmission values may be due to a number of competing factors including: a trend towards lower peat humification in the upper levels of cores, as decay increases as a function of the time since peat (Amesbury *et al.* 2008; Chambers *et al.* 2011); oxygenation of the peat matrix due to water-table draw down in causing increased decay; and variation in climate through time (e.g. Charman *et al.* 2006, and Amesbury *et al*. 2008). Only SH8 had sufficient samples in the 'dry' and 'wet' categories to carry out covariance analysis between samples within the core (it showed consistently low water table measurements during monitoring). Similar results were found to the results described above: Crumpling scores were significantly higher in the dry section of the core, suggesting that grains may become more crumpled due to water table draw down. However, other damage types showed higher scores in the wetter section of the core (corrosion, degradation and breakage). This may suggest that these patterns are responding more to past processes, rather than recent/modern water table variation.

Principle components analysis (PCA) was employed as the main ordination technique for the multivatiate statistical analysis of taxon-weighted damage scores (i.e. samples plotted against crumpling, breakage, corrosion, and degradation scores). PCA was used in preference to detrended correspondence analysis (DCA), as DCA 'down-weights' rare species (i.e. taxa or 'pseudospecies'). As corrosion, degradation, breakage, and crumpling scores have widely varying means and ranges (figure 5.27) DCA causes all samples to plot between crumpling score and breakage score (the highest scoring and this most frequent or extensive damage types in all 7 cores), and a long way from crumpling and degradation scores (the least common/extensive damage types) (figure 6.1). Although DCA plots are useful for demonstrating that crumpling is the most common and/or extensive damage type across all the samples (something which may not adequately demonstrated by comparing the means and ranges of values), using PCA allows the different condition scores for each sample to be compared more directly, so that variation in damage type through the cores can be visualised and analysed (see figures 6.2 to 6.8).

PCA plots of all damage scores, plotted alongside water table zones (figure 6.2), indicate that samples which are constantly above the water table suffer from higher levels of damage, particularly crumpling (supporting the findings above). However there is little appreciable difference between pollen condition in samples which are permanently saturated with water, or those in zones of fluctuating water-table (and thus seasonally dry). This suggests that to cause significant or measurable damage to pollen grains, water-table levels must be consistently low, causing peat to become dry and oxygenated. However, PCA plots, with samples categorised by core (figure 6.3), show that the pattern of damage is not only higher in samples which are above the water-table in recent years (i.e. the last 2 years of recorded water-table data): Cores which have lower water-table levels (coloured red: SH8 with consistently low water-table; and orange: LK2, SH7, and B19) have a tendency to have more damaged pollen *throughout* the cores then cores taken from locations with consistently high water-table levels (coloured green: LK4, SH10, and B15) (figures 6.3). This is an unexpected result, as we would expect samples from below the water-table in all cores (whether the upper samples of that core currently suffer from water-table draw-down or not), to have similar levels of damage

6.2.3. Correlations and covariance between pollen condition and other environmental variables

6.2.3.1. Overall correlations

Carrying out Pearson's correlation analysis on the whole dataset of 7 cores brings a number of statistically significant correlations to light (table 6.2). Statistically significant correlation between overall TW damage score and TW corrosion, degradation, breakage, and crumpling scores are due to autocorrelation, as overall TW damage score is, in effect, a combination of the other scores. However, the degree of correlation (the value of the correlation coefficients) suggests that crumpling may have the greatest influence on overall damage, followed by breakage, degradation, and corrosion. The initial hypothesis, that water-table draw-down causes increased damage to pollen remains, seems to be supported by the negative correlation between water-table residence time and TW damage and crumpling scores and positive correlation with pollen concentration. This indicates that sections of the core which suffer from reduced water-table levels, and consequent drying of the peat matrix, have more damaged (and more particularly more crumpled) pollen grains and lower pollen concentrations than samples which are consistently below the water-table (or saturated). Corrosion scores are also positively correlated with the percentage of robust grains, perhaps indicating that corrosion, amongst damage types, is particularly likely to destroy weaker grains, or make them unidentifiable.

Other statistically significant correlations may be more difficult to explain: for example, that % transmission is negatively correlated with residence time (peat is less humified in samples which are more often above the water-table or ‘dry’). This appears to go against the hypothesis that the peat matrix (as well as microfossils) will be more damaged in ‘drier’ samples. Although this initially was through to be due to an increase in % transmission measurements near the surface (see figure 5.22), it was found that there was no statistically significant correlation between humification and any damage score, even when samples in the top 20cm of all cores were removed from the analysis. This may indicate that humification patterns can be attributed more to past climate change or human impact then recent water-table draw-down. Positive correlation between corrosion score and water-table residence time may indicate that although current processes (i.e. water-table draw-down) may not be causing increased level of corrosion in samples near the surface, higher corrosion may have occurred in response to processes occurring in the past as lower peat deposits were forming. This may also explain the negative correlation between crumpling scores (which are higher near the tops of cores, potentially in response to current drying of the peat matrix) and corrosion scores (which are higher at lower levels within the peat matrix, potentially due to past environmental conditions). Although these analysis show us the overall patterns, analysing the entire dataset as a whole may mask differences between cores, between mires (with potentially different site formation processes), or through time.

When correlations between damage scores, % transmission, water-table residence time, pollen concentration, and % robust grains (excluding spores) were compared within each core, there were few statistically significant correlations (at a 0.05 significance level using Pearson's correlation), and none which occurred across all cores. Only in core LK2 is there a correlation between % transmission and any damage score: a negative correlation between crumpling score and % transmission, supporting results from other analyses (see above), that more grains are crumpled where peat is more humified. Also, negative correlation between crumpling score and residence time (i.e. more crumpling in samples which are most often above the water-table) is only seen at SH8 and SH10. Correlation between individual damage scores (corrosion, degradation, breakage, and crumpling) and overall damage score is obviously autocorrelation, but may suggest that in different cores the major controllers of overall damage may be different: At LK2 and SH7 crumpling has the highest correlation with overall damage; crumpling and degradation appear to be controlling factors at LK4 and SH8; and breakage appears to be the controlling factor at SH10, B15 and B19.

6.2.3.2. Intra-mire variation in the condition of the palaeoenvironmental resource

Taking each mire in turn, this section compares the condition of microfossils and organic remains from the test core(s) (those with the lower water-table) and control core (that with consistently high water-table) within each mire. From the initial hypothesis, we would expect to only see differences in the cores within the zone subject to differential water-table conditions, with the 'drier' test core showing higher damage scores near the surface of the peat due to water-table draw-down.

Larkbarrow

At Larkbarrow, analysis of variance (ANOVA) shows that LK2 ('drier' test core) has significantly higher mean damage scores across all samples than LK4 ('wetter' control core). LK2 also shows a slightly lower mean and range % transmission (more humified peat), however this is not a statistically significant difference. Although these mean and range values only compare the datasets from these cores as whole units (rather than taking into account changes through the cores), comparing damage scores plotted stratigraphically shows that as the damage scores for LK2 are higher throughout the majority of the core then those for LK4 (figure 5.28). Differences in peat humification between the cores (less humified at LK4, more humified at LK2) are, unexpectedly, more pronounced towards the base of the core, rather than the upper sections of the cores (figure 5.22). PCA plots of damage scores from both Larkbarrow cores show that grains from LK2 suffer from more of all types of damage than those from LK4 (figure 6.4). These results indicate that although samples from LK2 exhibit more damaged grains and more humified peat then those from LK4, this difference is greater in samples lower in the core, rather than upper samples which are subject to different modern water-table conditions. This suggests that past events may have had a greater impact on conditions within the mire than modern water-table draw-down.

Swap Hill

At Swap Hill, SH8 (the core from the 'driest' location, with consistently low water-table readings see figure 5.10) has higher mean damage scores and lower % transmission than SH& and SH10, in most cases showing a separate range of values (higher humification pollen damage) to these cores. SH10 and SH7 show a similar range of values through the core, but SH7 (the 'dryer' of the two) shows higher mean damage scores and lower % transmission (figures 5.28 and 5.22). PCA plots of damage scores show that samples from SH8 have higher overall damage scores and more crumpled and degraded grains than SH7 and SH10 (figure 6.5). Samples from SH7 are less widely distributed than those of SH8, and cluster nearer the centre of the plot, suggesting they suffer from less damage than those from SH8. Although samples from SH10 show a tendency towards higher breakage scores, in general they plot away from other damage types, demonstrating lower levels of other types of damage.

Beckham

At Beckham, B19 (the core from the 'drier' location) has higher mean damage scores and lower % transmission then B15. Although this difference is not statistically significant (ANOVA at a 0.05 significance level), the peat matrix at B19 is more humified than at B15. Stratigraphically plotted damage scores (figure 5.28) show that B19 has higher levels of damage than B15 in the top section of the core which is particularly affected by water-table draw-down. PCA plots of damage scores show few clear patterns, with both cores showing a mixture of damage types (figure 6.6).

Summary

At all of the mires, the range and mean humification and damage scores are higher from cores taken from locations where water-table levels are lower (from recent monitoring and modelled data). However, visually comparing damage scores plotted by depth (figure 5.28) indicates that these differences are only consistent in the upper sections of the cores, which are affected by modern water table draw-down, at Beckham. At Swap Hill and Larkbarrow, cores from locations with low water-table in the present (LK2, SH7, SH8) have higher damage scores and more humified peat than the control cores (those with high-water-table LK4, SH10) throughout the cores, rather than just in the sections of the profile which are subject to water-table draw-down. Once again, this may suggest that water-table draw down may have been more extensive in the past, or that the 'drier' coring locations may have had less favourable conditions for the preservation of pollen over a long period of time. Testate inferred surface wetness data support this conclusion at Beckham, where surface wetness suggests lower water-table levels at B19 throughout the profile than at B15 (see figures 5.43-44). However, the testate amoeba results are not conclusive at the other mires. Indications of surface wetness from testate amoebae assemblages may not, in any case, be particularly reliable, due to poor preservation, and the low numbers of amoebae identified (see section 5.6.4).

6.2.3.3. Inter-mire variation in the condition of the palaeoenvironmental resource

Inter-mire variation in the condition of the palaeoenvironmental resource was explored as a means to investigate the effects of varying mire formation processes. If there are found to be much larger differences in the condition of remains between mires, than between cores from the same mire, this would suggest that inter-mire differences in mire formation or taphonomic (post-depositional) processes may be a major factor in controlling the condition of the palaeoenvironmental resource. Plotting PCA score (generated from damage scores) for all samples from all seven cores produced an ordination plot in which the distributions of samples from all cores overlap, with no distinct clusters of points according to mire (figure 6.7). This suggests that intra-mire and within-core variation are more significant factors affecting damage scores than mire-specific processes. It seems likely that variation both within mires and within cores is masking any variation between mires, and that differential, mire-specific, formation processes do not have a significant impact on the level of damage suffered by pollen in any of the studied mires.

6.2.3.4. Variation through time in the condition of the palaeoenvironmental resource

Variation in the condition of the palaeoenvironmental resource through time was investigated to look at the differential impacts of modern water-table draw-down and the impact of past processes on the condition of the palaeoenvironmental resource. Variation was explored using Regional Pollen Zones (RPZ: see section 5.6.3.2), to allow broad trends to be compared across all cores (rather than just those with radiocarbon dated samples). Variation in the condition of the resource was also compared to climate reconstructions (Charman *et al.* 2006, Amesbury *et al.* 2008) and to the timing of changes in pollen taxa; particularly to those changes which suggest human impact in the local landscape

All samples (from all seven cores) were assigned to a RPZ. The covariance between damage scores of samples between RPZs was then analysed (figure 6.8). The results indicated that while there was no significant difference (at a 0.05 significance level) in overall damage or breakage score between RPZs, there were significant differences in corrosion, degradation and crumpling scores. While mean corrosion scores are high in RPZ1 (6500-5200 cal BP) and low in RPZ 6 (550 cal BP – present), patterns of crumpling are more fluctuating: higher in RPZ 2, 4 and 6, and lower in RPZ 1, 3, and 5. Degradation scores have a very high mean and range in RPZ2 (5200-4050 cal BP), but have comparable means across all other RPZs. At the base of some of the cores (particularly SH8, SH10, and B15), higher damage scores and peat humification correspond with low organic content. However, as peat inception begins at different times in these three cores (indicated by radiocarbon dates and biostratigraphic correlation) this effect may be associated with early peat formation processes, or paludification, rather than a specific climatic events or dry-shifts. For examples, slow peat accumulation or sediment in-wash during the early stages of peat formation at these locations, or may represent the transition from underlying mineral soils to peat (Moore and Bellamy 1973; Charman 2002). Although there is a statistically significant difference between levels of peat humification between RPZs, this is likely to be caused by very low % transmission readings (low humification) near the surface of all of the cores (see section 5.6.2).

The plot of PCA scores (generated from TW corrosion, degradation, breakage and crumpling scores) for all samples categorised by RPZ (figure 6.8) shows no clear overall pattern by zone, except that samples from RPZ6 (550 cal BP-present) plotted to crumpling (to the right of axis 2) and away from other damage scores. This suggests that more samples had crumpled, or extensively crumpled grains towards the peat surface. This may indicate that modern water-table draw down is having a greater effect on the condition of pollen than events (caused by either human impact or climatic change). The broad spread of samples across the plot indicates that some samples have a particularly high level of damage (figure 6.8). However, these more damaged samples do not seem to come exclusively from any one RPZ, as there is a fairly even spread of high scoring samples between RPZs. The plot is dominated by the higher damage scores of SH8 in particular (especially TW crumpling scores) but also by the dominance of TW breakage scores in SH10, suggesting that trends in this overall PCA plot of damage scores are skewed or dominated by high levels of particular damage in some cores.

Pollen damage scores, as well as % transmission and testate amoeba data were also compared to climate reconstructions, to look for correspondence between past climatic events and the condition of the palaeoenvironmental resource through the cores. Visual correspondence between the pattern of overall damage scores through time (in dated cores LK2, SH8 and B15), and wet- and dry- periods outlined by climate reconstructions from Charman *et al.* (2006) and Amesbury *et al.* (2008) shows that there was a tendency towards more damaged pollen in drier, warmer, periods, and less damage in wetter, colder periods. This is as expected as during drier, warmer periods water-table levels are likely to be lower potentially allowing drying of upper levels of the peat. Peat formation will also be slower, leading to greater decay in the acrotelm (upper layer of peat) where decay rates are higher (Belyea and Clymo 2001, Charman 2002, Chambers *et al.* 2011). However, when stratigraphically plotted data for individual damage types (TW corrosion, degradation, breakage and crumpling scores) was compared through time in three dated cores, trends were more complex and less clear. Visual analysis of the stratigraphically plotted data (figure 6.9) shows that corrosion scores seem higher in dry shifts at LK2 and B15, and crumpling scores appeared higher at SH8.

Analysis of the covariance (using ANOVA) between damage scores of samples (from the three dated core) which fall within wet and dry periods of climate reconstructions (Charman *et al.* 2006, Amesbury *et al.* 2008) indicated that damage scores were almost always higher in dry-shifts (table 6.3). Analyses using the Amesbury *et al.* (2008) reconstruction show that overall damage scores at SH8 and B15 were significantly higher during dry periods. At B15, corrosion scores were higher during dry periods, while at SH8 crumpling scores were higher, suggesting different processes may have controlled damage to pollen at these locations. Analyses using the Charman *et al.* (2006) reconstruction indicated that overall damage scores varied significantly between wet- and dry-shifts, but that corrosion scores were significantly higher at LK2 during dry-shifts. Carrying out similar analyses on percentage transmission data indicated that humification did not significantly vary between wet and dry periods in any of the core, using either of the climate reconstructions. This was supported by the lack of clear visual trends (from stratigraphically plotted data) to indicate that peat humification or testate amoeba-inferred surface wetness co-varied with the available climate reconstructions (figures 5.22 and 5.46).

Finally contemporaneity between pollen taxa changes and changes in the condition of the palaeoenvironmental resource were also examined. The aim was to assess whether local human impact could have had an impact on the condition of the palaeoenvironmental resource in the more distant past, as well as in the last 60-150 years through land management practices (drainage and peat cutting). There are archaeological indicators for human inhabitation of the area around the mires during the Mesolithic, Neolithic and Bronze Age (see section 5.2). Radiocarbon dates indicate that by the Bronze Age, peat formation had begun at all three mires, and taxa changes within the core indicate a reduction in aboreal taxa, most likely indicating woodland clearance between around 3500 and 2000 cal BP (1550 and 50 BC) , during RPZ 3 and 4 (but extending into RPZ 5 at B15). Increased charcoal concentration, contemporary with decreases in arboreal taxa at LK4, SH8, and B15 suggest that this deforestation could be accorded to human impact. Wood in the base of peat profiles at LK2, SH7, SH8 and B15, indicates that all the sites were actually wooded to some extent, perhaps with alder fen-carr-type woodland during their early formation (between 6500 and 3500 BP/ RPZ 1 to 3). Thus these mires are likely to have received arboreal pollen from trees 'on-site' rather than just local woodland (figures 5.12-18).

Pollen damage scores indicate higher corrosion and degradation within layers of wood peat. This may indicate different, or slower, peat formation processes under woodland, due to higher evapotranspiration and reduced surface runoff (Charman 2002), allowing higher chemical oxidation and microbial activity to take place in the acrotelm (Jones *et al.*

2007). There were also noticeable peaks in damage scores, particularly in broken and crumpled grains, after a drop in arboreal pollen taxa in RPZ4 at LK2, LK4, SH7, and SH8 (figures 5.29-33). Increased TW crumpling and breakage scores may be consistent with greater mechanical damage, which may be due to transport of grains (Jones *et al.* 2007). This could result from re-mobilisation of grains, or post-depositional transport of grains, caused by increased erosion, owing to woodland clearance or local agricultural activities. There was also a contemporary increase in the percentage of robust taxa at LK2, LK4, and SH7, indicating a change in preservation conditions perhaps due to damage to redeposited pollen. There were no clearly visible bands of sediment or mineral inclusions within the peat profiles, which would indicate an influx of redeposited eroded material (Wilmshurt and McGlone 2005; 2005a). However, there were slight decreases in the percentage of organic material at LK2, LK4, SH7, and more humified peat (increased % transmission readings) in cores at Larkbarrow and Swap Hill, at a similar time to the noted reduction in arboreal taxa and increase in damage scores (largely during and after RPZ4: 3250-2920 cal BP/AD30-300BC). This could suggest a low level of fine sediment in-wash, potentially of redeposited peat or peaty/organic soil, which would be possible at these sites due to their topographic position down-slop from blanket peat areas, and because they are partially groundwater fed. The observed patterns are slightly shifted in time at B15, with a decrease in arboreal taxa towards the end of RPZ4 (as this core was dated, local/inter-mire variation in pollen taxa is apparent). A similar trend of increasing damage scores (TW breakage, corrosion and degradation scores) and increasing humification is detected following this change in vegetation. However, similar patterns were not apparent at SH10 and B19, perhaps due to the lower sampling resolution at B19 (as the core was only 85cm long) or due to the later peat inception at these locations.

These results suggest that both climate change and past human impact (in the form of Bronze Age woodland clearance and potential agricultural activity) had an impact on the condition of palaeoenvironmental remains within contemporaneously forming peat deposits.

6.3. Summary

There are a number of overall conclusions which can be drawn about the effects of water-table draw-down on the palaeoenvironmental resource. Based on Bunting and Tipping's (2000) methodology, it was found that very few samples were in such poor condition that they were deemed to be unreliable. Of the identified 'unreliable' samples, only just over half were found to be within sections of the core affected by current water-table draw-down. This suggests that pollen grains are particularly robust and resistant to damage even in zones of the peat matrix which are continuously above the water-table. Cores which have higher water-table levels in the present have better preserved pollen throughout their profiles than cores which are subject to low or fluctuating water-table levels. However, only at Beckham is there a clear stratigraphic pattern, with the greatest differences between the 'dry' (or 'test') and 'wet' (or 'control') core in the zone of water-table draw-down. There were no clear inter-mire differences in the distribution of the condition data, indicating that no one mire suffered from much more extensive damage to pollen than the others, nor did they suffer from significantly different types of damage. There are correlations between both regionally (Amesbury *et al.* 2008) and nationally (Charman *et al.* 2006) identified periods of climatic change (particularly dry-shifts) and pollen condition. This suggests that the condition of palaeoenvironmental remains throughout the peat profiles has been affected by past water-table variation. However, past human impact on the landscape (e.g. drainage, tree removal, and potentially agricultural practices) may also account for some variability in the condition of palaeoenvironmental remains through the peat profiles. The interaction of these different effects may play some part in reducing the overall expected correlations between climatic patterns and the condition of remains. Overall, the preservation of palaeoenvironmental remains appears to be affected by recent damage to mires (resulting in current water-table draw down), past climate change, and human disturbance of the landscape. This has created a palimpsest of palaeoenvironmental condition data, which we can only disentangle through detailed observation and statistical analyses of trends within these recorded datasets.

CHAPTER 7: DISCUSSION

7.1. Introduction

This chapter brings together results of both the spatially-extensive survey and the site-based intensive survey from chapters 4, 5 and 6. The implications of these results for the extent and condition of the palaeoenvironmental resource in upland areas are discussed, as is the archaeological potential or value of this resource. The chapter is therefore split into three sections on the extent of the resource, the condition of the resource, and approaches to valuing the resource. Each section also includes discussion of the wider applicability or relevance of the methods developed for this study, and the results obtained.

7.2. Spatially-extensive survey

7.2.1. The extent of the palaeoenvironmental resource in mires on Exmoor

The results of the extensive survey of mires indicate that earlier surveys of peatlands on Exmoor, which used broad-scale gridded sampling approaches and focussed on the extent of blanket peat (Merryfield 1977; Bowes 2006), underestimated the extent of peatlands on Exmoor by at around 50%. Merryfield (1977) and Bowes' (2006) surveys estimate the total area of blanket peat on Exmoor at under $4km^2$, whilst the extensive survey carried out for this project identified 119 mires covering an area of around $2km^2$ in a survey area of around $150km^2$ (within open access land inside Moorland Units). The differing approaches taken to the surveys - the larger-scale gridded sampling approach taken by Merryfield (1977) and Bowes (2006) versus the more targeted approached to identifying individual mires taken by this survey – mean we cannot rule out that some of the mires identified in this survey were previously subsumed within the broader, less precisely defined areas of blanket peat defined by earlier studies. We also must recognised that, in comparison to the current survey, the previous figure of 4km^2 of peat, may be an underestimate, as the minimum depth for peat used in these earlier surveys was 50 or 60cm, as opposed to the 40cm used in this survey, in accordance with Evans and Warburton (2007), and as used by the Soil Survey of England and Wales (Burton and Hodgson 1987). However, the extent of mires defined in this survey undoubtedly goes beyond that of previous surveys, defining many small mires in and around valleys which had not been previously detected by large-scale gridded peat depth surveys.

Mires were identified across the upland area and often in close proximity to archaeological sites. This suggests that evidence from a number of these mires may provide a useful resource for investigating the environmental context of archaeological sites across the moorland through time (possibly shedding light on their construction and use, or the perception of them by later populations). Also, there is potential to use palaeoenvironmental reconstructions from samples from these mires to build up a fuller picture of the mosaic of environmental change across Exmoor, for example looking at patterns of woodland clearance (Fyfe *et al.* 2003), or fluctuations between grass and heather moorland (Chambers *et al.* 1999). The survey found a greater number of mires at higher elevations, and that deeper peat tended to be found in these mires. This means there is high potential for future palaeoenvironmental studies to produce high-resolution or long time-depth palaeoenvironmental records from these locations, which may shed more light on the inhabitation of higher upland areas throughout the Holocene. The English Heritage Research Strategy for Prehistory (Consultation Draft: EH 2010) stresses the importance of integrating palaeoenvironmental and archaeological methods in both its Critical Priorities and Research Themes (e.g. Critical Priority 1: Integrating approaches to prehistoric landscapes; Critical Priority 2: Setting prehistoric sites in context; and Research Theme 6: Studying human interactions with the environment). This suggests that knowledge of the distribution of mires with high potential for palaeoenvironmental sampling will facilitate the integration of palaeoenvironmental research into future archaeological research projects. The wide distribution of mires identified using this survey method, and the small surface area of many of these mires (and thus small RSAP), mean that many could be potentially be ideal sampling sites for archaeological projects aiming to reconstruct local landscapes or set individual archaeological sites in environmental context. The mapping of mires undertaken by this project could also facilitate the ongoing creation of a detailed mosaic of the changing patterns of vegetation across Exmoor through time.

In comparison to the whole of the UK, the area covered by peat on Exmoor is relatively small: around 6km^2, in comparison to current estimates of the area of peatlands in the UK ranging from 14,000-50,000km^2 (e.g. Immirzi et al. 1992; Lindsay 2010). Although this may mean that, in terms of carbon storage, for example, Exmoor's peatlands may seem insignificant on a national scale, they do have great archaeological value, owing to the distribution of mires within a mosaic of important cultural landscapes. The mires mapped by this survey will be of considerable use to palaeoenvironmental researchers and archaeologists to allow the targeting of palaeoenvironmental sampling (see above). Although fairly small in comparison to larger upland areas such as Dartmoor, the Peak District, or the Pennines, Exmoor is already beginning to provide an excellent case study for the development of upland landscapes and ecology through time in response to climate, and human settlement and land management practices.

7.2.2. The overall condition of the palaeoenvironmental resource in mires on Exmoor

The walkover survey provides a snapshot of mires in 2008-9, in terms of the peat and vegetation condition, and the type and extent of threats to mire condition. The majority (92.5%) of mires have already seen the loss of peat through erosion, with a high level of damage suggesting extensive erosion at 13% of mires (mires in condition 4 and 5). Only 7.5% were deemed to be in 'stable' condition, or currently showing no signs of active erosion. This suggests that increasing damage to the palaeoenvironmental resource could be occurring at the majority mires due to water-table draw-down, loss of peat, or potential loss of chronological integrity of peat deposits. Forty-five percent of identified mires have very humified peat (an average of level 3 or 4 on the Troels-Smith [1955] scale throughout the peat profile). This suggests that plant macrofossils or organic archaeological remains may already be extensively decayed or lost in many of these mires.

7.2.3. The resource assessment methodology

7.2.3.1. Identifying mires

The data have shown quite clearly that small mires in upland areas cannot be easily detected though desk-based survey. Drainage ditches and vegetational changes indicating spatial transitions from grass or heather moorland to vegetation types commonly found on mires (e.g. cotton grasses *Eriophorum vaginatum* or *angustifolium* or rushes such as *Juncus effusus*) are frequently clear on aerial photos. However, ditches seem to continue into areas of shallow peaty soil, and species of mire vegetation which can be identified from their texture or colour from aerial photos often grow on these seasonally wet shallower peaty soils, as well as on areas of deeper peat. Therefore, purely desk-based surveys to identify peat coverage will overestimate the extent and number of mires. The results of the survey suggest that the use of indicator species to detect mire locations - such as Bog Asphodel (*Narthecium ossifragrum*) or Round-Leaved Sundew (*Drosera rotundifolia*) which are often considered indicators of a ‘healthy’ mire system in terms of vegetation (NE 2006) - also led to an overestimate of the number of mires, as these were found on both areas of shallow peaty soil and deeper peat. Finally, the results also demonstrate that following an imposed, rigid, gridded approach to field survey such as that used by Merryfield (1977) and Bowes (2006) will result in the omission of small mires from any ‘audit’ of mires.

The results of this survey suggest that there is at present no rapid methodology for undertaking palaeoenvironmental resource assessment other than by a combination of desk-based and spatially-extensive walkover survey. However, it might be possible to develop innovative methodologies for detecting mires, perhaps through the use of high-resolution remote sensed data, alongside the dataset produced by this survey. LiDAR (Light Detection and Ranging) surveys are now available for many upland areas of the UK (including Exmoor National Park since 2010), and provide 50cm resolution topographic model of the ground surface. This highly detailed digital elevation model may allow us to assess whether there are common topographic conditions within which small mires accumulate, or commonalities in the surface texture of mires, thus making it possible to model or predict the spatial distribution of mires across an upland area based on a number of predefined criteria (e.g. gradient, texture, altitude, etc). The dataset produced by this survey, showing mire distribution (where peat is and is not found) and depth, may allow the 'ground-truthing' of techniques for identifying areas with high potential for peat formation based on remote-sensed data. Furthermore, although it was not possible to distinguish between areas of shallow peaty soil and deeper peat by simple visual analysis of aerial photos or false colour infrared images, using the results of the extensive survey, more sophisticated digital processing of these images could be carried out to assess the possibility of identifying mire locations through digital analyses. For example, digital analyses of aerial photos involving classifying different vegetation types by the colour and texture of sample areas could potentially allow mire areas to be automatically selected (e.g. Kadmon and Harari-Kremer 1999). Compact Airborne Spectrographic Imaging (CASI) or Hyperspectral Imaging, which is often collected alongside LiDAR data, has been used, with some success, to distinguish between different peatland vegetation types in Northern Finland (Arkimaa *et al.* 2005), suggesting there may be potential to extend these techniques to identifying mire vegetation in UK uplands. The Trent Valley Geoarchaeology project (Carey *et al.* 2006; Howard *et al.* 2008; Challis *et al*. 2011) used airborne LiDAR topographic data alongside LiDAR intensity (or near infrared radiation reflectance: NIR) data to map palaeochannels and moisture levels of near-surface soils and sediments. This allowed the identification of both archaeological sites through cropmarks, and locations with high potential for preserved organic or palaeoenvironmental remains. Data encompassing a number of spectral bands are routinely collected alongside LiDAR topographic data. This means that there may be the potential to develop more powerful modelling to detect peat based on topographic (slope, surface texture or roughness) surface wetness data, and data indicative of different vegetation communities. The resource provided by this survey may facilitate the development of new methods form mapping the peatland resource in much larger upland areas of the UK, where extensive walkover survey is not a realistic option.

Data collected from Exmoor demonstrate that peat depth does not correlate with peat age or inception date. There is no clear clustering of basal radiocarbon dates from blanket peat, small upland mires (valley, soligenous, and spring mires) or floodplain mires from this region (see figure 7.1). This is true even for blanket peat, the growth of which has generally postulated to have been triggered in England and Wales by human action and climate change between the Neolithic to the Late Bronze Age/Early Iron Age (Simmons 1969; Moore 1993; Edwards 1999). These findings are reinforced by results from the intensive survey which suggest that peat inception dates may vary between neighbouring mires as well as within one mire. For example, based on biostratigraphic correlation, peat initiation at SH10, the deepest peat core, appears to have taken place later then a SH8.

7.2.3.2. The condition assessment method: effectiveness of proxies

The walkover survey involved assessing both the condition of each mire identified, in terms of threats or damage to the peat matrix (e.g. peat piping, channel erosion, trackway erosion, peat cutting), as well as the condition of the peat within each mire (defined as the humification of the peat matrix). One of the major aims in assessing both mire and peat condition, alongside a number of other variables (including vegetation condition, mire area, and mire elevation), was to evaluate potential effectiveness of using different variables as a proxy for peat or mire condition, perhaps facilitating the development of less labour-intensive surveying methods: for example using digital analysis of aerial photos (see above), or existing vegetation surveys, as a proxy for mire or peat condition. However no statistically significant correlation was found between mire and peat condition, indicating that poor mire condition or extensive visible threats to the peat matrix do not necessarily mean that the peat matrix itself will be more humified. Covariance analyses also suggested that neither mire area, nor topographic position (in terms of elevation, or position within catchment: i.e. combe head, soligenous, or valley mire) were controlling factors for mire condition or peat condition. A significant relationship was seen between peat condition and peat depth: demonstrating that deeper peat tends to be less humified than shallower peat. More detailed analysis of peat stratigraphy would be useful to analyse whether peat near the surface is generally more humified than deposits deeper in peat profiles. If this was true, it could suggest that peat condition near the surface is deteriorating, or peat accumulation has slowed or stopped, due to modern/recent climate or management conditions.

The condition of vegetation on the surface of a mire (assessed using Natural England's [2006] Common Standards for Monitoring guidelines) was not found to be a good indicator of the condition (or depth) of the underlying peat matrix. Furthermore, a greater number or more extensive threats to the condition of the mire did not mean that mire vegetation was in poor condition. This means that vegetation surveys cannot be used to attribute mire or peat condition to individual mires. However, these results may be due to the scale of the survey used, which was based on limited number of vegetation quadrats in each mire, rather than a more detailed survey of the mire as a whole. Comparing mire and peat condition to more comprehensive vegetation surveys (for example in SSSI areas) may show more correlations between mire vegetation and the extent of damage to the peat matrix.

The lack of effective proxies for mire or peat condition defined by this survey is one of its draw-backs if it came to using similar methods in other regions. The labour-intensive nature of both mire detection and mire and peat condition assessment, means that while such a walkover survey could be carried out across a relatively small upland area like Exmoor in a matter of weeks or months (with repeat condition survey being much faster), covering a much larger upland area would be much more time consuming, and labour-intensive. This would especially be the case in more remote areas, with higher altitudes and less hospitable climates, such as Snowdonia National Park, the Pennines, or the Scottish Highlands.

7.3. Site-based/intensive survey

7.3.1. Effects of land management practices on water-table levels

The results of monitoring water-table levels across three mires over two years demonstrate that water-table levels in the case study mires is strongly controlled by precipitation (see section 5.3). Water-table levels depend on prevailing conditions in the days preceding the dipwell readings with antecedent moisture storage causing water-tables to be consistently high in winter due to more frequent rainfall, and more fluctuating in summer when rainfall events are less frequent but often intense (Branfireun and Roulet 1998; Charman 2002). The results also demonstrate that physical damage to the peat, caused by drainage or peat cutting, results in reduced water-table levels. The extent of water-table draw-down, both in terms of depth and spatial extent, was found to be controlled by the size or depth of the drainage ditch or peat cut i.e. in comparison to small or shallow ditches, larger and deeper features caused water-table levels to be lower in nearby dipwells, and reduced water-table levels over a wider area. The position of dipwells relative to damage features also controlled the magnitude and amplitude of the water-table response to rainfall events: i.e. dipwells near to larger damage features had consistently low water-table levels; in dipwells near to smaller damage features (or further away from large features) the amplitude of readings was high; and dipwells which were the furthest from damage features had the most consistently high water-table levels.

Precipitation patterns during the 2-year monitoring period were essentially similar to those of the last 35 years in both the amount of precipitation and the amplitude of precipitation events. It was therefore assumed that water-table levels at each of the dipwells would not have varied markedly in their annual patterns over this period. Aerial photos, accompanied by written references (see section 5.2) indicate that the peat cutting (at Larkbarrow) and the drainage of the peat (at all three mires) is likely to have occurred more than 60, but less than 150 years ago. If precipitation patterns over this period were similar to those over the last 35 years, it seems reasonable to assume that water-table conditions similar to those observed during the monitoring period prevailed since the mires were subject to peat cutting or drainage. This is supported by monthly precipitation data from the Met Office Hadley Centre Observations Dataset (Alexander and Jones 2001) from the Southwest England and Wales region, which show that there has been no clear trend towards increasing (or decreasing) rainfall over the last 138 years (see figure 7.2). This suggests that water-table levels recorded during the monitoring period can be projected back to when the drains were cut and peat extracted from these mires. A caveat to this is that erosion may have led to lateral or vertical extension of drains since they were dug, leading to a potential reduction in water-table levels over time. However, without firm knowledge of when drains were dug, or of erosion rates over time, we cannot model this loss due to erosion, or quantify its impact on water-table levels with the mires. It was concluded that dipwells readings and precipitation data cannot be used in a straightforward way to model past water-table levels, as periods of unusually high rainfall or drought, outside the boundaries of what was recorded during the monitoring period, cannot be effectively modelled. However, it may be possible to make predictions about the effects climate change (Murphy *et al.* 2009) on water-table levels (see section 7.4.1.).

7.3.2. Water-table draw-down and the integrity of the peat matrix

Age-depth models constructed for three of the peat cores, using a combination of radiocarbon dating and SCP dating markers from more modern samples (see sections 3.3.5.1 and 5.5), indicate that peat has been accumulating at all coring locations until at least recently. At locations on all three mires (LK2, LK4, SH10, and B19), SCP records suggest that peat continued to accumulate at these locations until at least 1970 (±5 years) (Rose et al. 1995; Rose and Appleby 2005). As there are errors associated with SCP dating (particularly as no sites from Southwest England are included in the calibration dataset: Rose and Appleby 2005) and the top sample taken from the majority of cores was from a depth of 2cm rather than from the very top of the cores, it is not possible to definitively say whether or not peat is still accumulating at all coring locations. Overall, it seems unlikely that peat is currently accumulating at locations where the top of the peat profile is constantly above the water-table, and particularly at locations where the zone of water-table fluctuation is well below the surface of the peat (as at SH8 and B19). As the surface of the peat is no longer waterlogged or anaerobic, organic matter may decay more quickly, precluding peat formation (Ingram 1983; Clymo 1992; Charman 2002). The reduction in the percentage of organic material in upper samples of the cores (see figure 5.20) may be caused by drier conditions at the surface of the peat leading to slower peat accumulation (or no peat accumulation) and more degraded organic material near the peat surface.

Analysis of the current rates of decay within the peat using the ‘cotton strip’ method (see sections 3.3.4 and 5.7.1) indicate that decay rates in the peat are more rapid in sections of the core which are continuously above the water-table than in zones of fluctuating water-table, and within these 'dry' sections of the matrix, increasingly high towards the surface of the peat. The lowest rates of decay were in sections of the peat which were permanently saturated. This conforms to expected results, as decay rates are higher in the acrotelm then the catotelm (Clymo 1992), and highest nearer the surface where the peat is likely to be more oxygenated. These results also suggest that, if current water-table conditions persist (or reduce due to climate change or erosion), decay of organic remains in zones of the peat that are consistently above the water-table will increase, and decay will be more extensive nearer the surface of the peat. Redox and pH readings were taken both in the field and in cores in the lab using hand-held monitoring equipment (see section 3.3.4). These indicate that whilst redox readings are generally higher from sections of the peat which were seasonally or continuously above the water-table (figures 5.48-5), all readings appeared to be within expected ranges for waterlogged deposits in which pollen remains are preserved (Corfield 2007: see figure 5.49). However, the variable results, and the difficultly of obtaining consistent readings, means that the results from these methods may not reliable. *In situ* probes may provide a more reliable method for pH and redox monitoring within peat profiles (e.g. Lillie *et al.* 2007).

Water-table draw-down lowers the level of the acrotelm-catolem boundary, increasing decay rates in the sections of the peat profile which are above the water-table (Ingram 1982; Clymo 1992). Reduced waterlogging and increased oxygenation of peat increases the rate of oxidation and reduction reactions and allows aerobic bacteria to operate (Charman 2002). Therefore, in sections of the peat profile which were more often above the water-table during the monitoring period we would expect more humified peat, and slower rates of peat accumulation. As predicted, increases in peat humification were detected in cores where the upper sections of peat were above the water-table. This was clearest in the visual analysis of peat humification (figure 5.21), which showed that peat humification was particularly high in sections of the cores which were permanently above the water-table during the monitoring period. The results produced by photospectrometric methods were less clear. Although these showed an increase in peat humification within the top 10cm of the cores where the upper sections of the peat were permanently above the water-table, the causal relationship between ‘un-saturated’ peat and high humification could not be demonstrated statistically. This may be because peat humification increases as a function of time since peat formation but the relationship between depth and peat humification is not linear. This is because environmental changes (temperature, precipitation, water-table depth) alter the rate of peat accumulation, and because decay rates are higher in the acrotelm than the catotelm. This means that decay rates do not decrease in a linear way with increasing depth (Clymo 1992). Therefore, the effect of decreasing humification near the surface of the peat may not be entirely removed by linear detrending, and thus may mask trends towards increasing decay rates at the surface of the peat caused by water-table draw-down.

The problems with interpreting peat humification results are also compounded by the fact that environmental conditions contemporary with peat formation also affect the level preservation of organic remains. This means that, alongside recent damage to peat, past climate and human impacts on the environment are also key to understanding patterns of peat humification through time (Blackford and Chambers 1993; Charman 2002; Chambers *et al.* 2011). The effects of past events and processes may be superimposed on any damage to pollen or increased humification caused by recent/modern water-table draw-down, preventing clear correlation between humification and any one of a number of environmental factors.

7.3.3. Water-table draw-down and palaeoenvironmental remains

The majority of pollen samples from all cores were shown to reflect the environment contemporary with peat formation. Over 91% of pollen samples passed all of Bunting and

Tipping's (2000) tests, indicating that the assemblages were not significantly biased by post-depositional taphonomic processes. Unbiased assemblages were recovered from sections of the peat which were permanently above the water-table, demonstrating the durability of pollen grains. Although these results may not be surprising, as work on pollen preserved in buried soil and archaeological deposits often demonstrates the resistance of pollen grains to decay (e.g. Dimbleby 1985; Tipping *et al.* 1994), they do allow us to make a key point: that even in peat profiles where water-table draw-down has been both significant and long-term, the recovered pollen assemblages reflects the environment contemporary with peat formation. This means that they are still a reliable basis for discussion of this past environment, rather than only reflecting post-depositional taphonomic processes.

Visual analysis of all types of damage score (TW corrosion, degradation, breakage, and crumpling scores) shows patterning which is complex and difficult to interpret. Although overall pollen damage scores fluctuate greatly in the top 20cm of all the cores, there does appear to be a general trend towards higher damage scores in all cores except LK4, (which was one of the locations with consistently high water-table levels). This pattern could be due to drying out of the upper layers of peat, causing increased compaction (and therefore crumpling and breakage of grains: Lowe 1982, Jones *et al.* 2007) and increased oxidation and microbial action very near the peat surface (therefore increased corrosion and degradation of grains: Havinga 1984, Delcourt and Delcourt 1980; Jones *et al.* 2007, Tweddle and Edwards 2010; Twiddle and Bunting 2010). It was only at Beckham that differences in pollen damage scores between the 'test' (B19) and 'control' (B19) cores were as we would expect: i.e. with higher damage scores predominantly in the upper sections of the core affected by recent water-table draw-down (i.e. samples from B19 show greater damage than B15 in the sections of the core which is constantly above the water-table).

Although average pollen damage scores were found to be higher in cores taken from locations where water-table levels were lower, there was no statistically significant relationship between the length of time a sample was above the water-table (water-table residence time) and the overall level of damage to pollen grains (or overall pollen damage score). However, the results showed that samples which were at least seasonally above the water-table were significantly more likely to have elevated pollen crumpling cores, suggesting that water-table draw-down may be a cause of more frequent or extensive crumpling to pollen grains. This relationship was strongest at SH8, the location with the most significant water-table draw-down. These findings agree with Campbell's (1991) neotaphonomic investigations, which indicated that wet-dry cycles cause increased mechanical damage to pollen grains. Another explanation of these high crumpling scores in the sections of peat which are above the water-table may be due to compression of pollen grains, due to increased bulk density of more degraded peat (Delcourt and Delcourt 1980; Charman 2002; Jones *et al.* 2007). These results suggest that to cause significant or measurable damage to pollen grains, water-table levels must be consistently low, causing peat to become dry and oxygenated over an extended period.

There were also some unexpected results: for example, at Larkbarrow and Swap Hill, pollen damage scores were not only higher in samples which were above the water-table, but indicated that cores which have lower water-table levels (LK2, SH7, SH8) have a tendency to have more damaged pollen *throughout* the peat profile then cores taken from locations with consistently high water-table levels (LK4 and SH10). These results suggest that the locations of the cores most effected by water-table draw-down due to drainage and peat cutting (first occurring between 60 and 150 years ago), may have been less favourable for pollen preservation over a longer period. This could be due to the digging of drainage ditches along natural drainage channels, which may have already been causing some water-table draw-down. However, the reasons for these patterns are difficult to explain, and may require more detailed assessment of the ontology of these mires. Unfortunately, testate amoebae were not preserved in sufficient concentrations in the peat to allow the reconstruction of surface wetness using a transfer function (although it has recently been suggested by Payne [2011] that applying transfer functions from ombrotrophic to minerotrophic mires may not be effective anyway).

There have been few investigations of pollen condition from peat deposits, as opposed to neotaphonomic studies (e.g. Campbell 1991, 1999; Twiddle and Bunting 2010; Lebreton *et al.* 2010), and studies from sediments other then peat (e.g. lacustrine sediments: Wilmshurst and McGlone 2005). It is therefore difficult to compare the results of condition assay of pollen from this survey to other studies. This problem is compounded by the fact that few studies record all damage types using the same condition categories or criteria, or present all their results in a clearly re-analysable way in publications. As the method used for pollen condition classification was based on that used by Jones *et al.* (2007), the results (before taxon-weighting of damage scores, which was developed for this project) are directly comparable. The range of values from all the Somerset Levels sites showed general trend towards higher biochemical (corrosion and degradation) and lower mechanical (breakage and crumpling) damage to pollen grains than those from the Exmoor mires described here. Jones *et al.* (2007) suggest that the high biochemical damage values are due to oxidation or microbial action as opposed to pollen transport or compression, which they cite as the causes for biochemical and mechanical damage respectively. In contrast, the results of this study indicated that increased crumpling scores corresponded with areas of the peat which were seasonally or permanently above the water-table. Although arguments have been made about causes of mechanical and biochemical damage, for example, neotaphonomic experiments by Campbell (1991) suggest that mechanical damage to pollen is more likely to be caused by wet-dry cycles, it is difficult to analyse these causes in relation to the Somerset Levels sites as little contextual information is provided for each site with reference to the extent of water-table draw-down or specific threats from peat wastage. A commonality between the pollen preservation indexes (or damage scores) between the Exmoor and Somerset Levels sites is the lack of clear correspondence between sample depth within the peat matrix and the number of damaged grains or the extent of damage. This demonstrates the combined effects of both current/recent and past processes on pollen condition throughout peat profiles (Jones *et al.* 2007).

7.3.4. The impact of past climate change and human impact on the palaeoenvironmental resource

The previous section suggested that complex patterns of pollen condition and humification could not only have been caused by recent/modern water-table draw-down. Fluctuating patterns of damage scores and humification, as well as testate species assemblages, indicate that both climate change and human impact through time have had effects on the preservation of the palaeoenvironmental resource, which may 'mask' changes due to water-table draw-down. The key questions that are addressed in this section are whether the condition of the palaeoenvironmental resource through the seven extracted cores can allow us to separate the effects of human impact and climate change and identify individual events.

Regional Pollen Zones (RPZ) were created by using biostratigraphic markers to correlate levels between the dated and undated cores from each mire (see section 3.3.6.2), allowing the condition of various palaeoenvironmental proxies to be compared through time. Variation in the dominant types of damage to pollen through time suggests that varied processes may have caused damage to pollen grains. These differential patterns can be used to give an insight into the taphonomic processes affecting pollen assemblages through time (Wilmshurst and McGlone 2005; 2005a; Tweddle and Edwards 2010). Some clear trends demonstrate the impact of past environmental conditions on the condition of pollen remains: for example, corrosion scores tended to be higher in deeper samples. This could potentially be explained by slower peat formation in the early stages of paludification (Moore and Bellamy 1973), and therefore increased oxidation of pollen grains in newly forming peat, causing corrosion (Havinga 1984; Delcourt and Delcourt 1980; Jones *et al.* 2007). These results are similar to those found by Jones *et al.* (2007) at Glastonbury Lake Village, where they suggest that high levels of corrosion at the base of the peat, particularly to grains of taxa which were likely to grow in fen woodland (i.e. *Alnus, Corylus, Betula*), suggest slightly wet woodland conditions. The pollen assemblages SH8 and LK2, where the trend to high corrosion scores were particularly marked, are also dominated by similar taxa, indicating that similar fen woodland conditions may have existed at these sites. This conclusion is also supported by the presence of wood peat at the base of these cores.

Past climatic conditions have been modelled using surface wetness reconstruction from testate amoeba and peat humification analyses from ombrotrophic mires in a number of regions, including Charman *et al.* (2006) in Northern England; and Amesbury *et al.* (2008) in Southwest England (see sections 2.3.1.2 and 2.3.2.3). Pollen damage scores and humification data were compared to climate reconstructions, to look for correspondence between past climatic events and changes in the condition of the palaeoenvironmental resource through time. Pollen damage scores were higher in samples which corresponded with dry-shifts in climate models defined by Charman *et al.* (2006) and Amesbury *et al.* (2008). This indicates that shifts in regional climate have had an impact on the condition of pollen remains within the three studied mires. It also suggests that pollen may become increasingly damaged in response to the warmer drier summers and more intense precipitation events postulated by UK climate predictions (Murphy *et al*. 2009). More frequent wet and dry cycles, due to reduced antecedent moisture within the peat (caused by higher temperatures and longer drier spells) and short periods of intense rainfall, may also cause increased mechanical damage to pollen remains (Campbell 1991).

Percentage transmission data indicate that humification did not significantly vary between wet and dry periods in any of the cores. This is unexpected as both climate reconstructions (Charman *et al.* 2006 and Amesbury *et al.* 2008) were created using humification (and testate-inferred surface wetness) data. These results may indicate that sampling resolution may be too low, or error boundaries on the dating of individual samples (using age-depth modelling) may be too wide, to pick up the more rapid climate shifts. The fact that the studied mires are also partially groundwater fed (valley and soligenous mires), rather than ombrotrophic may mean that they are less sensitive to climatic changes (Charman 2002). However, increased humification caused by both recent and past human impact may also mask changes in peat humification due to climate change. There was also little correspondence between testate amoeba-inferred surface wetness and climate reconstructions. However, Payne (2011) suggest that testate amoeba–based surface-wetness transfer functions developed for ombrotrophic mires, may not be suitable to apply to testate amoeba data from minerotrophic fens, due to differing amoeba populations. Also, poor preservation levels, and differential preservation of particular types of testate amoeba (owing to shell/test composition) within minerotrophic sedge-dominate peatlands, may also mean that climate reconstruction based on these types of assemblages may not be reliable (Mitchell *et al.* 2008; Payne 2011).

Detecting human impacts, as opposed to climate change, based on the condition of the palaeoenvironmental resource was more difficult to detect and test statistically. The analyses consisted of visual analyses of patterns in the stratigraphically plotted pollen taxa and condition data, as well as charcoal concentration, humification, and loss on ignition data through time (using RPZ to compare observed patterns between dated and undated cores), to look for contemporaneous changes which may indicate local human impacts on the landscape causing changes to the condition of the palaeoenvironmental resource. Taxa changes within the core indicate a reduction in aboreal taxa suggest that woodland clearance occurred between around 3500 and 2000 cal BP (1550 and 50 cal BC). Contemporary increases in charcoal concentration (at LK4, SH8, and B15) suggest that this deforestation could be accorded to human impact. These changes correspond with noticeable peaks in damage scores, particularly in mechanical damage (breakage and crumpling) of pollen grains, increases in peat humification and the percentage of robust taxa, and decreases in the percentage of organic material in cores at Larkbarrow and Swap Hill. Increased mechanical damage to pollen grains may be indicative of transport and redeposition of pollen grains from eroded sediments, as a result of accelerated erosion due to woodland clearance or local agricultural activities (e.g. ploughing). Although there were no clearly visible bands of sediment in-wash (as were detected by Wilmshurt and McGlone [2005; 2005a]), redeposited eroded material may have consisted largely of fine organic material or sediment from peat or peaty soil deposits higher in the hydrological catchment of the studied mires.

This evidence is supported by archaeological and palaeoenvironmental evidence from other areas of Exmoor, which indicate continued or expanded woodland clearance throughout the Bronze Age (Merryfield and Moore1974; Francis and Slater 1990; Fyfe *et al*. 2008) and into the Iron Age (Fyfe 2000; Fyfe *et al.* 2003). These trends, alongside the construction of monuments such as stone settings (Gillings *et al.* 2010) and field systems (Riley 2009), indicate widespread inhabitation and agricultural activities on Exmoor's upland areas. Stone setting and Bronze Age tumuli within the $2km^2$ around the mires (Jamieson 2003) indicate Bronze Age inhabitation of the area. Although there are no known field systems or settlements dated to the Bronze Age or Iron Age near to the study sites, this is not particularly surprising, as limited areas of Bronze Age field systems are known from Exmoor, and evidence of Iron Age settlement is virtually unknown in the archaeological record, despite indicators of agricultural intensification in this period from the palaeoenvironmental record. This means that the lack of archaeological evidence does not necessarily preclude agricultural land use during this period in the hydrological catchment area of the studied mires. These conclusions may be further refined by higher resolution palaeoenvironmental analyses and dating, and particle size analysis may allow the detection of layers of sediment in-wash within the peat. Although speculative, these observations serve to illustrate ways in which human impact on the landscape can be detected through analysis of taphonomic changes to palaeoenvironmental remains.

7.3.5. Implications of site-based assessment of the condition of the palaeoenvironmetal resource within peat

The results of pollen condition assessment from this survey indicated that pollen remains tend to be preserved to a level where assemblages are still useful and reliable indicators of the past environment, even in mires which show clear evidence of damage spanning at least 60 years. The increased pollen damage scores near the surface of the peat, as well as correlation between the time peat samples spend above the water-table and crumpling of pollen grains, suggest that water-table draw-down does have some impact on pollen condition. However, damage to a mire (e.g. drainage ditches and channel erosion) may have to be fairly extensive or long-term before these effects become so severe as to cause pollen assemblages to be biased by post-depositional taphonomic processes (and therefore no longer a useful palaeoenvironmental proxy). Decay rates and peat humification increase towards the surface of the peat, particularly in sections of the peat profile which are permanently above the water-table. This suggests that organic remains which are less robust than pollen (e.g. plant macrofossils or organic archaeological remains such as wood), may more rapidly become degraded in these zones of peat profiles.

Ninety-five percent of mires surveyed on Exmoor showed visible damage to the mire surface, and therefore suffer from water-table draw-down or loss of the palaeoenvironmental resource due to sediment loss. This means that there some losses to the paleoenvironmental resource (whether that is plant macrofossils or archaeological remains) are likely at the overwhelming majority of mires. Pollen remains are likely to be preserved in all but the most severely damages mires, where water-table draw-down is both very extensive and long-term. Thirteen percent of mires were seen to suffer from damage indicating very extensive damage and active erosion. At these mires, water-table levels may continue to decrease, potentially causing damage to the palaeoenvironmental resource deeper in the peat profile. Another concern at these extensively damaged locations is the loss of the palaeoenvironmental resource through erosion of sediment, or the erosion of large sections of peat as edges of eroding channels are undermined and collapse. Water-table draw-down may also mean that peat is no longer able to accumulate at locations where the upper sections of the peat are no longer seasonally waterlogged (i.e. permanently above the water-table). This means that peat in these locations is no longer preserving a record of the contemporary environment, meaning the palaeoenvironmental record extracted by future researchers will be truncated.

The results of the intensive site-based survey, however, show that the picture is not entirely bleak. There may be potential to define areas in which the palaeoenvironmental resource is at greater risk of damage or loss, as this degradation is generally localised around damage features. Small damage features, such as peat cuts or small drainage ditches, have a relatively localised impact on the water-table. For example, peat cutting at Larkbarrow caused the top few 1-2cm of peat within 20m to be continuously above the water-table. However larger drainage ditches at Swap Hill and Beckham caused more extensive water-table draw-down over a wider area. This means that whilst the condition of peat and palaeoenvironmental remains may be poor and peat accumulation may have halted near large drainage features, away from these features the condition is likely to be good. There is therefore the potential to map areas in which the palaeoenvironmental resource is ‘at risk’. For example, LiDAR data could be used to detect ditches and peat cuts and buffer these features according to their extent and depth. This would allow areas to be highlighted in which the palaeoenvironmental resource may be degrading more rapidly and where peat is no longer accumulating due to reduced water-table levels. Although more spatially intensive monitoring would be necessary to allow the horizontal and vertical extent of water-table draw-down caused by different sized drainage features to be modelled, the results demonstrate the potential to identify areas in which the palaeoenvironmental resource is currently risk both in Exmoor and other peatland areas.

7.4. Managing the palaeoenvironmental resource

7.4.1. The future of the palaeoenvironmental resource

What do the results of this survey suggest about the future of the resource? The condition of pollen remains in the majority of mires is likely to be good, or at least sufficiently reliable for palaeoenvironmental reconstruction, as pollen grains are particularly resistant to damage (Bunting and Tipping 2000). However, increased pollen damage scores, increased humification, and higher decay rates in samples which were continuously above the water-table, suggests that under similar management and climate conditions the condition of pollen and organic remains will deteriorate at the majority of mires. Active erosion at over 90% of detected mires suggests that even under current climatic conditions, peat will be lost (as either sediment in groundwater, as in larger pieces as sections of ditches collapse), and water-table levels may continue to reduce. Thus increasing areas of mires may have sections of the peat matrix which are continuously above the water-table, diminishing areas of actively accumulating peat. From this research it is not possible to state at what rate pollen, or other organic remains, may be extensively damaged or lost due to these processes.

UK Climate Projections (UKCP09: Murphy *et al.* 2009) suggest that even under low emission scenarios mean annual temperatures will increase nationally by 2080, with greater increases in mean temperatures in summer than winter. The predictions indicate that, while annual mean precipitation levels may remains similar, mean winter precipitation will be higher and summer precipitation lower. Also, a greater number of heavy rainfall days (over 25mm/day) are predicted in both winter and summer. Regional predictions also suggests that under medium emission scenarios, in Southwest England mean winter precipitation levels may increase (around 17%), but summer precipitation levels may decrease markedly by up to 41%. This is the greatest predicted summer precipitation decrease across all UK regions except the Channel Islands. Warmer, drier summer conditions and decreased rainfall are likely to have the greatest effect on the palaeoenvironmental resource, leading to lower water-table levels in mires and a greater volume of peat continuously above the water-table. Overall, if cimate change conformed to these predictions (Murphy et al. 2009), this could lead to: accelerated decay of organic remains in upper levels of peat; decay of organic remains at deeper levels within peat profiles; a reduction or cessation of peat accumulation over greater areas of mires; and increased particulate loss of peat due to peat desiccation and heavy overland flow during heavier rainfall events. Overall, this suggests that management intervention may be required to prevent accelerated losses of the palaeoenvironmental resource at mires where erosion is already active. This might include blocking drainage ditches to raise water-tables to reduce peat loss through erosion.

The ability to define mires where accelerated losses of the palaeoenvironmental resource may become an issue in the coming years may help heritage managers to play a more active role in directing peatland ‘restoration’ projects, by suggesting target mires. This involvement could mean that they are able to play a role in the development of ditch blocking techniques which do not involve moving large blocks of peat to form dams, therefore helping to preserve the statigraphic integrity of the peat matrix. Whilst, in national terms, the amount of peat on Exmoor is fairly small, the nature and extent of damage to peatlands on Exmoor is also less extreme than in other upland areas of the

UK. For example, in the Peak District and the Pennines extensive gully erosion, erosion of peat block, peat mass movements, wind erosion of desiccated peat and bog bursts or peat-slides are serious issues affecting the preservation and integrity of the palaeoenvironmental resource in upland peat (Mills 2002; Evans and Warburton 2007). Survey methods similar to those developed for this survey (perhaps with modified mire condition criteria or damage categories) could allow an overview of damage to peatlands to be gained across these areas. Repeated surveys using the same methods over the following years to monitor the condition of mires and the peat matrix, could allow rates of change and thus levels of threats due to different types of damage (or management practices) to be defined at mires across the surveyed areas. In much larger upland areas, where damage to peatlands is more extensive, some use could be made of APs or LiDAR data to map damage to mires. APs could also be used to record the changes in mire condition over the last 50 years, during which time a number of series' of vertical aerial photos are available for most parts of the UK.

7.4.2. Valuing the palaeoenvironmental resource

7.4.2.1. Developing a valuation scheme

This section proposes a flexible heritage 'valuation' scheme for upland mires. An assessment of the relative archaeological potential or value of mires may be useful in guiding future palaeoenvironmental research or conservation work. As value is always relative and dependent on the frame of reference (Mathers *et al.* 2005), the criteria used to rank mires of assess archaeological potential must therefore be defined clearly (Deeben and Groenewould 2005). With this in mind, the scheme proposed here uses a number of quantifiable standards of both data collection and point (i.e. score/value) allocation, in order to outline one possible means of ranking mires in terms of their archaeological potential or value. It also attempts to separate sites into two categories; 'valuable' mires in good condition with few visible threats to peat, and 'valuable' mires which are already extensively damaged, and in which the palaeoenvironmental archive may be under threat in future, particularly in light of climate change predictions. It must be stressed that although the standards used are based on current research agendas, they should be regarded as an “heuristic device” (Debben and Groenwoult 2005, 292) to allow us to deal with a specific problem.

The first stage in this process is to decide what ‘services’ a mire which preserves a palaeoenvironmental archive could provide to archaeology. A simple system was developed to allocate points based on how well each mire fulfilled certain criteria, based on walkover survey data and other spatial datasets collated in the project GIS. The criteria used here were developed using the research aims outlined in the Exmoor National Park Archaeological Research Framework 2011-15 (ENP RF: Wilson-North 2011) and the South West Archaeological Research Framework (SWARF: Webster 2008). The system was deliberately kept simple, facilitating evaluation and (if necessary) alteration of the assessment criteria, to allow the system to be adapted to new research agendas, or for application to other regions. The datasets used in this project could potentially be reanalysed using different criteria for point allocation, for example mires with peat depths of 2m or more, or within 1km of Bronze Age monuments, could be selected to adapt the system to different research projects.

Mires with deeper peat were allocated more points than shallow mires, as although the relationship between age and depth of peat is not linear (see figure 7.1), it is more likely that deeper peat *either* has an earlier inception date than shallower peat *or* preserves higher-resolution palaeoenvironmental records. Therefore deeper peat has the potential to allow researchers to build a more detailed narrative of past landscape changes, extending further into the past or building up a more detailed reconstructions for selected period of time than a shallow peat sequence would allow. The more varied formation processes for small mires may mean that deep peat deposits may accumulate quickly under some circumstances (for example at Moles Chamber: Fyfe 2000), for example when drainage is blocked. This could be important in terms of research, increasing (for example) our knowledge of upland use in Mesolithic and Neolithic times (Riley and Wilson North 2001), or allowing higher resolution analysis of changes throughout transitional periods (e.g. the Bronze Age/Iron Age transition). Mires at which peat is currently thought to be accumulating were also allocated points. This was determined on the basis of vegetation condition; where this is classed as 'good', it is likely that peat is continuing to form, and that the palaeoenvironmental record includes an archive up to the present day. This may provide information on recent climate change (ENP RF aim 2, SWARF aim 23), or allow the impact of recent land management to be detected, facilitating the investigation of drivers for change in moorland ecology (Chambers *et al.* 1999).

Mires within areas designated as having exceptional archaeological and historical importance (AEAHIs: Riley and Wilson-North 2004; Fyfe and Adams 2008) were allocated one point, as they have the potential to provide a detailed environmental context to important known archaeological sites and to add another layer to descriptions of the special landscape character of these areas (ENP RF aim 6: landscape-based research, SWARF aim 1a). Points were also awarded based on the numbers of Scheduled Ancient Monuments (SAMs) within 1km of a mire: This distance was deemed a suitable 'Relevant Source Area for Pollen' (RSAP) for small spring and valley mires (Sugita 1994; Davies and Tipping 2004). The true RSAP for each mire may in reality vary depending on the size of the mire, its topgraphic setting, the nature of surrounding vegetation, and may also vary through time, and therefore is difficult to define precisely for each mire individually. It would be possible to refine the point allocation to address particular research questions: For example, prehistorians interested in monumentality might use the presence of stone settings and barrows to assign points to mires (ENP aim 4: relict prehistoric landscapes; SWARF aims 3, 25, 28, 54, 57). The condition of the peat matrix itself (peat humification assessed on the Troels-Smith 0-4 scale) was used as the final criterion for allocation of points. Intensive site-based analysis of the condition of pollen remains suggests that while peat humification has some effect on pollen condition, it is rarely so bad as to damage or bias the assemblage to the extent that it is unworthy of analysis (Bunting and Tipping 2000). Only in very humified or dry peat was the condition of pollen significantly altered by oxygenation and resultant decay within the peat matrix. For this reason, peat in condition 0-3 was allocated one point, whilst peat in very poor condition (4) was not given any points.

Another approach that was considered, but not factored into the final analysis, was prioritising mires in areas where little is known about the archaeology. A larger number of points could be allocated to mires with fewer recognised HER sites in the surrounding landscape, helping to address the imbalance in research, which tends to focus on standing monuments. This criterion was not used as part of the current valuation system as many research questions focus on setting known archaeological sites in their environmental context: e.g. ENP RF key methods and techniques 4 (Wilson-North 2011) states that palaeoenvironmental sampling is required where relationships between cultural remains and environmental sequences can be established; and ENP RF1 (Wilson-North 2011) and SWARF aim 1 (Webster 2008) indicate that reconstructing past vegetation change in landscapes already considered archaeologically important should be encouraged.

Mires which had accrued a points total higher than the mean (2 points) were designated as ‘valuable’ or ‘important’ sites. The next stage of the analysis selected mires which are either in excellent condition (with few signs of visible damage to the peat matrix) or very damaged (with many or extensive visible threats to the peat matrix) and hence sensitive to loss of the archive. Mires which achieved a good mire condition scores (either in condition 1 or 2) (see fieldwork methodology) were deemed to be in ‘excellent’ condition.

Mires that achieved a poor condition score on field assessment (either in condition 4 or 5), and which also exhibited the types of damage that threaten the stratigraphic integrity of the site, or may even lead to its destruction (e.g. collapsed peat piping or extensive erosion: Fyfe 2006), were designated ‘very damaged’.

7.4.2.2. Results of valuation analysis

The ‘valuation’ analysis described above returned 37 out of 119 mires with higher than average points scores. Of these mires, 16 were in very good condition, whilst only four sites out of the 37 high-scoring mires were designated as very damaged (figure 7.3; table 7.1). It seems reasonable to assume that the mires in good condition will remain stable under a consistent management regime similar to that presently in place. However, mires which are already in a damaged condition are likely to deteriorate over time without conscious efforts to prevent the loss of peat or the damage to the palaeoenvironmental resource caused by water-table raw-down.

7.4.2.3. Embedding a valuation scheme into an ecosystem services approach to management.

In Southwest England, spatially-extensive peatland restoration projects are underway, making the need for an assessment of the ‘value’ or research potential of the palaeoenvironmental resource a priority. Although the aims of restoration projects are often in harmony with archaeological interests (e.g. rewetting and maintenance of high water tables) (Coles 1995), they have highlighted a problem that archaeology increasingly faces; to protect archaeological ‘assets’ (DCMS 2010) we must be able to place 'values' upon them. For peatland restoration projects, it is relatively simple to rank sites in order of importance, using estimates of biodiversity value or potential for carbon storage or capture (Maltby 2010; Rawlins and Morris 2010). However, conservation discourse tends to promote a view of heritage assets as “priceless” (Mason 2008, 304) and resists the ranking of sites (see section 2.5.3.1), in opposition to ‘economic discourse’ which is based on monetary values and promotes decision making on the basis of market forces. Fears that lower ranking sites may be perceived by non-specialists as unimportant and therefore not protected, or that these sites may be neglected by future researchers, may be at the core of opposition to heritage valuation schemes. However, the focus of research and conservation funding in a limited number of sites suggests that implicit valuation and ranking of heritage assets is already common, as theoretical models or guidelines for best practice are rare (Mathers *et al.* 2005). Creating explicit valuation systems may therefore be of benefit to heritage management, as it could allow the examination commonly used but uncritical assumptions about what constitutes archaeological value (see sections 2.5.3.1. for a more detailed analysis).

There are a number of drivers for the development of archaeological valuation systems in general, for example: to facilitate the allocation of limited funding for archaeological research; to allow the clear communication of research agendas to specialists from different disciplines with which archaeologists work closely (e.g. nature conservation); to allow the input of ideas into the ongoing development agricultural subsidy schemes which provide funding for the protection of archaeological sites; and to facilitate the development of different types of designation or protection for different types of archaeological sites or historic landscapes (Schaich *et al.* 2010). It is therefore pertinent to consider how the importance or value of archaeological sites and landscapes can be assessed, as well as working towards clear interdisciplinary communication of the resulting research agendas and systems of assessment. Any developed heritage valuation systems must therefore tread fine lines between: oversimplification and complexity (Grenville and Ritchie 2005), emphasis on research and ‘quality of life’ (or tourism) values (*ibid*.; Carver 1996); and clear and transparent aims/standards and adaptability (to varied research questions) or flexibility to move with changing research agendas (Mathers *et al.* 2005; Debben and

Groenwoult 2005) (see section 2.5.3.1). Any resulting system for assessing value should not be seen as set in stone: if the aims, standards, and basis in accessible data are clear, systems can be altered to move with changing research agendas, or adapted to answer more specific questions.

To return to the issue of valuing or assessing the archaeological potential of mires or peatland sites, we must address a key question: how can complex, multiple, and qualitative values can be summarised into simple quantitative values (Schaich *et al.* 2010)?. The recent focus in environmental management on the ecosystems approach (Rawlins and Morris 2010; Maltby 2010; see section 2.5.3.2) has led some to suggest that it is not a question of *whether*, but *how* historic environment values are integrated into wider valuation systems (Mason 2008; Schaich *et al.* 2010). Projects which seek to provide environmental benefits by boosting the 'ecosystem function' of upland peatlands, for example damming mires to prevent carbon loss, restoring wetland habitats, or improving hydrological management (Holden *et al.* 2007; JNCC 2011), can often improve conditions for the preservation of any archaeological or palaeoenvironmental remains within peat. However, they also present problems for historic environment managers for two main reasons: Firstly, in contrast to ecologists, archaeologists/palaeoecologists view the palaeoenvironmental resource as a finite resource, rather than one which can be restored or regenerated; and secondly, the methods for slowing water run-off and preventing erosion to peatlands often involve excavation of the peat and use of peat dams, potentially disturbing the stratigraphic integrity of the peat and inhibiting future palaeoenvironmental sampling and reconstruction. This means that the communication of a clear system of archaeological values of peatlands to other stakeholders involved in these projects is vital if damage to the palaeoenvironmental resource is to be avoided. Also, the communication of heritage values of peatlands may allow historic environment managers to make contributions to these projects in an active, rather than reactive, way: For example, suggesting possible locations for restoration projects at mires which have high archaeological potential, but at which the palaeoenvironmental resource is under threat due to extensive erosion or water-table draw-down.

The results of this survey have the potential to help historic environment managers to manage small upland mires effectively in a number of ways. Highlighting mires with high palaeoenvironmental potential could help to target future research projects into significant archaeological landscapes in the uplands, integrating archaeological and palaeoenvironmental studies (e.g. EH 2010). Mires identified as 'important' but also 'very damaged' could provide potential targets for mire restoration, to prevent further loss of a resource which has been shown to be important, or at least indicate sites where ecologically/hydrologically driven restoration projects could also benefit the sustainable management of the palaeoenvironmental resource. Although the lost or damaged palaeoenvironmental losses cannot be restored, further losses could be halted. The results of this survey could also be used to inform the management of other similar mires, perhaps preventing damage before it becomes more extensive, or mitigating against the destruction of these sites through drainage or development. Finally, communicating a system for assessing the archaeological value of mires to land managers may allow the integration these sites into schemes to protect the historic environment (Historic Environment Local Management [HELM] 2005; DEFRA 2006). For example, there is the potential for land managers to integrate protection of important palaeoenvironmental sites into land management schemes or to receive funding to protect them under stewardship or agri-environment schemes.

7.5. Summary

This chapter has highlighted the potential of the dataset produced through the spatially-extensive survey for targeting future palaeoenvironmental research or mire restoration projects. As well as providing a baseline survey for future mire condition monitoring on Exmoor, the survey outlined a straightforward and replicable survey method which could be extended to other regions. The chapter also suggested ways in which the results of the survey could be used as a tool to facilitate the development of less labour-intensive digital survey methods for identifying mires, or assessing levels of damage to the palaeoenvironmental resource within these mires, in other regions. The site-based intensive survey demonstrated, through water-table monitoring, that water-table levels in mires on Exmoor are strongly controlled by precipitation, and that drainage and peat cutting features cause localised water-table draw-down. The analysis of the condition of the peat matrix, palaeoenvironmental remains within the peat, and current decay rates, indicated that water-table draw-down causes accelerated decay of organic material and damage to the palaeoenvironmental resource. However, the palimpsest of effects on peat and pollen condition caused by past climate change and human impact meant that the effects of recent land management practices (peat drainage and cutting) was not easy to isolate through statistical techniques. However, one of the benefits of using a multiproxy approach was that limited success in some experiments did not preclude the interpretation of the results. Having a number of datasets to compare also facilitated more detailed interpretations of changes in the condition of the resource caused by modern/recent water-table draw-down as well as climate change and human impact through time. The potential future of the palaeoenvironmental resource was discussed, with reference to continuing or increasing water-table draw-down, particularly in the light of current climate change projections. Finally, a flexible heritage valuation system for the palaeoenvironmental resource was outlined. This could allow heritage managers to identify mires with high palaeoenvironmental potential and actively contribute to conservation strategies to preserve the palaeoenvironmental resource at these locations.

CHAPTER 8: CONCLUSIONS

8.1. Introduction

This research project aimed to assess the extent, condition, and value of the palaeoenvironmental resource in upland peat, using the case study of Exmoor's valley, spring and soligenous mires. The methodologies employed involved a combination of spatially-extensive walkover survey techniques and an intensive programme or water-table monitoring, coring, and laboratory analyses of palaeoenvironmental remains. This final chapter discusses the ways in which the results met the aims of the project, provides an outline of methodologies developed during the project, and a critique of the methods employed. Finally, a number of suggestions are made for work which could conceptually follow-on from this research, draw on the results of the project, or use or refine methods developed over the course of the project.

8.2. Project outcomes

To meet the aim of defining the extent of mires, spatially-extensive walkover survey was carried out, resulting in the production of a distribution map of mire polygons, detailing their area, and peat sampling locations, peat type, and peat depths within each mire. Various mire detection techniques were analysed, including visual analysis of aerial photographs (for land drains and mire vegetation), recorded locations of mire indicator species, Ordnance Survey Mapping, and digital elevation models. However, it was found that desk-based techniques overestimated the number of mires, indicating that field survey is necessary for successful mire identification. The results indicated that mires were distributed across the more central areas of the moor away from the coast, and that larger mires tended to form at higher altitudes. The small size of these mires (in comparison to areas of blanket peat), wide geographical spread across Exmoor's moorland area, and variation in topographic locations, make the palaeoenvironmental resource preserved within them particularly valuable for local-scale landscape reconstruction. This means that they have the potential to allow the mosaic of landscapes and vegetation change across Exmoor to be reconstructed, and provide detailed landscapes context to archaeological sites. The distribution map and accompanying database have high potential to be used to guide palaeoenvironmentlal sampling strategies for archaeological projects across Exmoor, particularly by those investigating vegetation dynamics through time (e.g. woodland character and loss, or heathland development), or to shed light on the landscape context and past perception of the more enigmatic standing monuments on Exmoor (e.g. stone settings: Gillings *et. al* 2010).

The mire distribution map and accompanying database also details the results of the extensive mire and peat condition survey: providing condition data for both the mire (in terms of visible damage to the mire) and the peat matrix (using the Troels-Smith [1955] system) at each sampling location, as well as overall averages for each mire. Vegetation condition assessment, based on mire vegetation indicator species, is also included. The results of this survey were used to develop a flexible system for the heritage valuation of mires, but also provide a baseline survey for mire and peat condition. The standardised survey methods (Troels-Smith [1955] peat classification, and mire condition key) mean that the surveying process is easily repeatable on Exmoor and could be applied to other upland areas in the UK. Repeated monitoring in relation to the baseline data provided by this survey may be particularly useful in monitoring the rate of change in the condition of the resource, particularly as over 90% of mires showed signs of active erosion. It is therefore likely that mire condition may deteriorate at these locations, and peat deposits in the vicinity of eroding drains may become more humified or lose material due to erosion. The results of the intensive survey, indicated that that drainage ditches and peat cuts, identified at around 80% of mires mapped across Exmoor, are a cause of localised water-table draw-down. Over extended periods (of up to 150 years) water-table draw-down results in increased decay of organic material and damage to palaeoenvironmental remains in the sections of the peat which are continuously above the water-table. It is also likely that peat will cease to accumulate in areas near to drainage features where the surface layers of the peat are no longer waterlogged for any part of the year. The implications of these findings for the wider resource on Exmoor (and other uplands) are that, although the peat matrix and pollen remains are still likely to be well preserved away from drainage ditches, near to more extensive, deeper, or more longstanding drainage features, the condition of palaeoenvironmental remains is likely to be poorer and deteriorate further over time. Regional climate projections of warmer, drier summers and increased high-intensity rainfall events (Murphy *et al.* 2009) mean that the condition of the palaeoenvironmental resource may begin to deteriorate more quickly in areas where it is already damaged, and damage may occur to remains over a wider area. This is owing to reduced water-tables, peat desiccation and particulate erosion, as well as losses of larger sections of peat through channel bank collapse. The 13% of mires which were already found to be suffering from extensive damage (in condition 4 or 5) are the most likely to be affected.

The flexible heritage valuation system was developed using the results of both the spatially-extensive, and site–based intensive, surveys, as well as historic environment designation datasets supplied by ENPA. It also used aims from current regional research agendas to guide the attribution of relative value of mires to archaeological and palaeoenviornmental research. This highlighted mires which were of high value to archaeology in two categories: those which are in excellent condition with little visible damage and thus potentially worthy of palaeoenvironmental investigation or designation/protected status; and those which are suffering from extensive damage which is likely to cause deterioration in the condition of palaeoenvironmental remains over time. The transparency of the valuation system means that there is potential to adjust the assessed criteria to incorporate different research agendas, or proxies for palaeoenvironmental condition, or extend this approach to other regions. Of the mires highlighted as valuable, those identified as being in poor condition, and suffering from a number of threats to the condition of the peat matrix, could be proposed as targets for mire restoration projects, allowing water-table levels to be raised and preventing further erosion of peat. This would allow historic environment managers to make a positive contribution to upland peat restoration projects, and perhaps facilitate more rapid palaeoenvironmental investigations at these locations. More intensive monitoring of damage at these mires could also increase our understanding of the rate of sediment loss, and water-table draw-down. Finally, highlighting a number of mires where the palaeoenvironmental record is likely to be both long-term and/or high resolution, provides a number of potential targets for palaeoenvironmental sampling to further a number of identified research aims, including: allowing higher resolution analysis of changes throughout transitional periods (e.g. the Bronze Age/Iron Age transition); providing information of the effects of recent climate change or land management; detecting drivers for change in moorland ecology; or providing detailed context to archaeological sites by allowing the reconstruction of relict landscapes (Webster 2008; Wilson-North 2011).

8.3. Development of methodologies

The project has led to the development of new methodologies, and the implementation of alterations or refinements to published methods. The methods used for the extensive survey was developed from those used by Fyfe (2005), and aimed to be transparent, standardised, and therefore replicable. This will allow future non-specialist surveyors (local authority staff, volunteers, or students) to monitor the condition of mires and peat deposits in uplands, and establish baselines against which subsequent surveys can identify trajectories of change in the condition of the resource. To this end, a version of the mire condition monitoring key developed for this project (Figure 4.12) was included in

Fyfe and Adams' (2008) guidelines for monitoring the condition of archaeological and palaeoenvironmental features or sites within designated AEAHIs. This will allow the condition of mires to be monitored, to either measure the rate of change in peat humification and mire condition at locations where active erosion has been recorded, or to identify the effects of climate change (Murphy *et al.* 2009) or changing land management practices (such as reducing the intensity of upland grazing: Holden *et al.* 2007) on the condition of the palaeoenvironmental resource.

The basic method for calculating damage scores for pollen assemblages was based on that developed by Jones *et al.* (2007). However, it was found that using these 'raw' pollen damage scores made comparison difficult between cores, particularly those in which similar changes in pollen taxa occur at different depths (i.e. where peat has accumulated at variable rates across a mire). This was because some pollen taxa were clearly more susceptible to different types of damage than others, or damage was more clearly visible on grains with less surface texture. The development of taxon-weighted damage scores, based on the calculated 'susceptibility rating' of each pollen taxon, allowed patterns in pollen damage to be observed and compared statistically by depth, and by water-table zone, by removing the skewing affect of different pollen taxa assemblage patterns. This allowed the affects of water-table draw-down on the condition of pollen remains to be analysed.

8.4. Critique of methodologies

As in all research projects, difficulties faced in the course of the research, in terms of both data collection and interpretation meant that planned methodologies had to be continually adapted or abandoned. The interpretation of palaeoenvironmental data in terms of responses to modern damage and water-table draw-down was problematic for a number of reasons. Firstly, it was found that pollen remains were particularly resistant to damage (as might be expected, as pollen remains can be preserved in soils and other contexts which are not continuously waterlogged). This meant that pollen in peat deposits must be exposed to oxidised conditions, potentially with repeated wet and dry cycles, over an extended period (perhaps up to 150 years) before any clear damage patterns can be identified. It was also the case that even in samples which had been continuously above the water-table over this period, and which showed clear signs of damage, the pollen assemblage still seemed to be unbiased, and thus appropriate for vegetation reconstruction. This means that, using the data from this project, we cannot predict the rate at which pollen assemblages become too damaged or unreliable to be considered a palaeoenvironmental resource. Conversely, the poor preservation of testate amoebae throughout the sampled cores meant that this data was not particularly useful as a condition indicator.

The condition of palaeoenvironmental remains, rather than just reflecting modern water-table conditions, in fact represented a complex palimpsest of overlapping signals in response to climate change and human impact through time, as well as modern peat drainage. It was found that modern water-table draw-down had not, to date, caused more extensive damage to palaeoenvironmental remains or the peat matrix than past climate change or human impacts. Separating modern impacts from past trends, to isolate different effects on the palaeoenvironmental resource, was therefore problematic. The interpretation of this complex palimpsest of data was aided by the generation of many different datasets (including pollen condition, humification, loss on ignition, charcoal concentration, and current decay rate data). The current decay rate data (from 'cotton strip' weight-loss analysis) not only pointed towards areas of the peat profile which were most likely to suffer from increasing damage over the coming years, but also allowed a clear picture of the current effects of water-table draw-down without the confounding factors of the effects of past climate or human impact. Radiocarbon and SCP-marker dating, age-depth modelling, and age correlation between cores using biostratigraphic markers, was also key to the interpretation of the data. However, more detailed dating of the upper layers of peat would be needed to gain a more comprehensive picture of the impact of water-table draw-down on peat growth. The selection of seven coring sites also enabled intra- as well as inter-mire comparisons to be made between the datasets, and analyses of strong differential patterns between cores to be interpreted. One of the benefits of using a multiproxy approach is that limited success in some experiments did not preclude the interpretation of the results. Having a number of datasets to compare also facilitated more detailed interpretations of changes due to modern/recent water-table draw-down as well as through time. However, there is still scope for further testing and validation of the data: for example, collating more pollen condition datasets could allow the validity of the pollen damage 'susceptibility ratings' to be tested. The fact that the ratings were both created from, and applied to, the same data may be seen as a source of error (despite the large size of the dataset: over 60,000 pollen grains).

8.5. Suggestions for further work

The results of the spatially-extensive survey and valuation of mires are already being used by ENPA Historic Environment Team both to guide palaeoenvironmental sampling strategy to investigate the development of moorlands through time, and to highlight areas of high palaeoenvironmental potential to sample in advance of ongoing mire restoration projects. The dataset may also be used in future to allow the team to suggest targets for mire restoration to prevent further losses to the palaeoenvironmental resource from mires which have high heritage 'value' or potential, but which are currently suffering from extensive erosion. The mire condition key and straightforward monitoring system used for this project also means that the condition of these mires could be monitored over time. The extensive survey data and valuation data, will be of use to a number of archaeological projects on Exmoor, facilitating the selection for palaeoenvironmental sampling locations and reconstruction of the local landscape context of archaeological sites. This could be particularly useful for adding to interpretations of the changing perceptions of, and use through time, of enigmatic standing monuments such as stone settings in central Exmoor (investigated through the Exmoor 'Miniliths' project: Gillings *et al*. 2010). The 'Exmoor Woodlands Project' (funded by the Exmoor Moorland Landscapes Partnership Scheme and still in the planning stages) aims to reconstruct the structure, character and fate of woodland cover on Exmoor during the early prehistoric period. The project will use the locations of samples where wood was found in the base of the peat profile during this project to develop a sampling strategy to locate preserved wood samples for radiocarbon dating and wood identification.

The systems developed for categorising mire and peat condition, and valuing mires are easily transferable to other upland regions in the UK and Northern Europe. However, the necessity of combining desk-based and field survey to accurately identify mire locations (and characterise peat extent and depth) could prove too labour-intensive to carry out across larger upland areas. Using Exmoor once again as a case study, the spatially-extensive mire dataset could be used to develop and a test (or 'ground-truth') GIS-based techniques for identifying mires using remote-sensed data. LiDAR and hyperspectral imaging (e.g. CASI data) already collected for many upland areas in the UK, could be used to detect locations with the right gradient for peat formation, as well as signals indicating particular vegetation types (Arkimaa *et al.* 2005) or levels of surface wetness (Carey *et al.* 2006; Howard *et al.* 2008; Challis *et al*. 2011). LiDAR data could also be used to detect the location and depth of drainage features. GIS mapping could then be used to create buffer zones around these features according to depth. Thus allowing the identification and mapping of areas within which the condition of the condition of the palaeoenvironmental resource likely to be poor or is at risk, and where peat growth may have ceased.

More detailed studies of mire ontology and the environmental conditions within the peat at the intensive survey mires could increase our understanding of the effects of drainage, and resultant water-table draw-down, on peat growth and preservation conditions within the peat. This would require high-resolution dating of upper sections of the peat profiles, for example using radionuclide dating (Oldfield *et al.* 1995; Appleby 2001). Magnetic susceptibility or trace element analysis could also be carried out in these sections of the peat profiles to test whether soils formation has begun, indicating the potential for mobility of palaeoenvironmental remains (i.e. pollen) within the peat. Cotton strip weight-loss analysis provided a quick and cheap method of assessing decay rates and current preservation conditions within the peat in relation to water-table draw-down. However, more effective seasonal monitoring could be carried out with *in situ* electrodes (rather than hand-held probes) to measure redox and pH at different levels within the peat profile. This could show whether there was seasonal improvement in preservation conditions when water-table levels were high, and provide data to allow the comparison of preservation conditions and pollen damage score. This type of data could also allow the comparison of results between different sites (e.g. in the Somerset Levels: Tinsley 2006; Brunning 2007; Jones *et al.* 2007) where both pH/Eh monitoring and pollen condition analysis have taken place. This could allow causes for different types of damage to pollen to be elucidated and more detailed data to be collected about conditions under which palaeoenvironmental remains are well, or poorly, preserved. Amalgamating the data from a number of studies of pollen condition could allow the general applicability of pollen damage 'susceptibility ratings' to be tested. There may even be the potential to develop the use of pollen condition data as an additional climate proxy, for example, in sediments where testate amoebae are not preserved.

New approaches to the assessment and valuation of the palaeoenvironmental resource in upland peat developed in the course of this project, will allow greater communication and collaboration between stakeholder groups, facilitate future integration of archaeological and palaeoenvironmental investigations, and highlight potential new lines of investigation for peatland and palaeoenvironmental research.

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APPENDIX 1: FIGURES

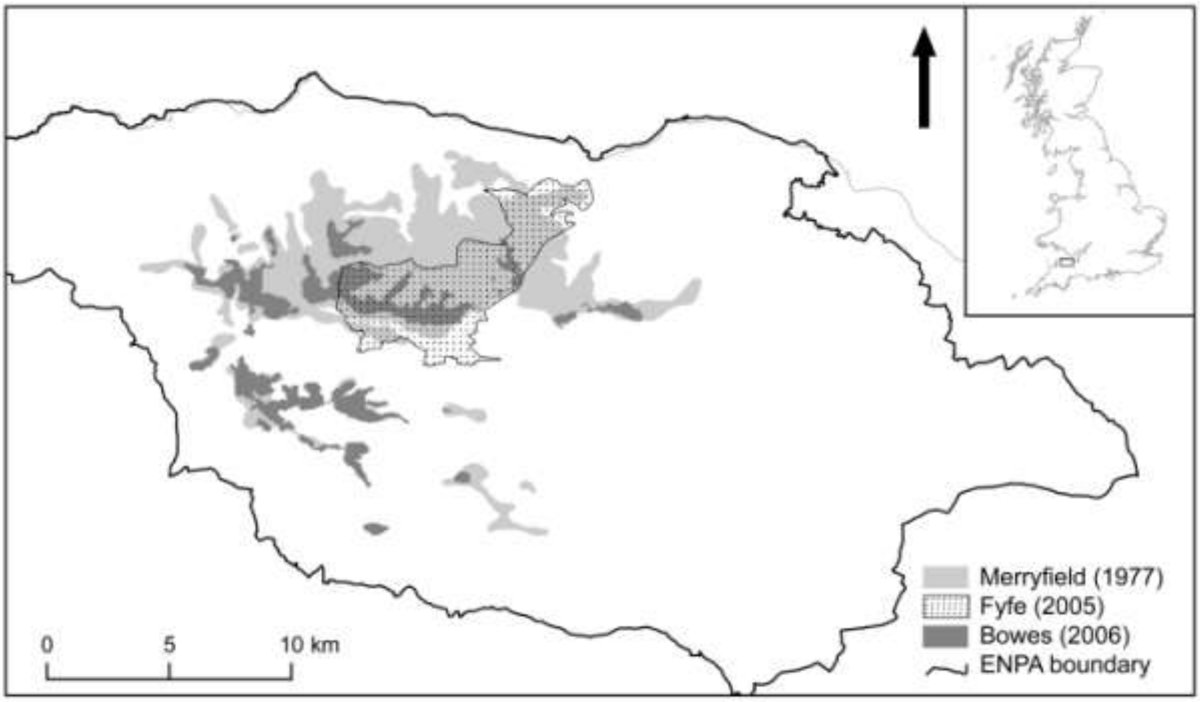

Figure 2.1. The extent of peat depth/mire surveys carried out by Merryfield (1977), Fyfe (2005) and Bowes (2006).

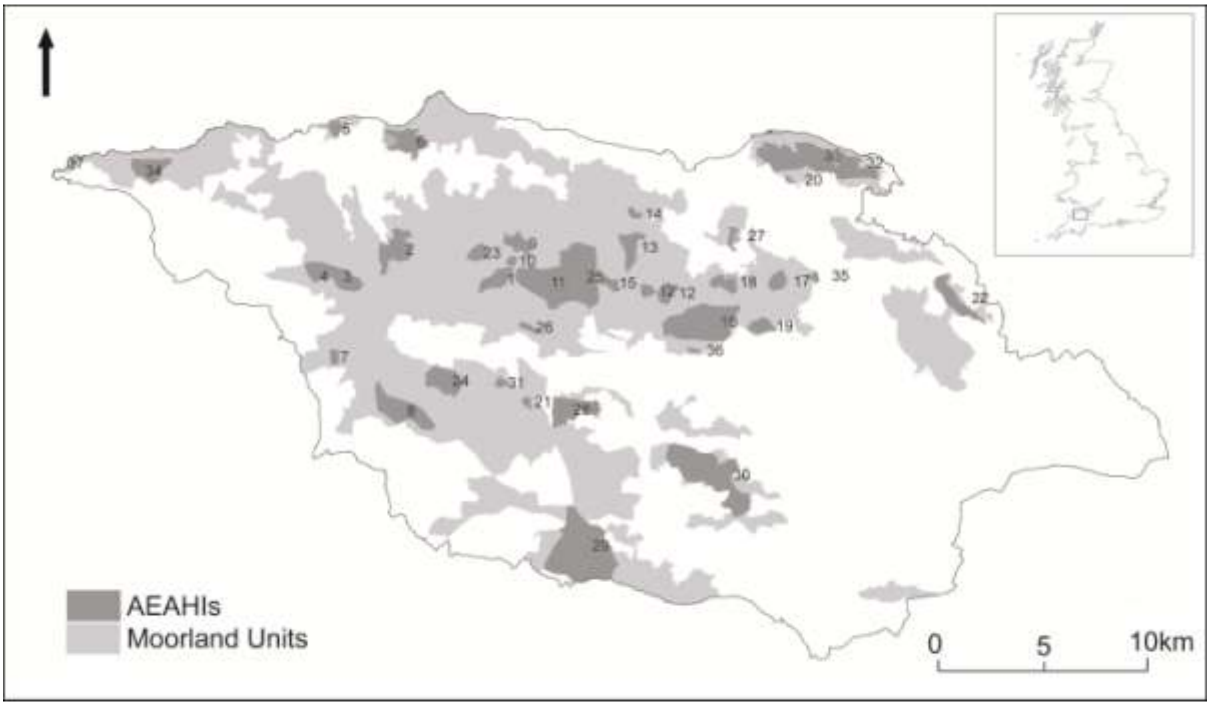

Figure 2.2. Areas of Exceptional Archaeological and Historical Importance (AEAHIs: Fyfe and Adams 2008, revised from Riley and Wilson-North 2004). The names and key archaeological components of these areas are described in table 2.6.

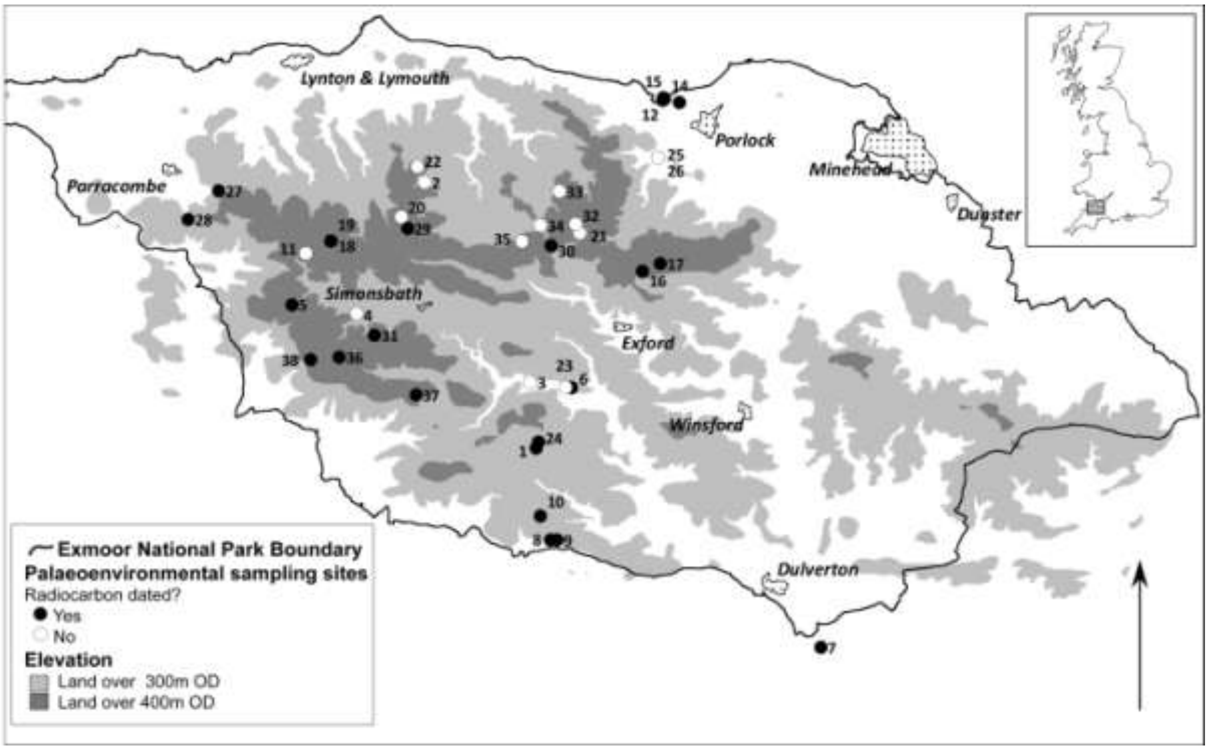

Figure 2.3. Location of palaeoenvironmental sites on Exmoor (see Table 2.8 for site details)

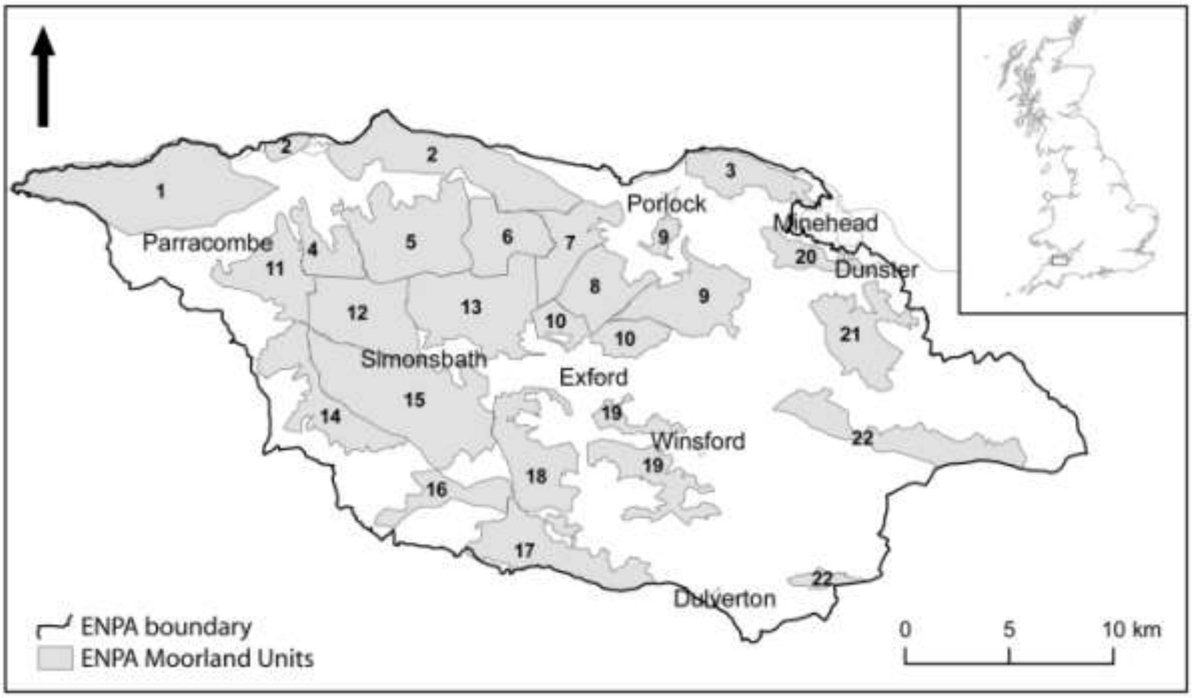

Figure 3.1. Moorland Units as defined in the 'Moorlands at a Crossroads' Report (Landuse Consultants 2004).

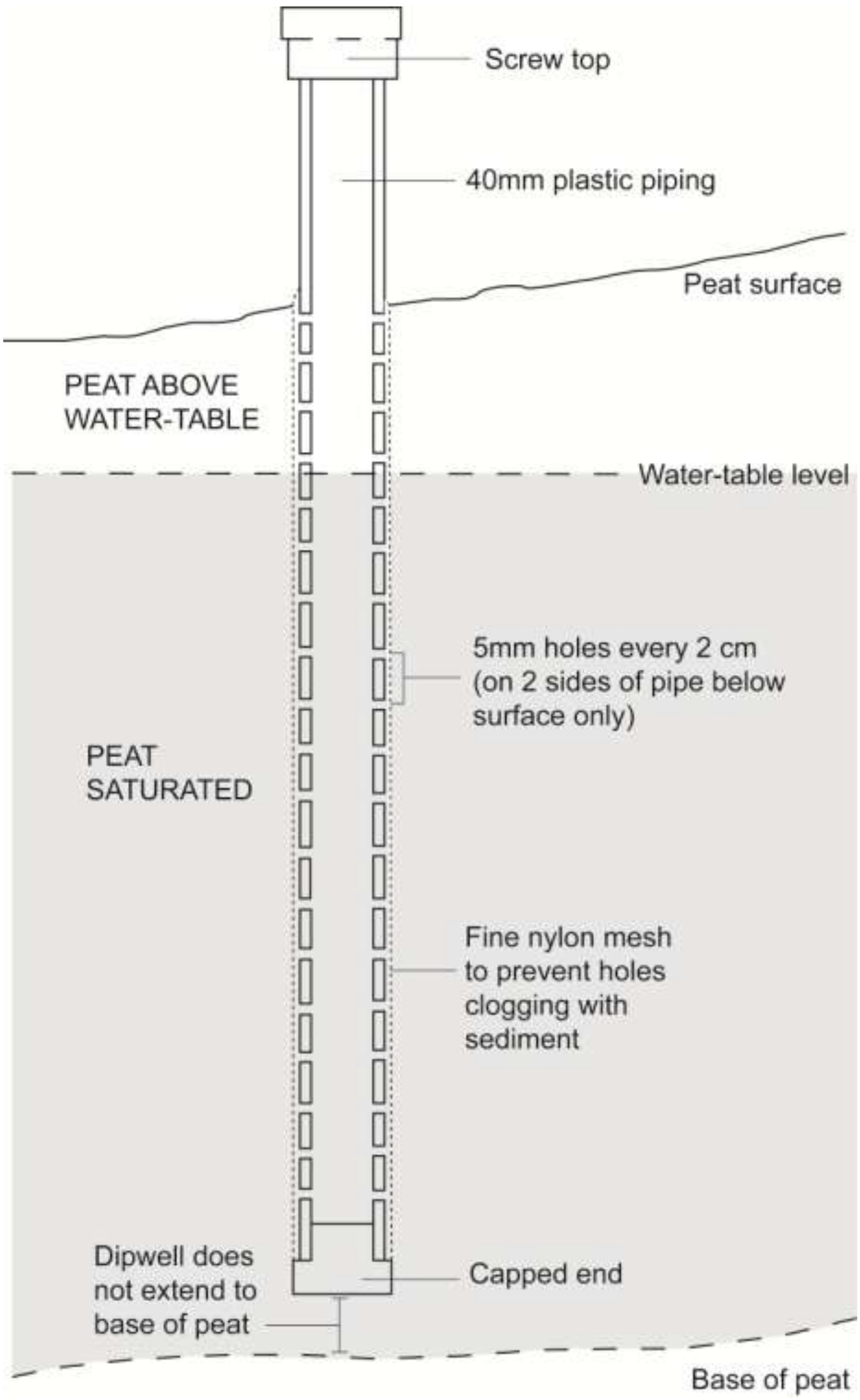

Figure 3.2. Cross-section of a dipwell.

Figure 3.3. Cotton strips stapled to stakes prior to insertion into the peat.

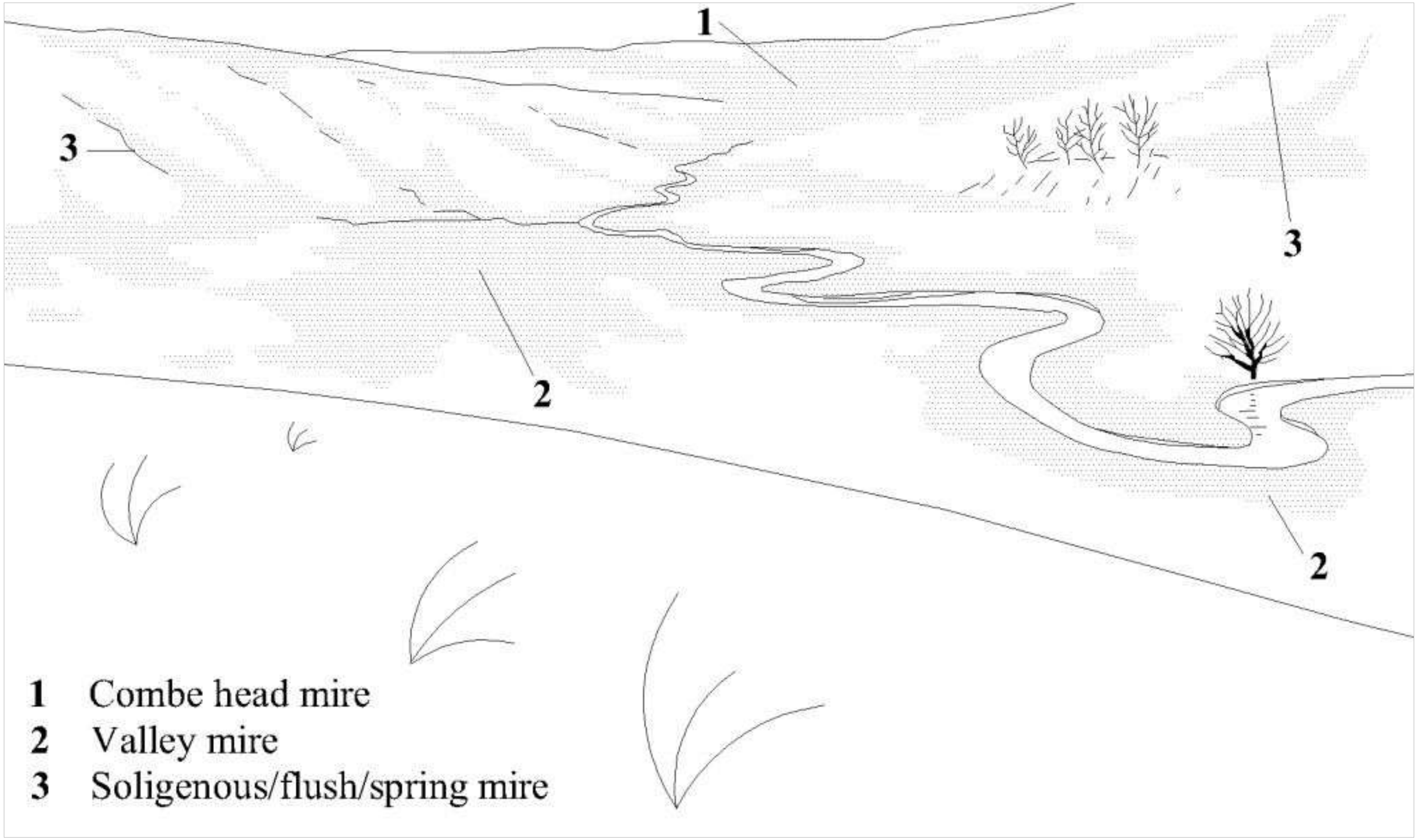

Figure 4.1. Locations of mire types identified in the survey

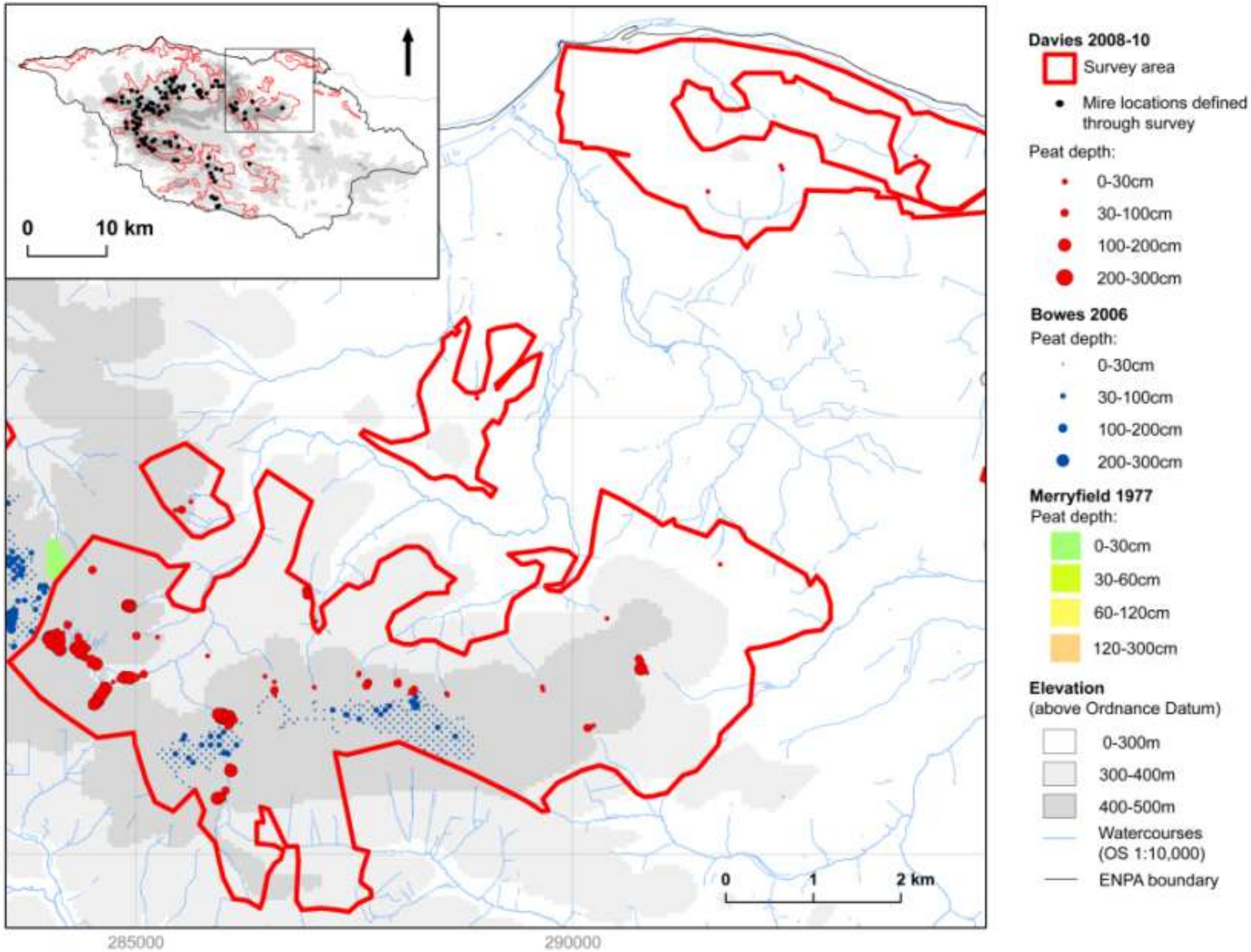

Figure 4.2. East Exmoor: Survey area, peat depth measurements and previous peat depth surveys (Merryfield 1977; Bowes 2006)

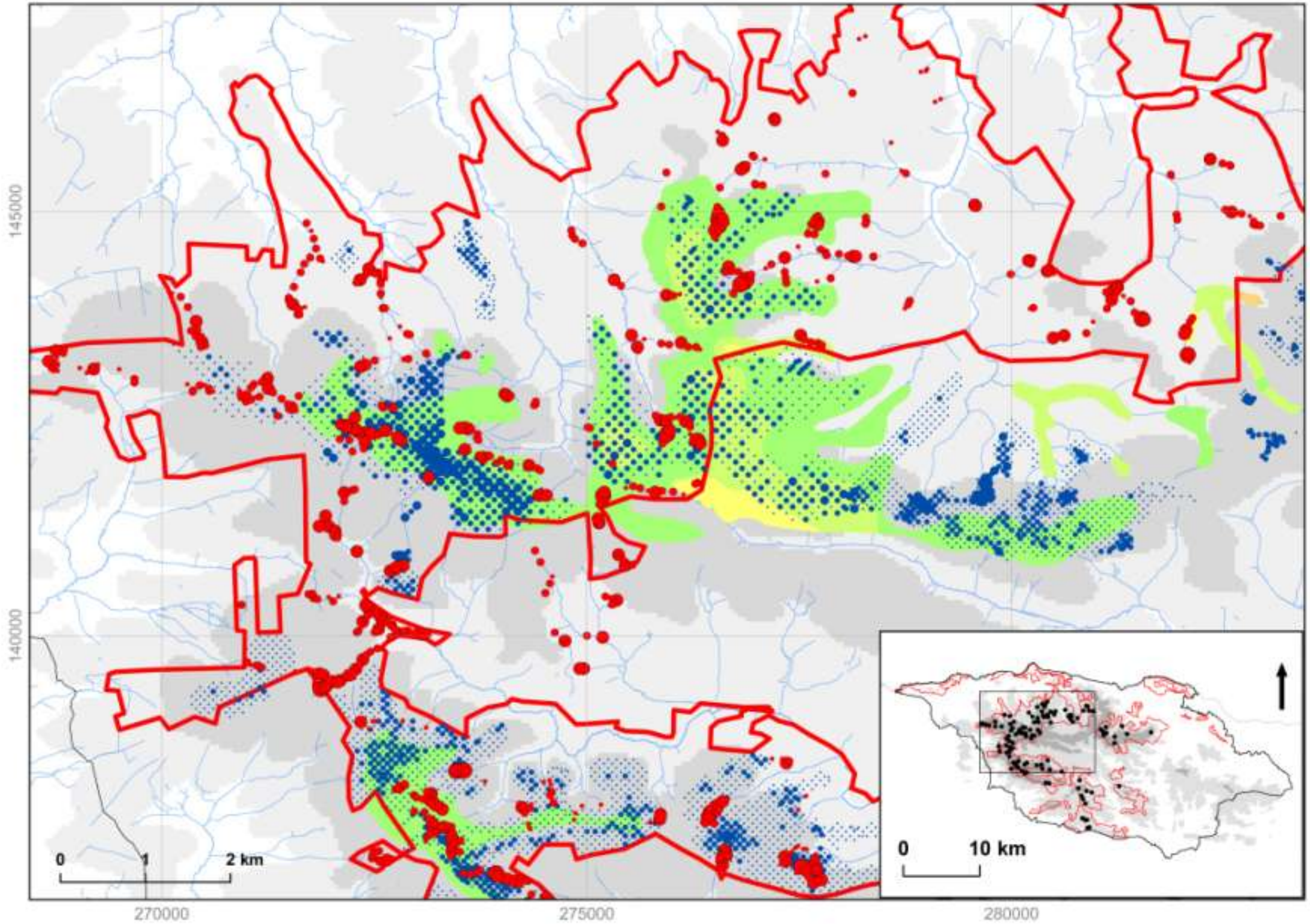

Figure 4.3. West/Central Exmoor: Survey area, peat depth measurements and previous peat depth surveys (Merryfield 1977; Bowes 2006)

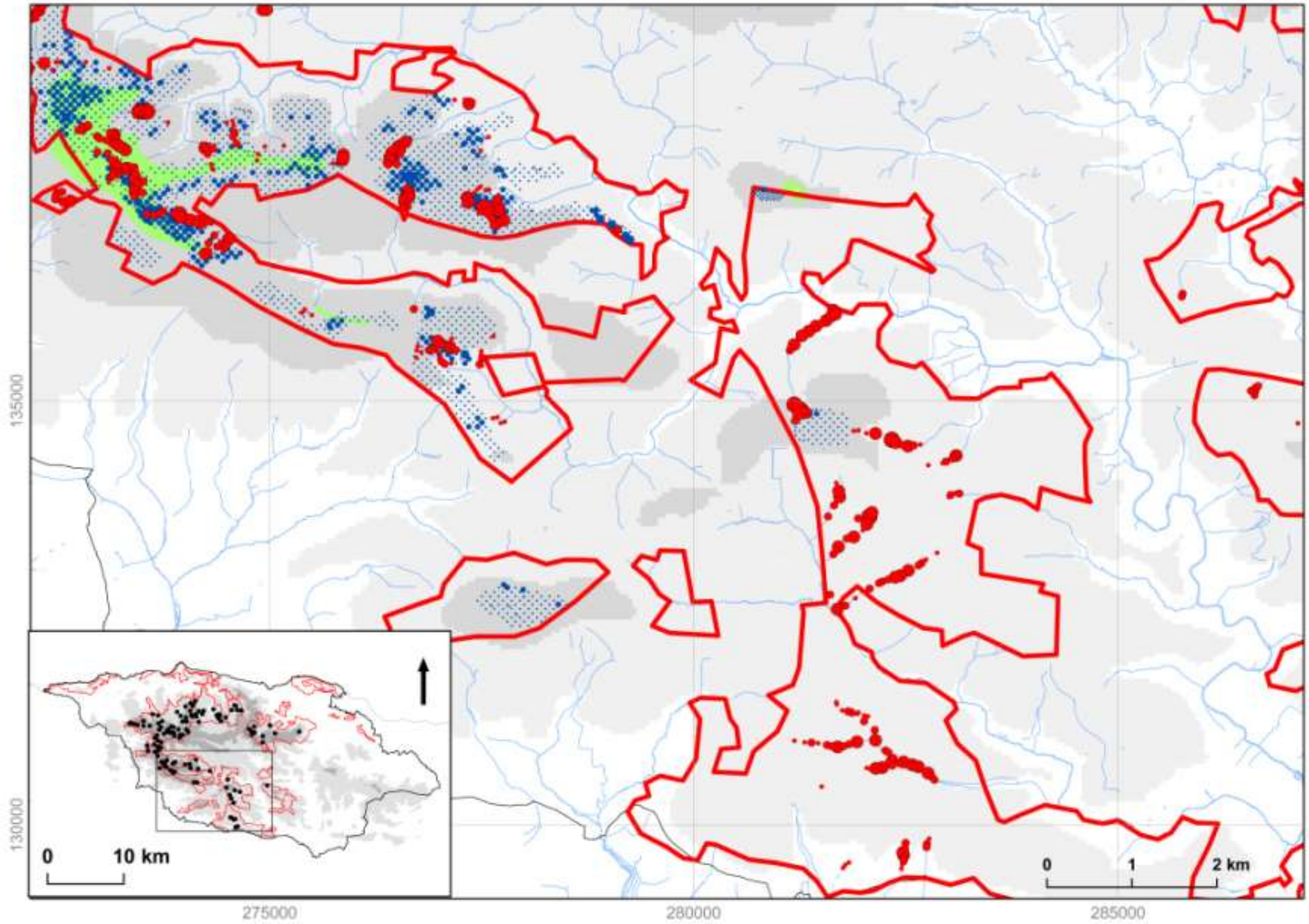

Figure 4.4. South Exmoor: Survey area, peat depth measurements and previous peat depth surveys (Merryfield 1977; Bowes 2006)

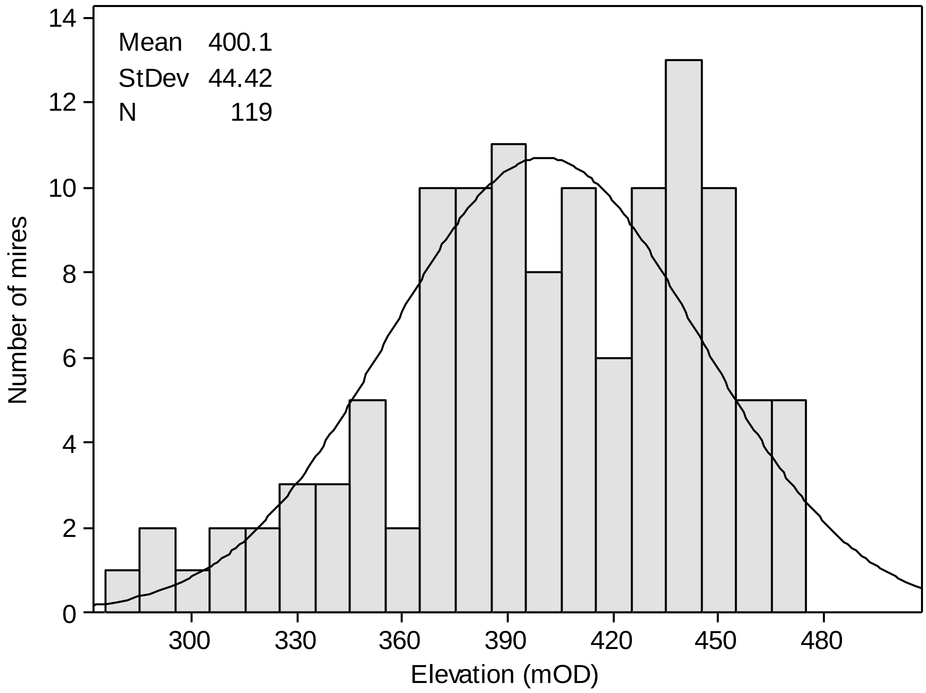

Figure 4.5. Number of mires found at different elevations (above Ordnance Datum).

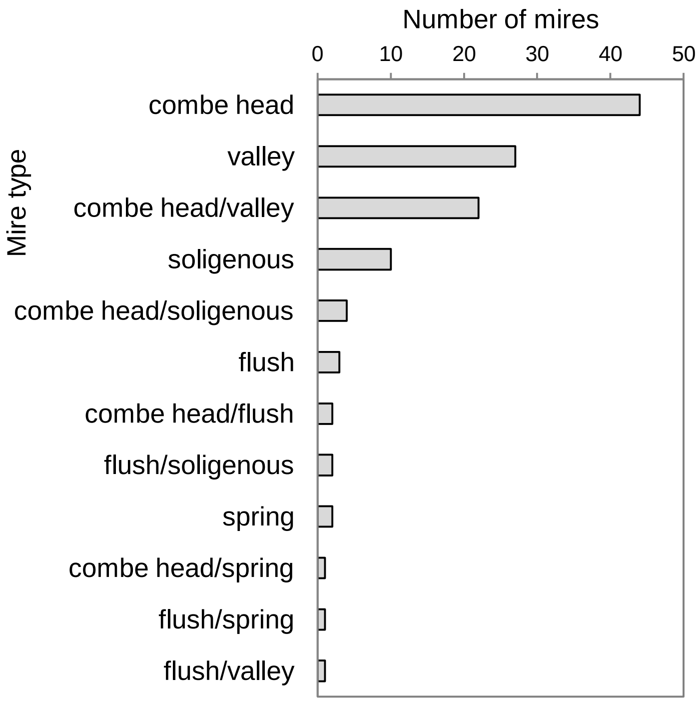

Figure 4.6. Number of mires from each mire type.

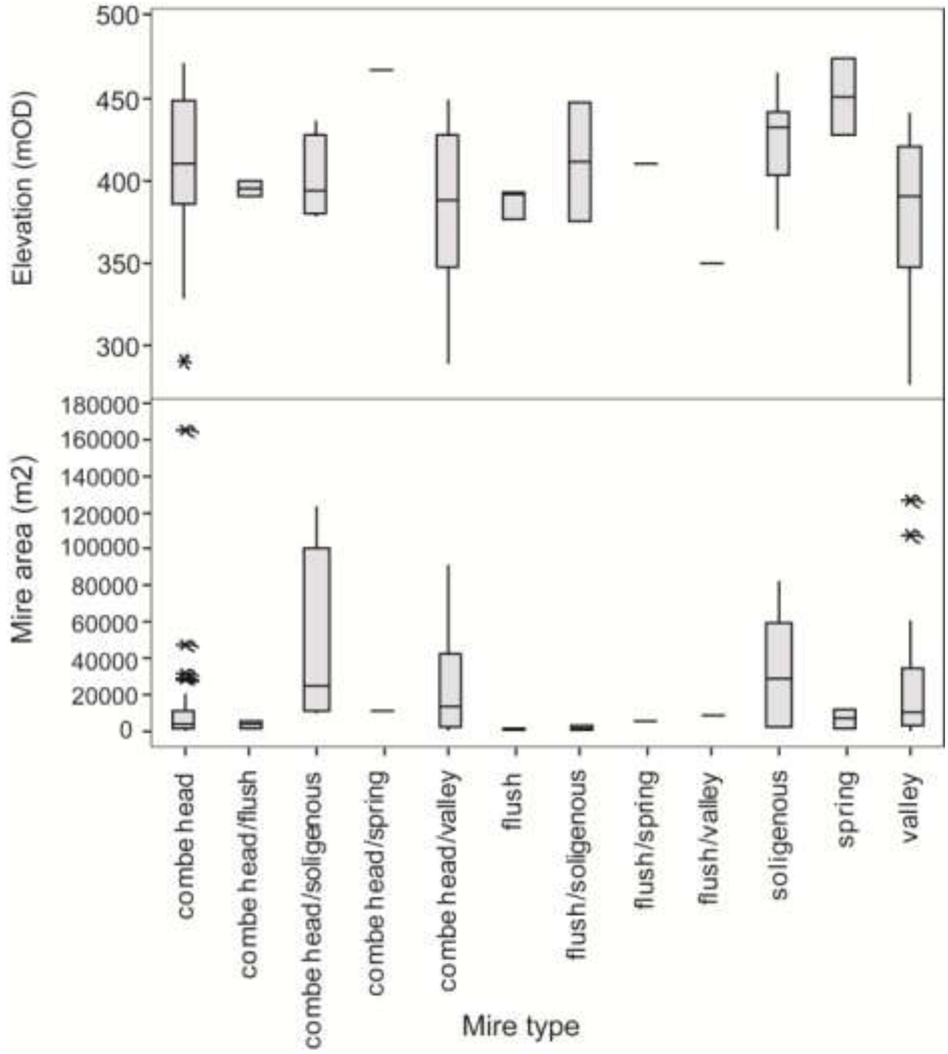

Figure 4.7. Boxplots of the distribution of elevation and mire area within different mire type categories.

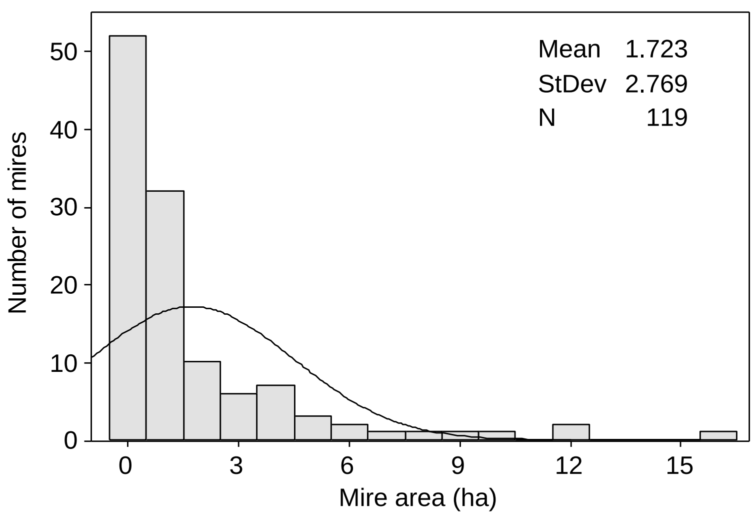

Figure 4.8. Number of mires of different areas.

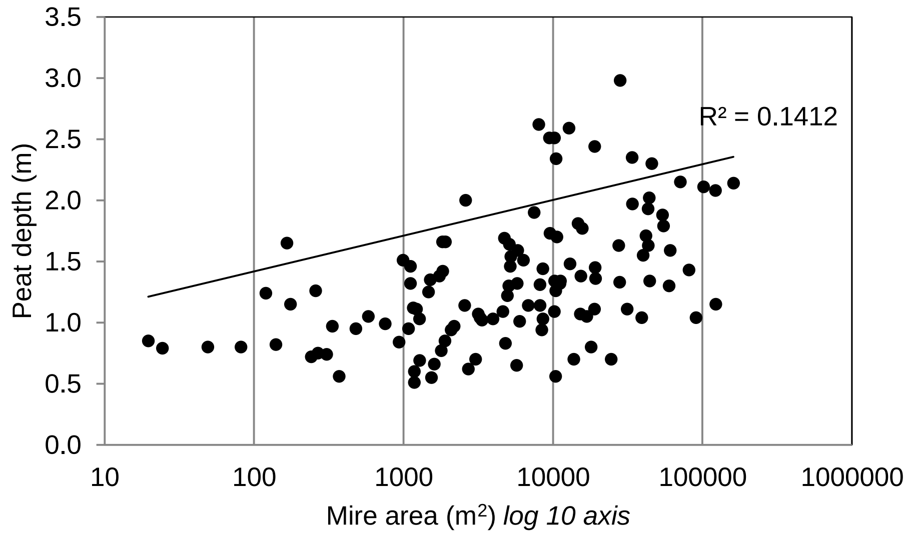

Figure 4.9. Mire area plotted against maximum peat depth at each mire. Mire area is shown on a log 10 as the majority of mires are under 10,000m^2 (1ha), with some much larger outliers (up to 151,000m^2/15.1ha).

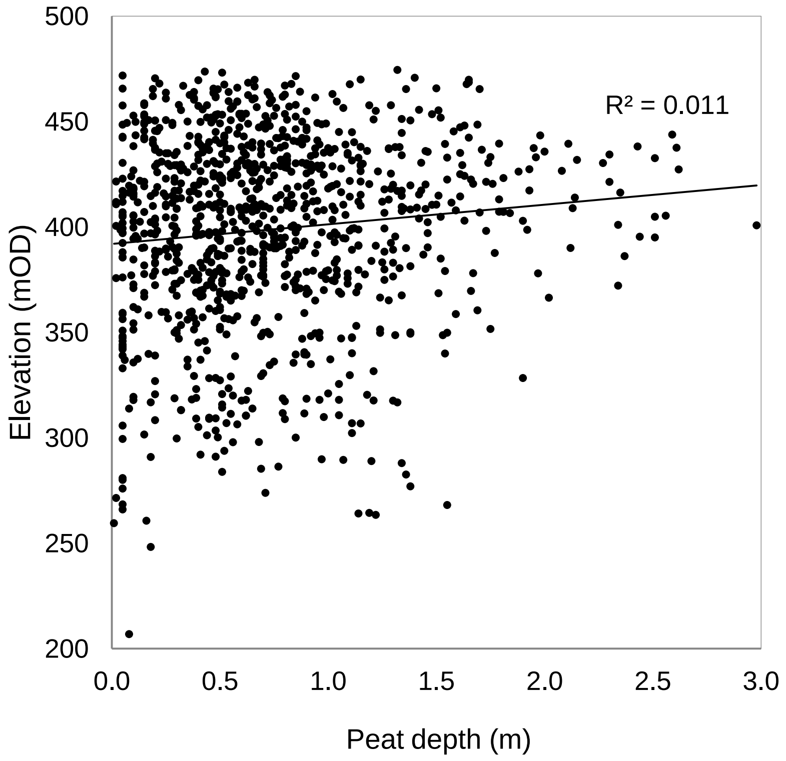

Figure 4.10. Elevation plotted against all recorded peat depths.

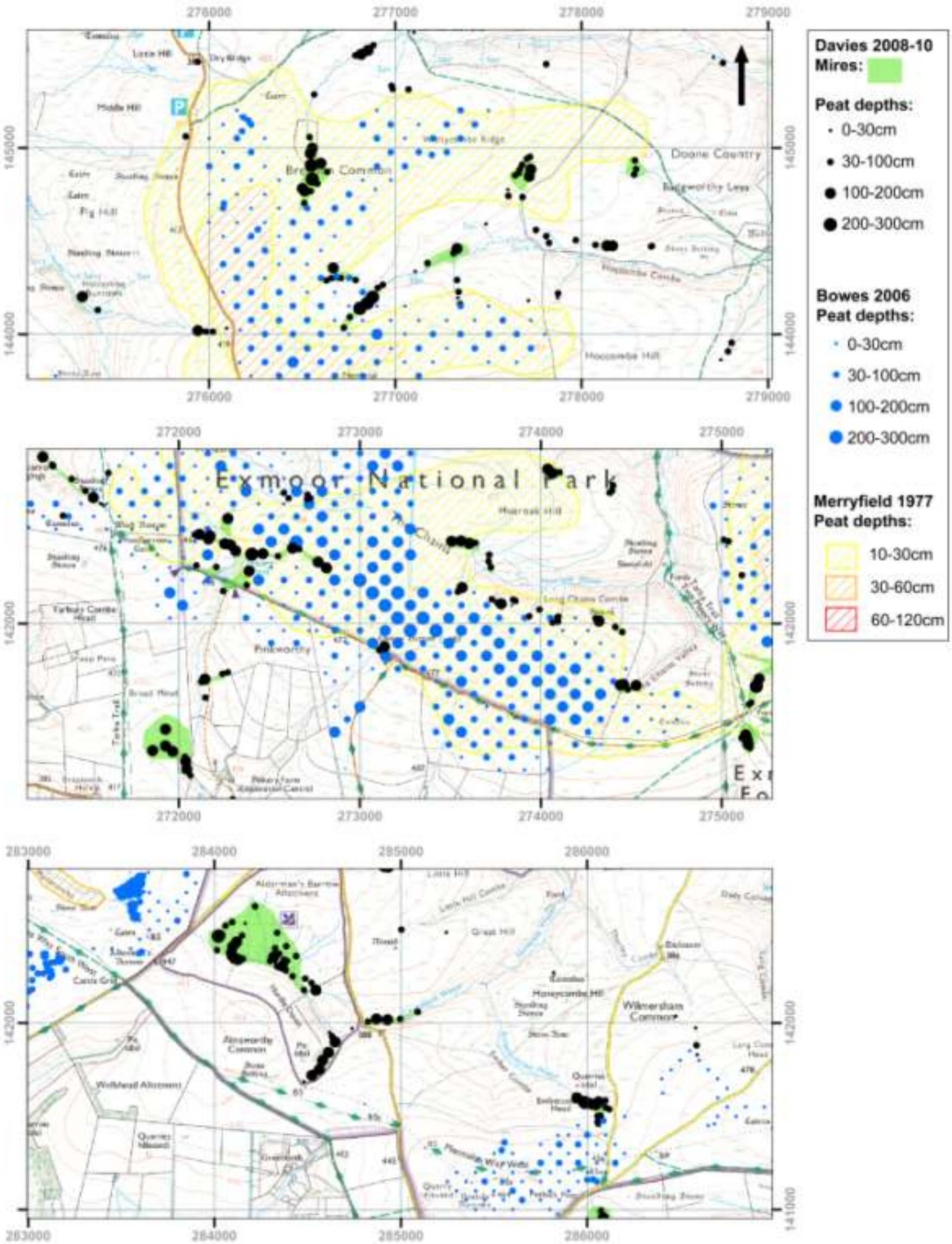

Figure 4.11. Comparison of peat depth data from the current survey against survey data from Merryfield (1977), and Bowes (2006).

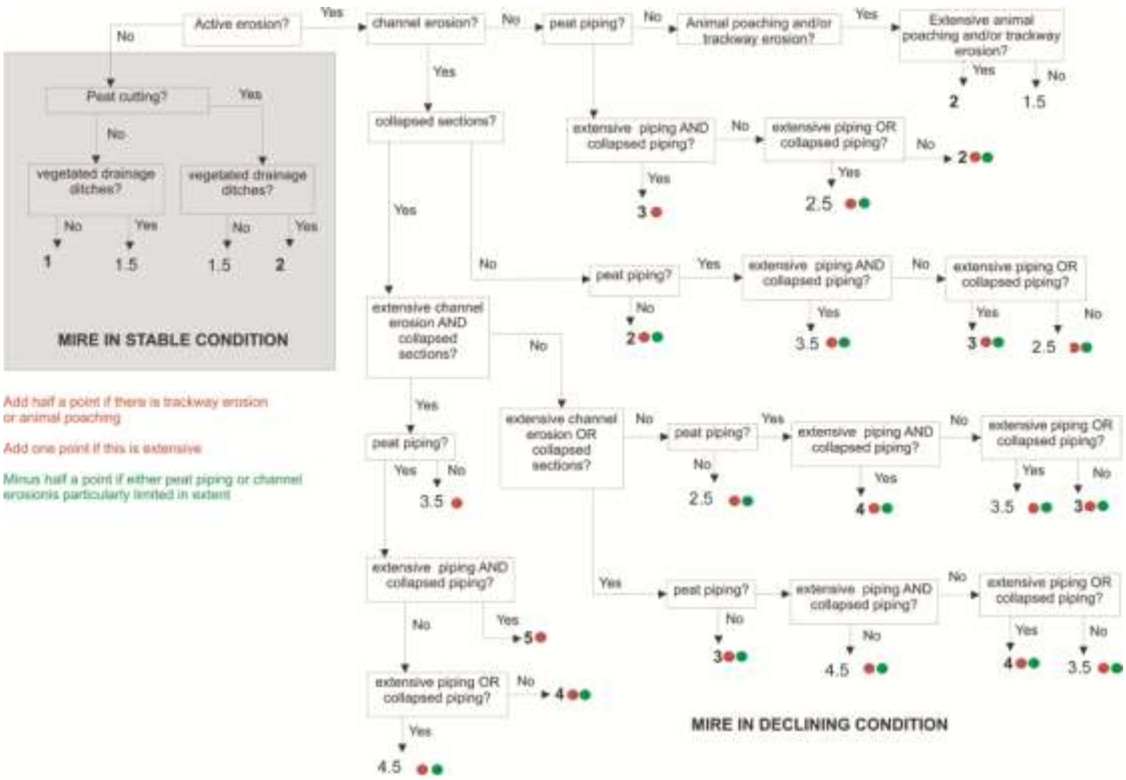

Figure 4.12. Mire condition key developed during pilot survey (May 2008), and used for field assessment of mire condition.

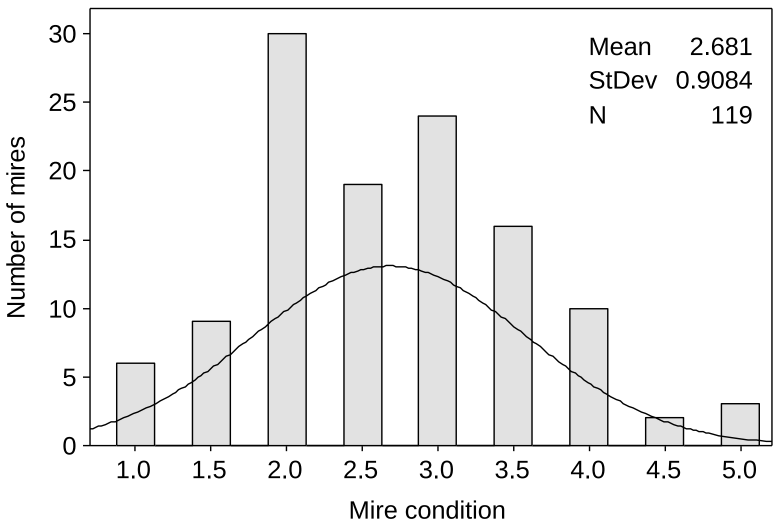

Figure 4.13. Number of mires in different mire condition categories (1=excellent, 5=poor).

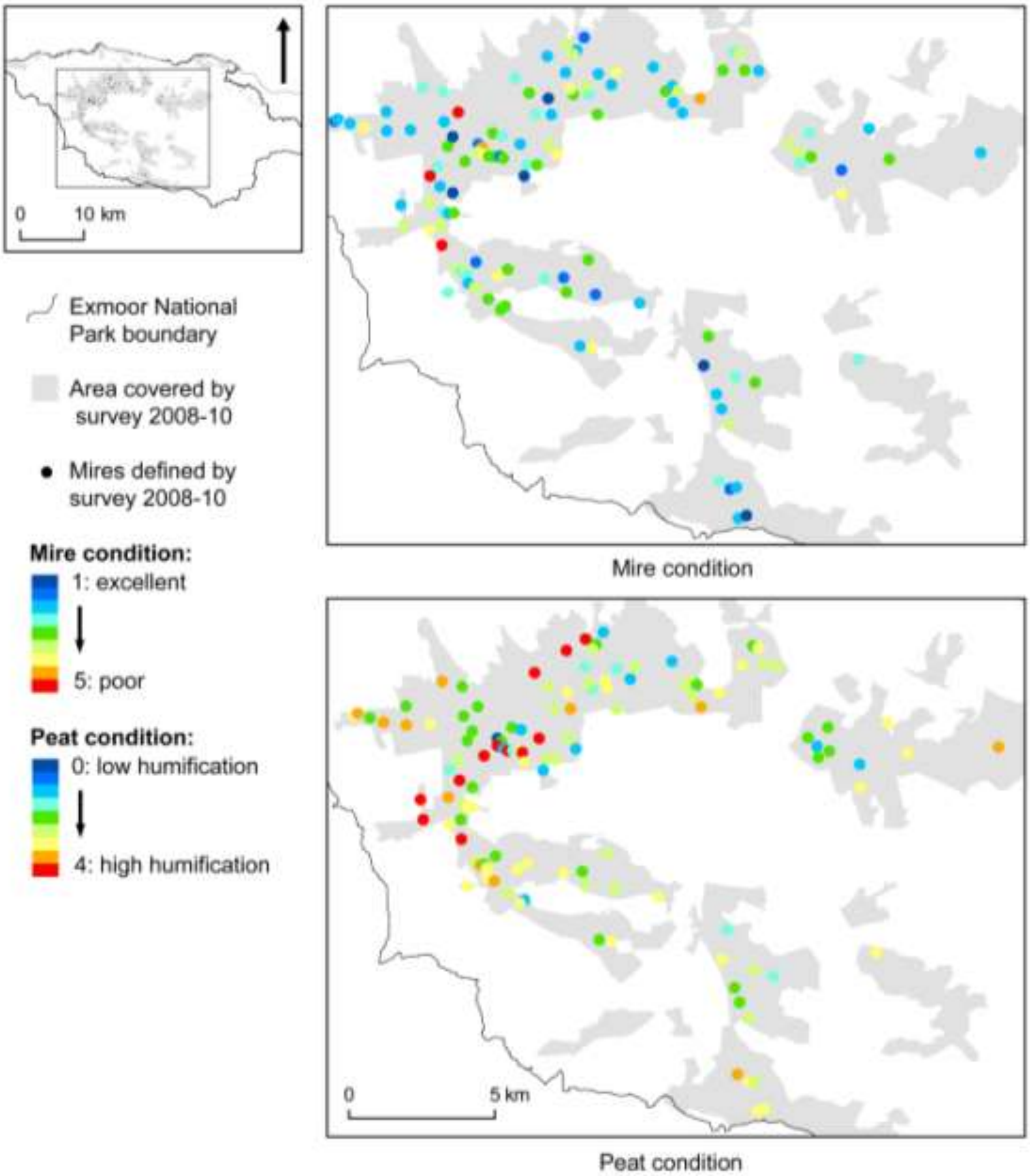

Figure 4.14. Distribution of mires colour-coded by mire condition *(above)* and peat condition *(below)* categories.

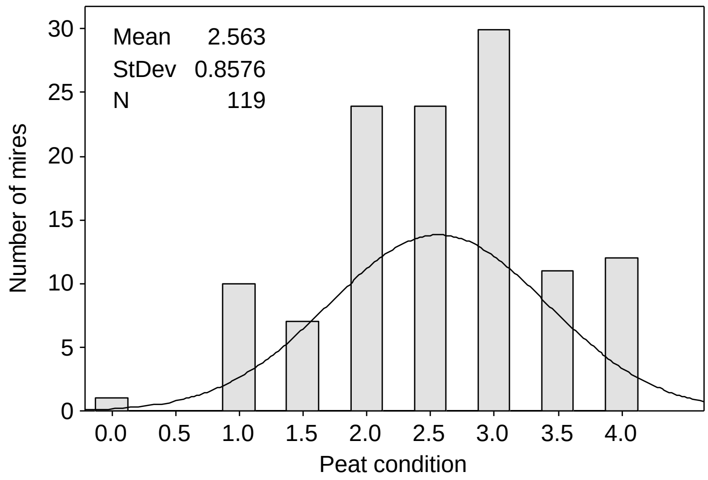

Figure 4.15. Number of mires with peat in different condition categories (0=low humification, 4=high humification).

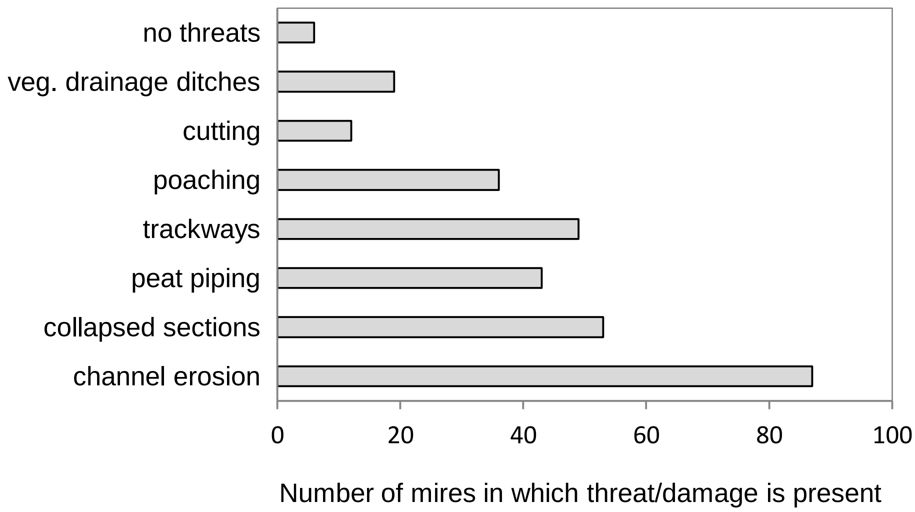

Figure 4.16. Number of mires in which different threats to the peat matrix were observed.

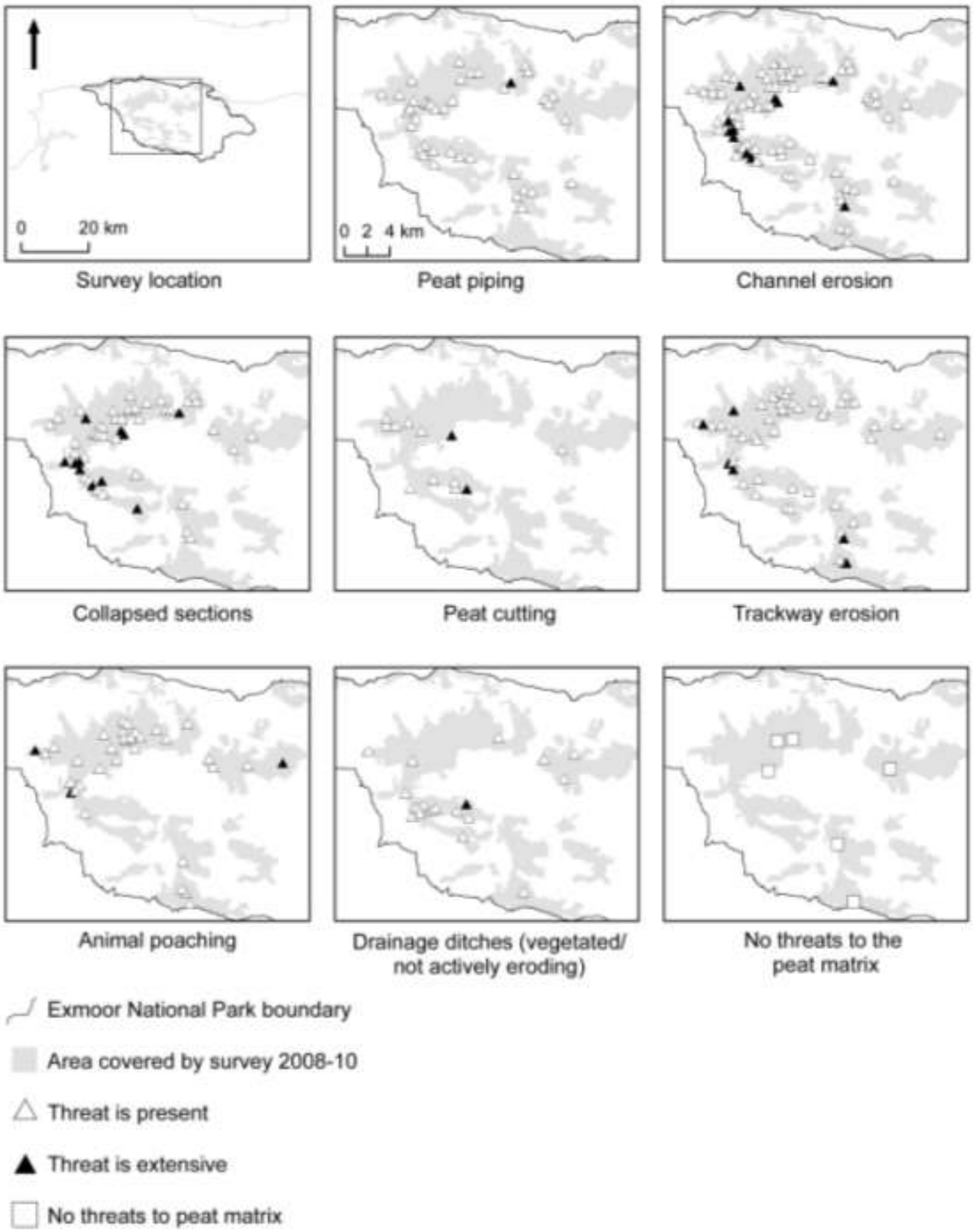

Figure 4.17. Distribution of different threats to the peat matrix. Each symbol represents a mire in which the threat/damage type is either present or extensive.

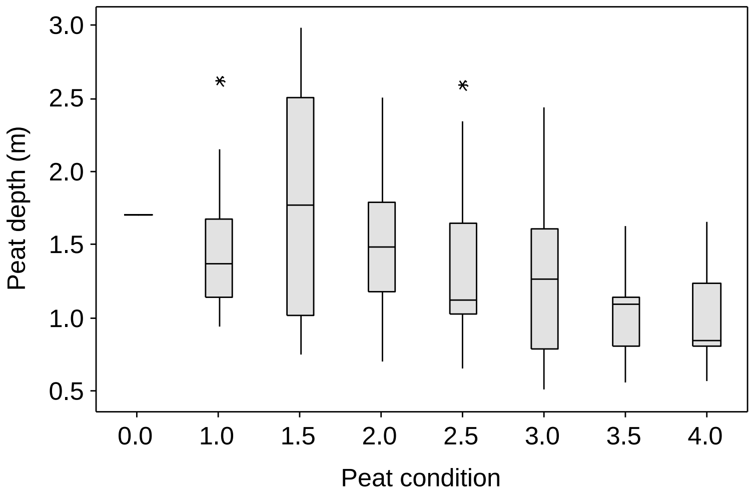

Figure 4.18. Boxplot of the distribution of peat depth between mires with peat in different condition categories.

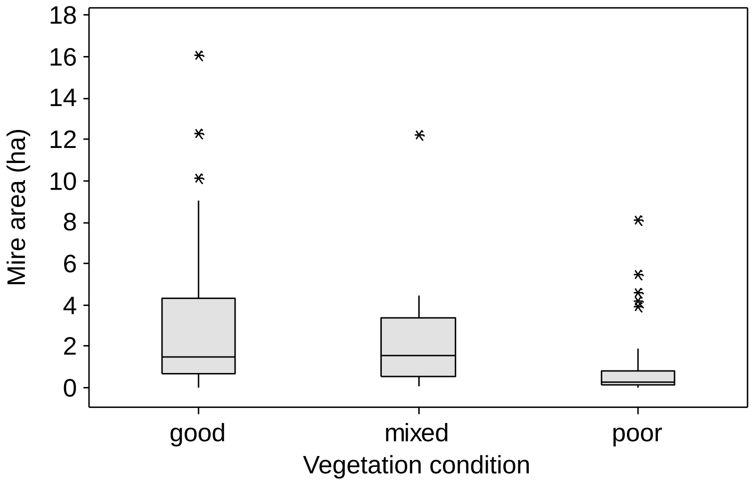

Figure 4.19. Boxplot of the distribution of vegetation condition between differently sized mires.

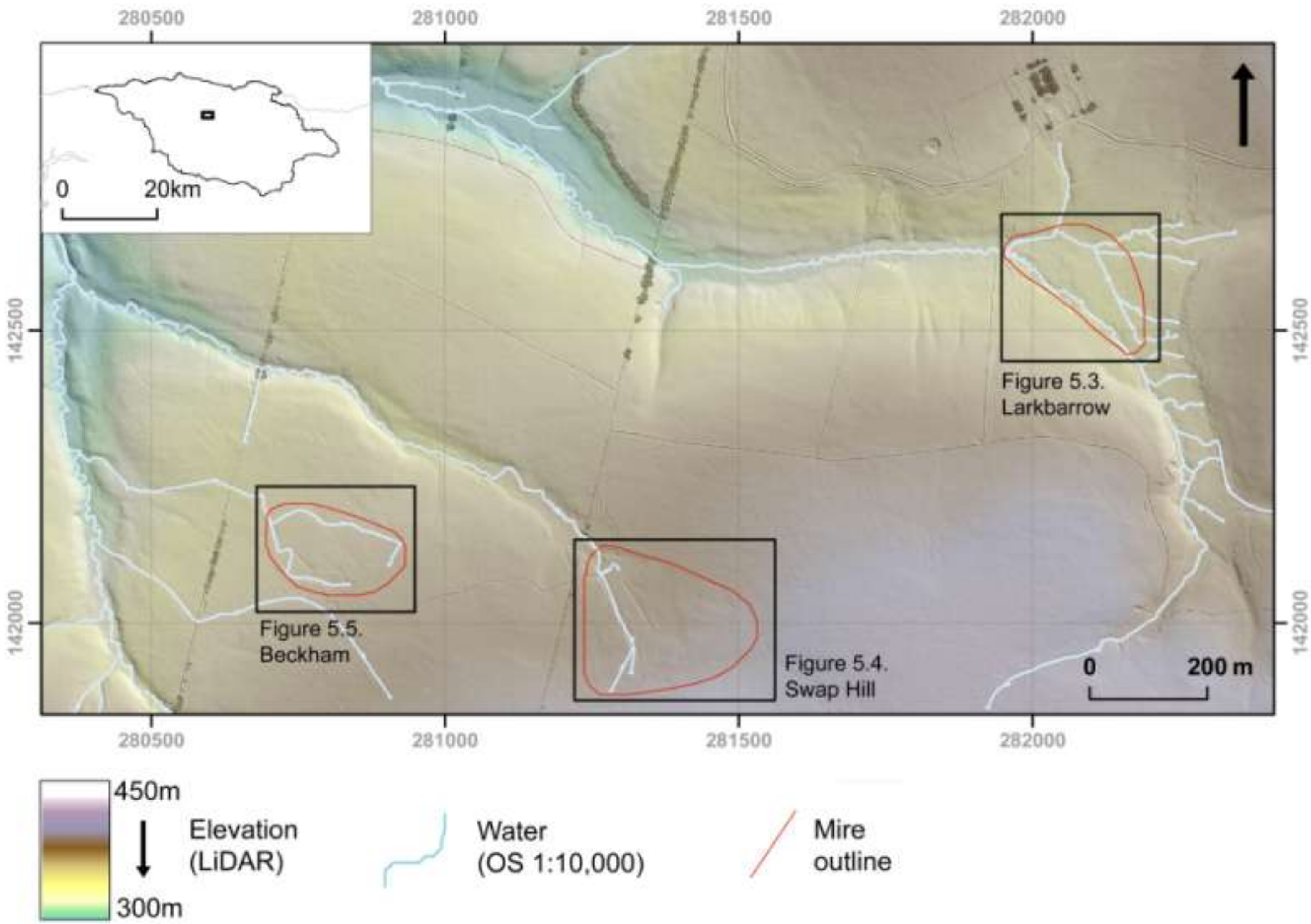

Figure 5.1.Locations of the studied mires

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Figure 5.2. Locations of known archaeological sites around Larkbarrow farm/mire. Reproduced from a survey carried out for English Heritage by Jamieson (2003)

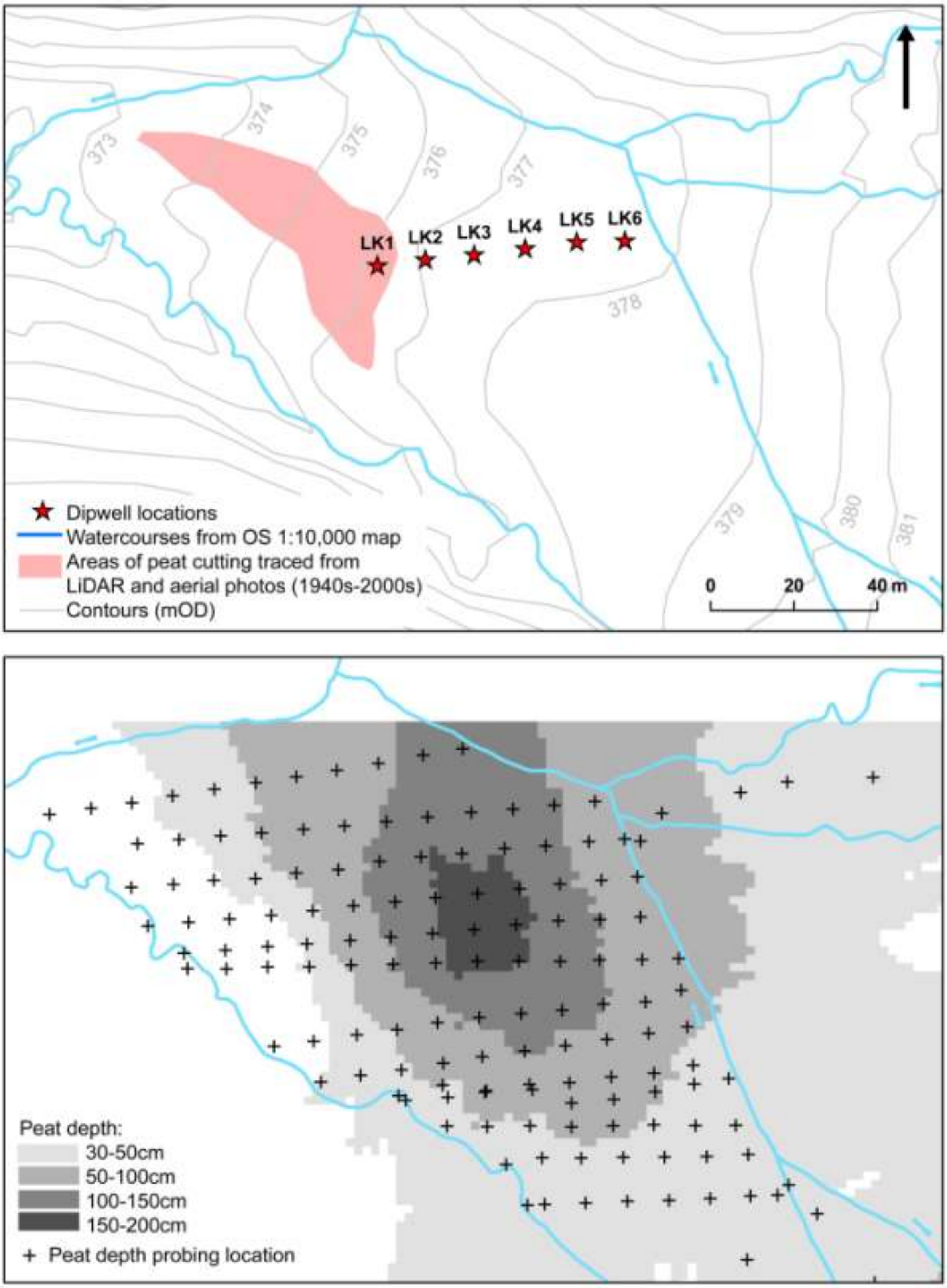


Figure 5.3. The mire at Larkbarrow. *Top:* topography and peat cutting features from LiDAR data and air photos. *Below:* Peat depth survey probing locations and interpolated peat depth.

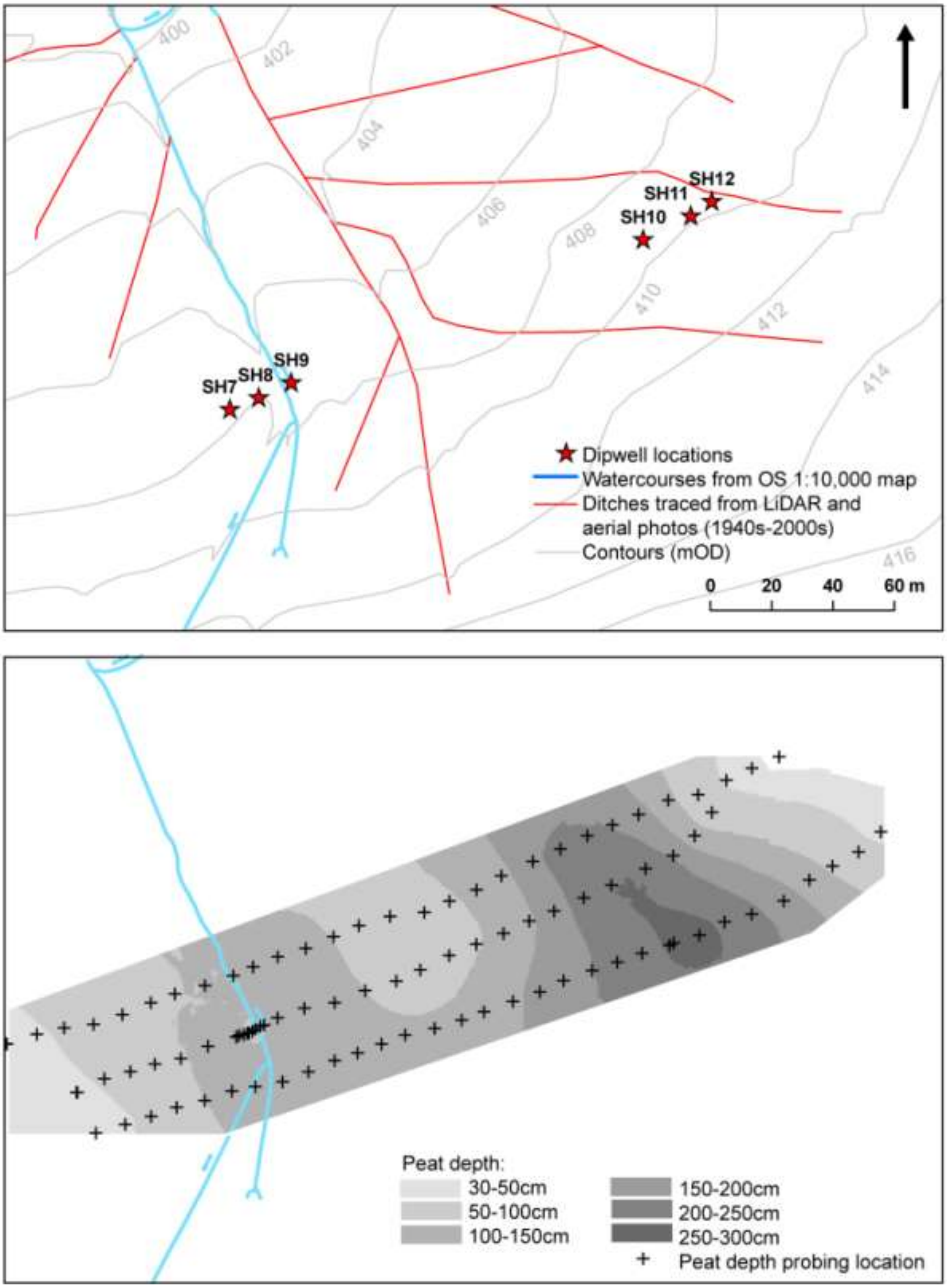


Figure 5.4. The mire at Swap Hill. *Top:* topography and peat cutting features from LiDAR data and air photos. *Below:* Peat depth survey probing locations and interpolated peat depth.

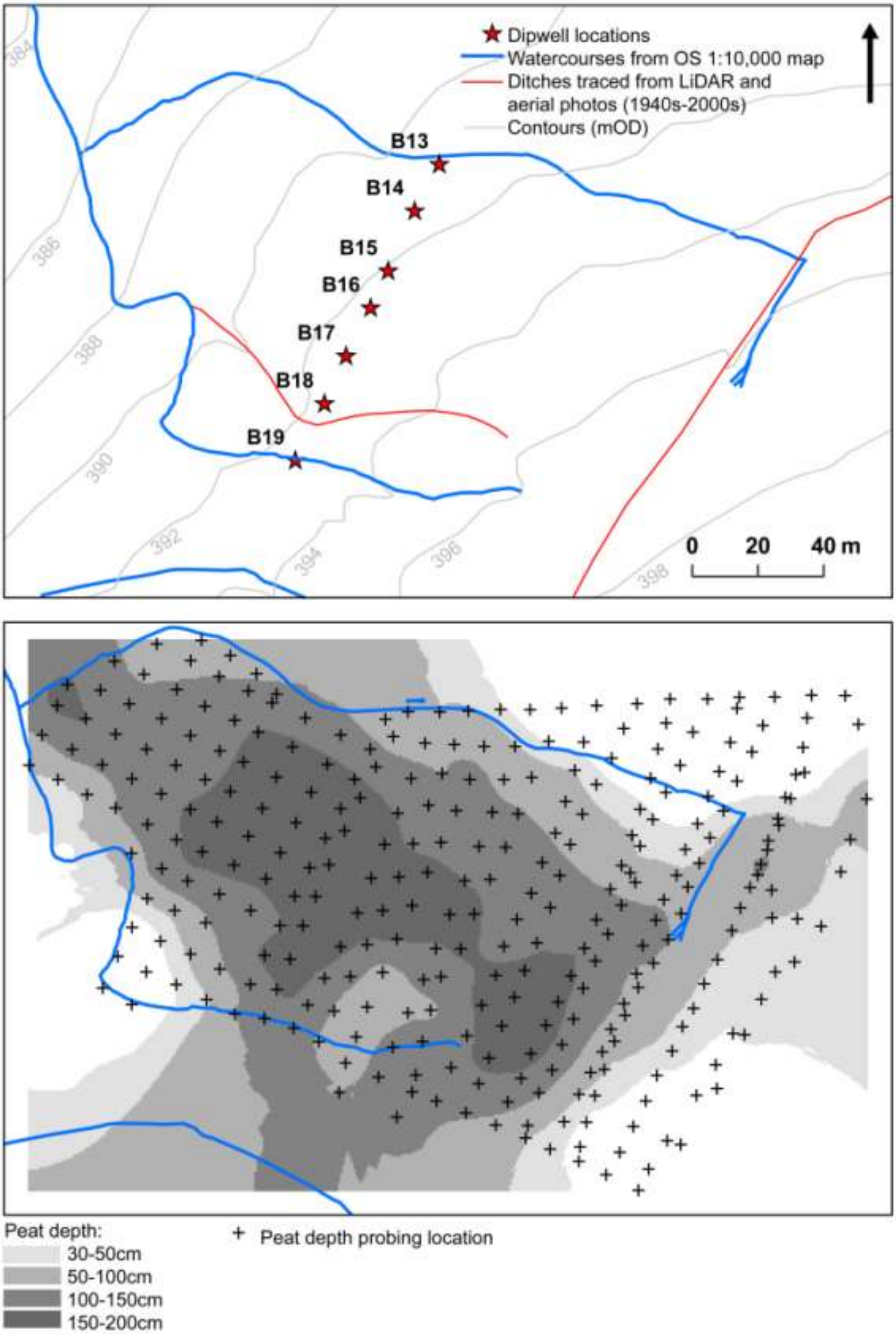


Figure 5.5. The mire at Beckham. *Top:* topography and peat cutting features from LiDAR data and air photos. *Below:* Peat depth survey probing locations and interpolated peat depth.

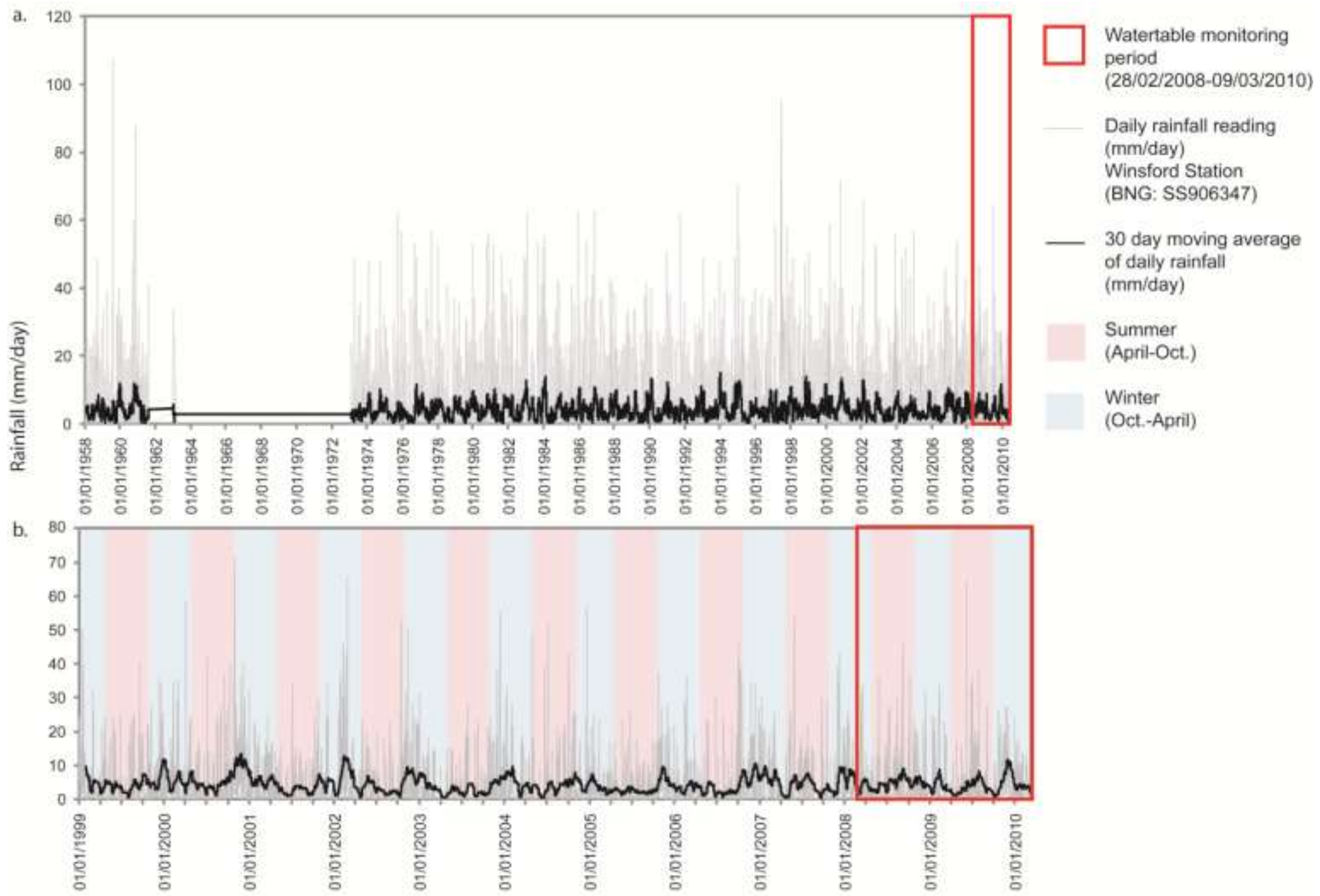


Figure 5.6. Daily precipitation data from the British Atmospheric Data Centre from Winsford weather station: **a.** Daily rainfall records from 01/01/1958 to 01/01/2010 (with hiatuses in recording in the 1960s and 70s); **b.** Daily rainfall records from 01/01/1999 to 01/01/2010.

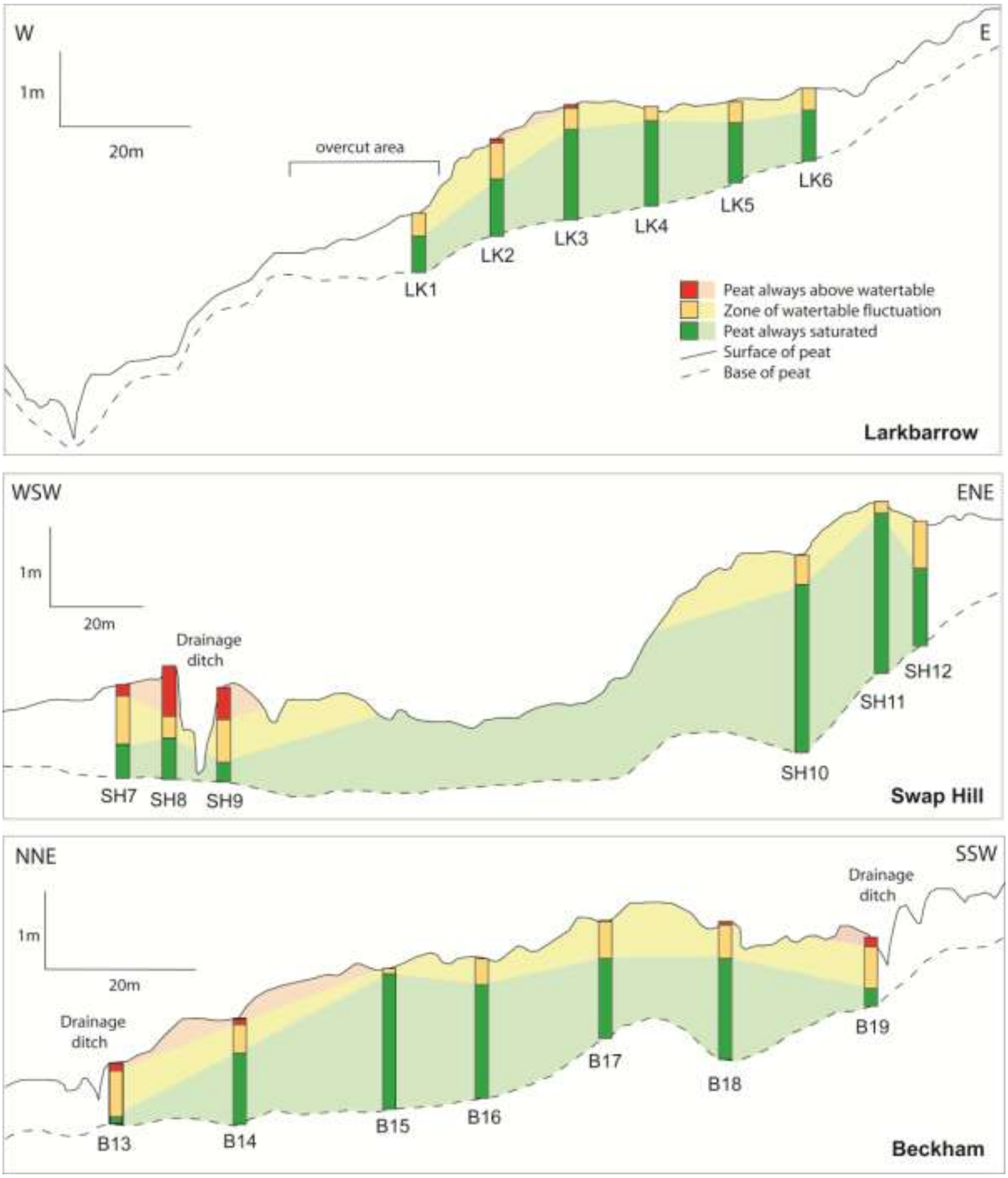


Figure 5.7. Cross-sections of the three studied mires showing topography (from LiDAR data), peat depth (interpolated from peat depth survey), the location of dipwells, and water-table zones from monitored data.

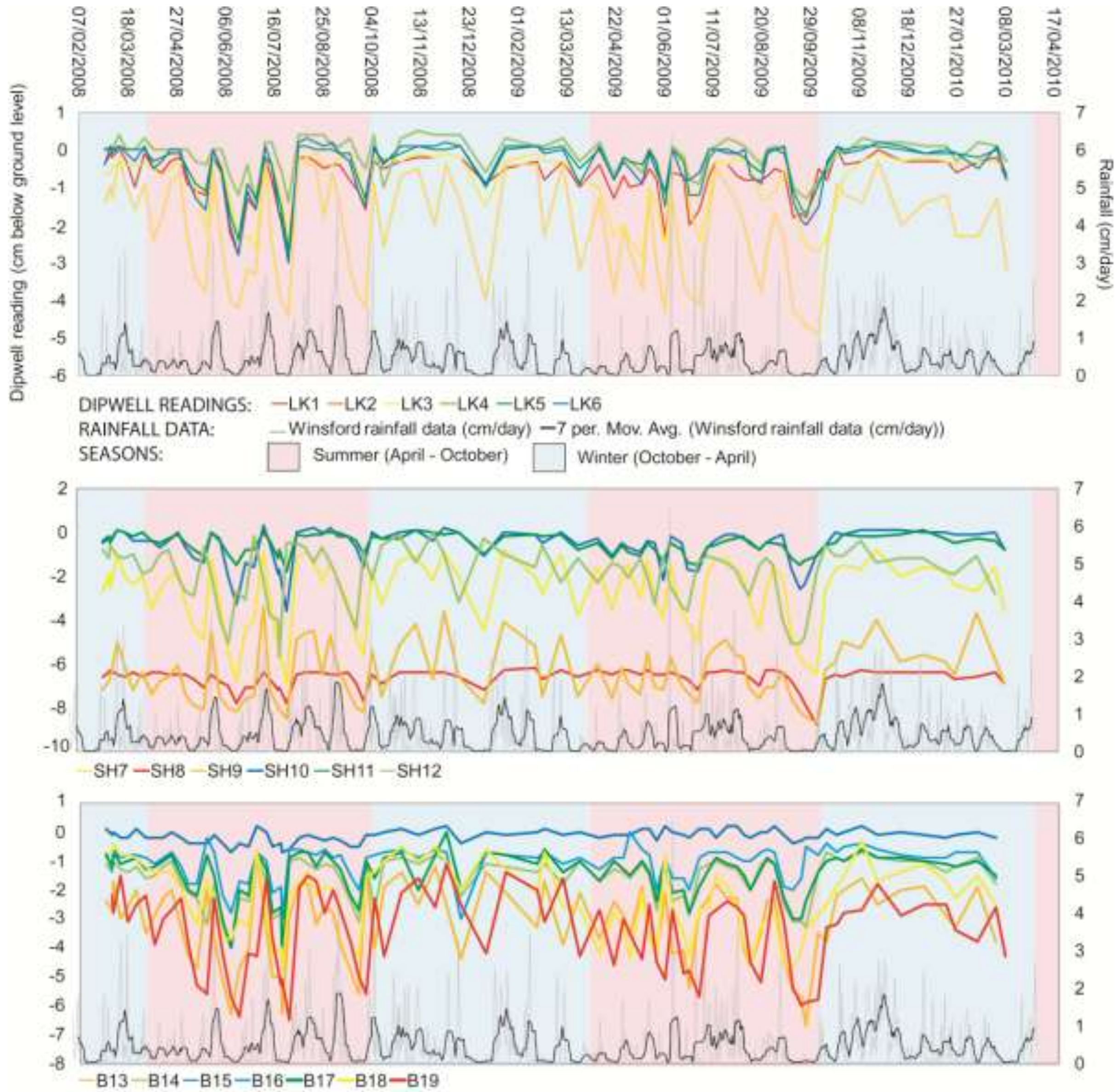


Figure 5.8. Monitored water-table data from three mires over the 2-year monitoring period, and recorded daily rainfall data from Winsford weather station.

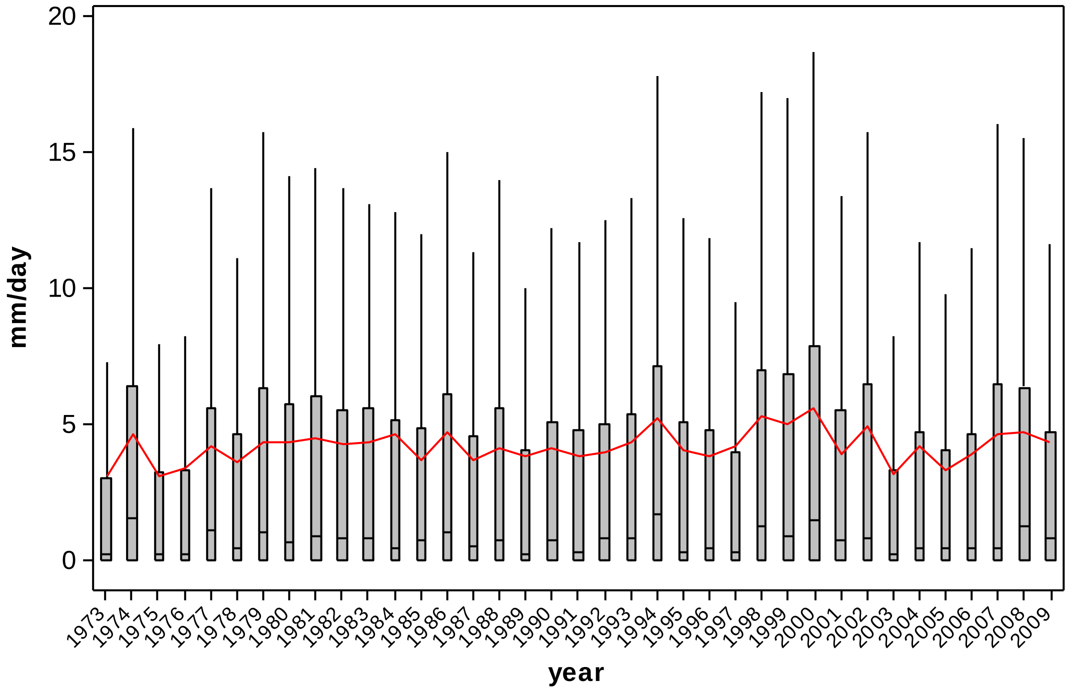


Figure 5.9. Daily precipitation between 1974 and 2009. Mean rainfall for each year is indicated by the red line.

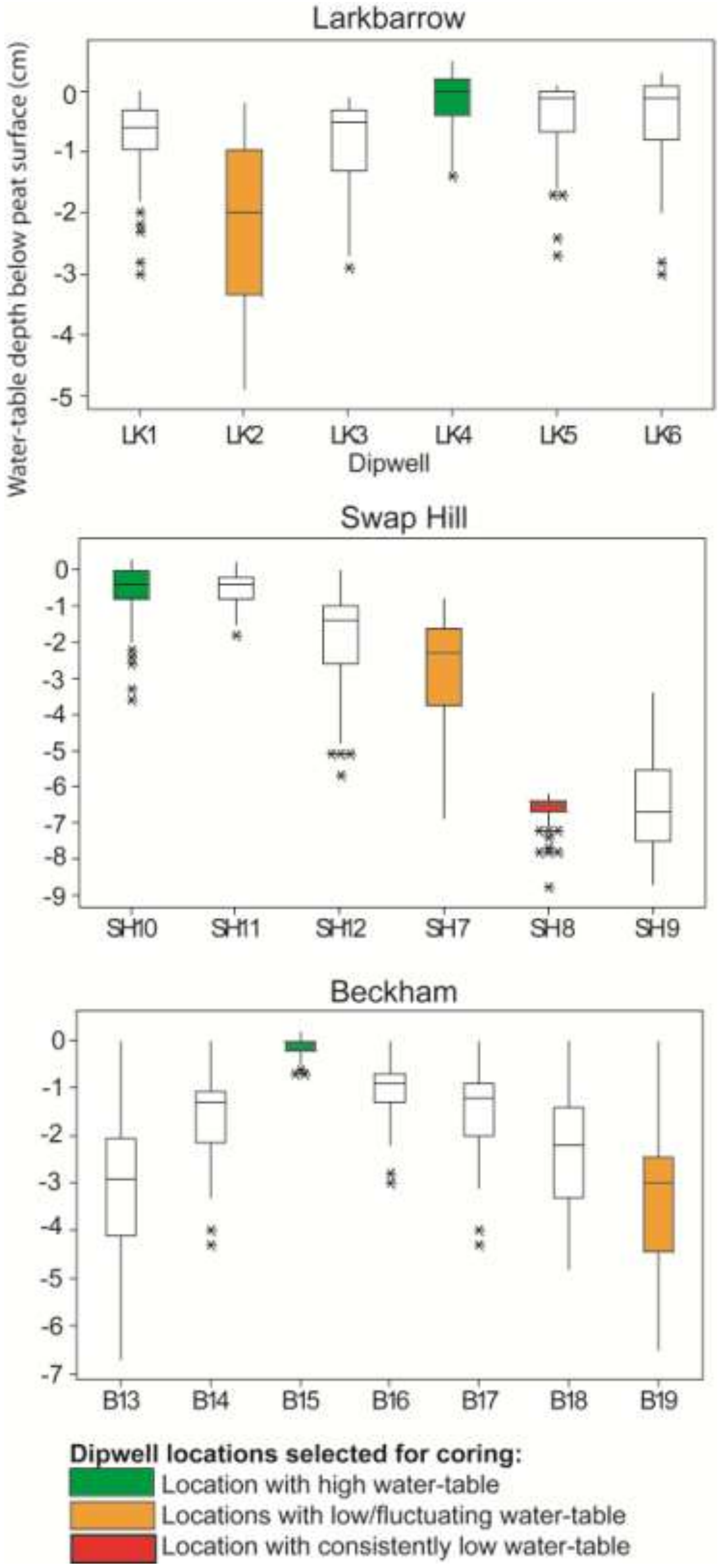
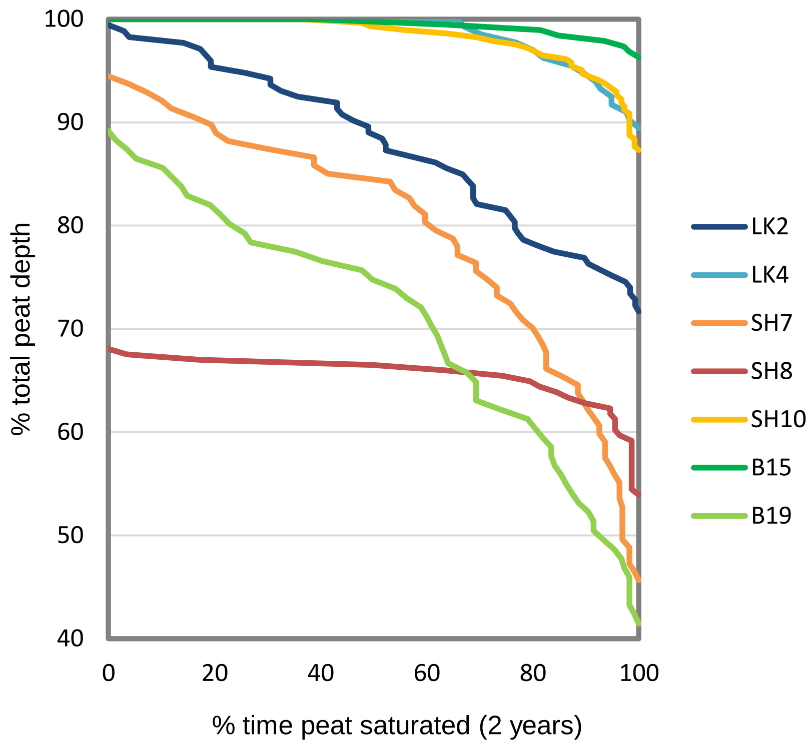


Figure 5.10. Dipwell recording data showing the mean and range water-table depth below the peat surface.



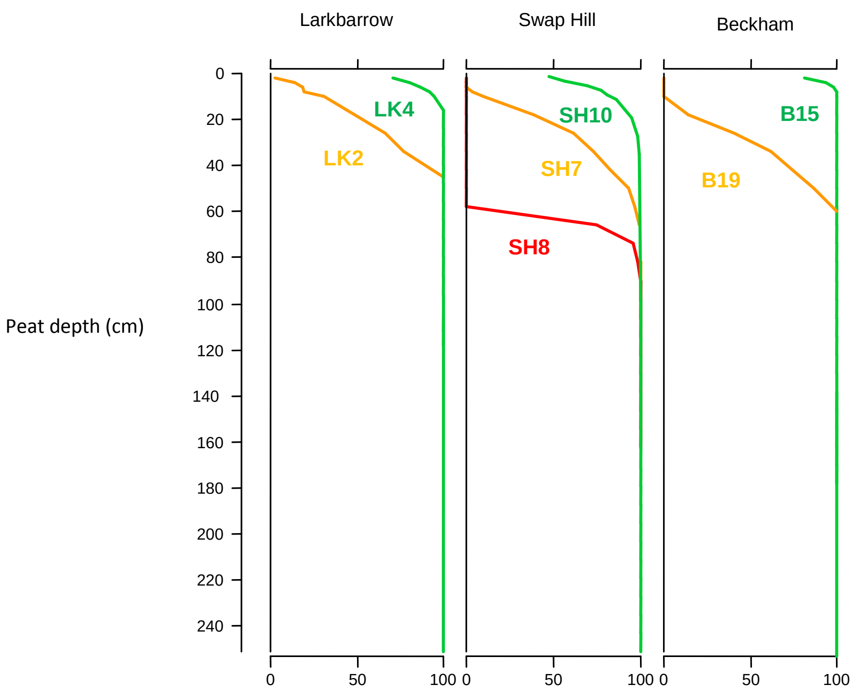


Figure 5.11. Water-table residence curves showing the cumulative % of the 2 year monitoring period that peat at different depths is saturated/below the watertable at 7 selected dipwell locations. Lower values indicate lower watertable levels and drier peat in the upper layers of the core. Above: all cores plotted against % depth. Below: Residence curves (plotted against absolute depth in cm) compared by mire.

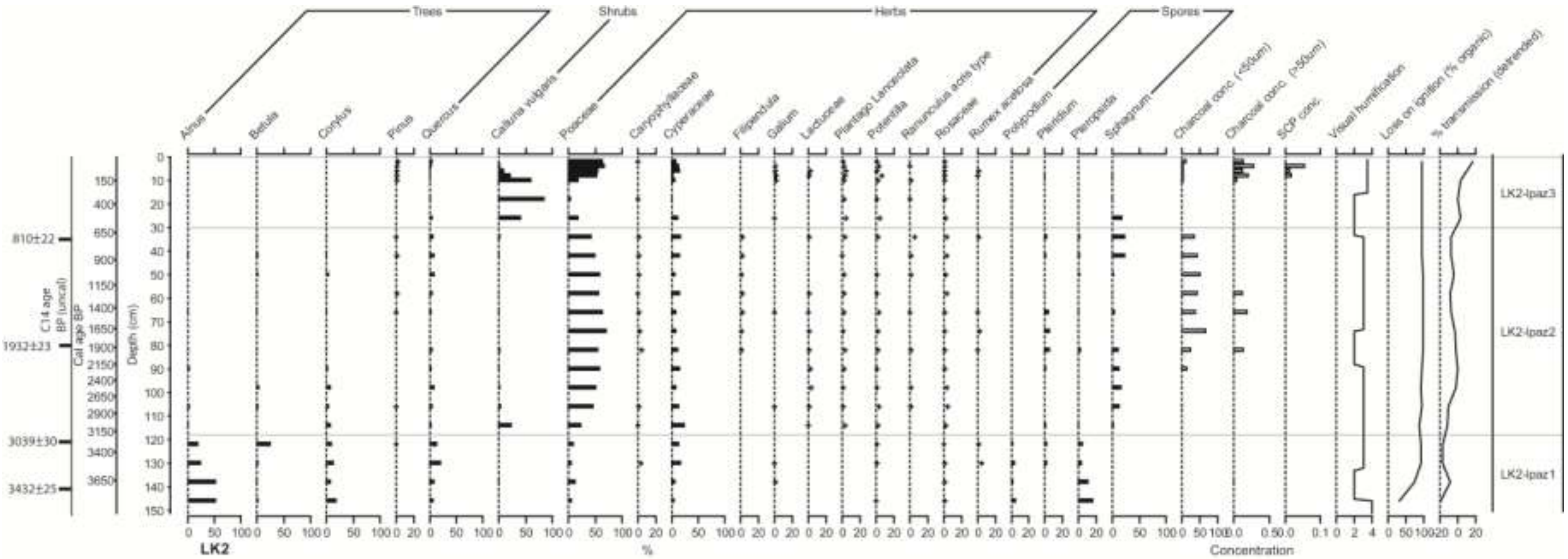


Figure 5.12. Pollen taxa summary data from LK2 showing all taxa equal to or greater than 2% of the total.

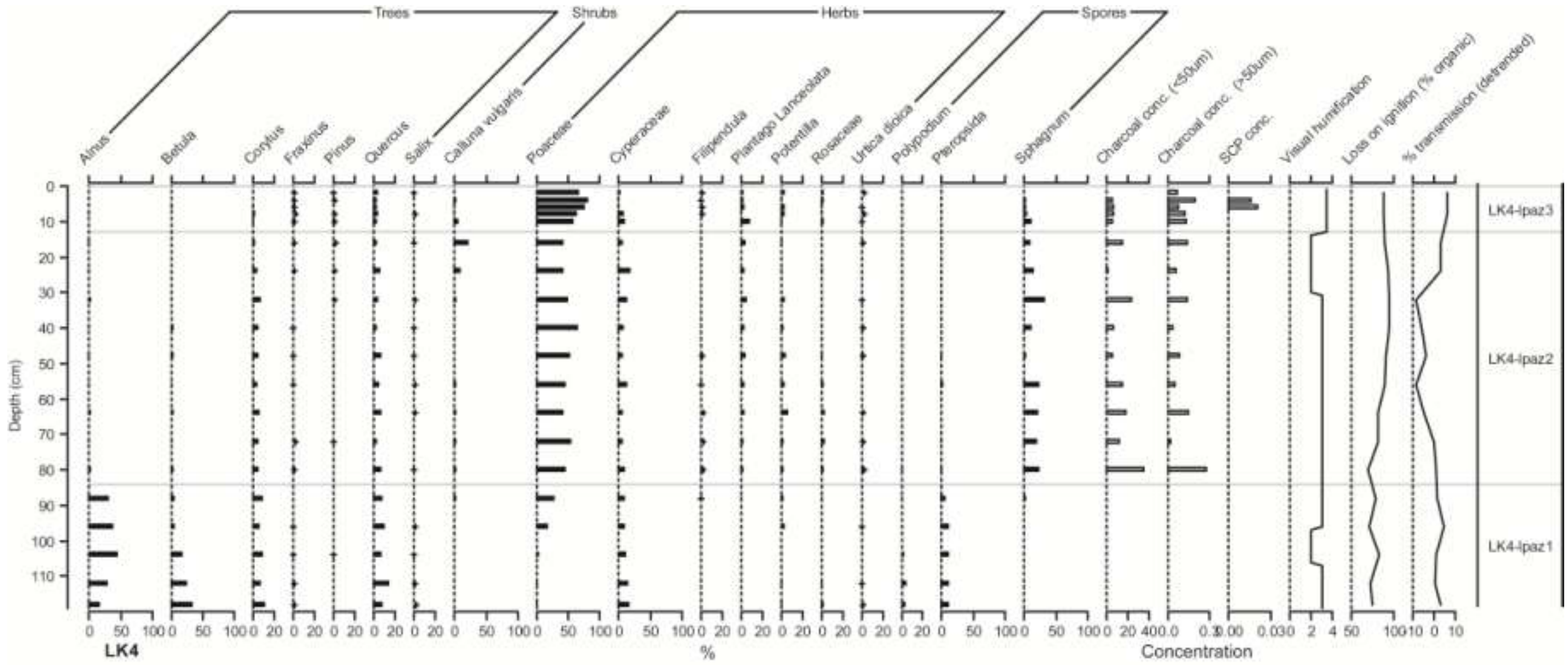


Figure 5.13. Pollen taxa summary data from LK4 showing all taxa equal to or greater than 2% of the total.

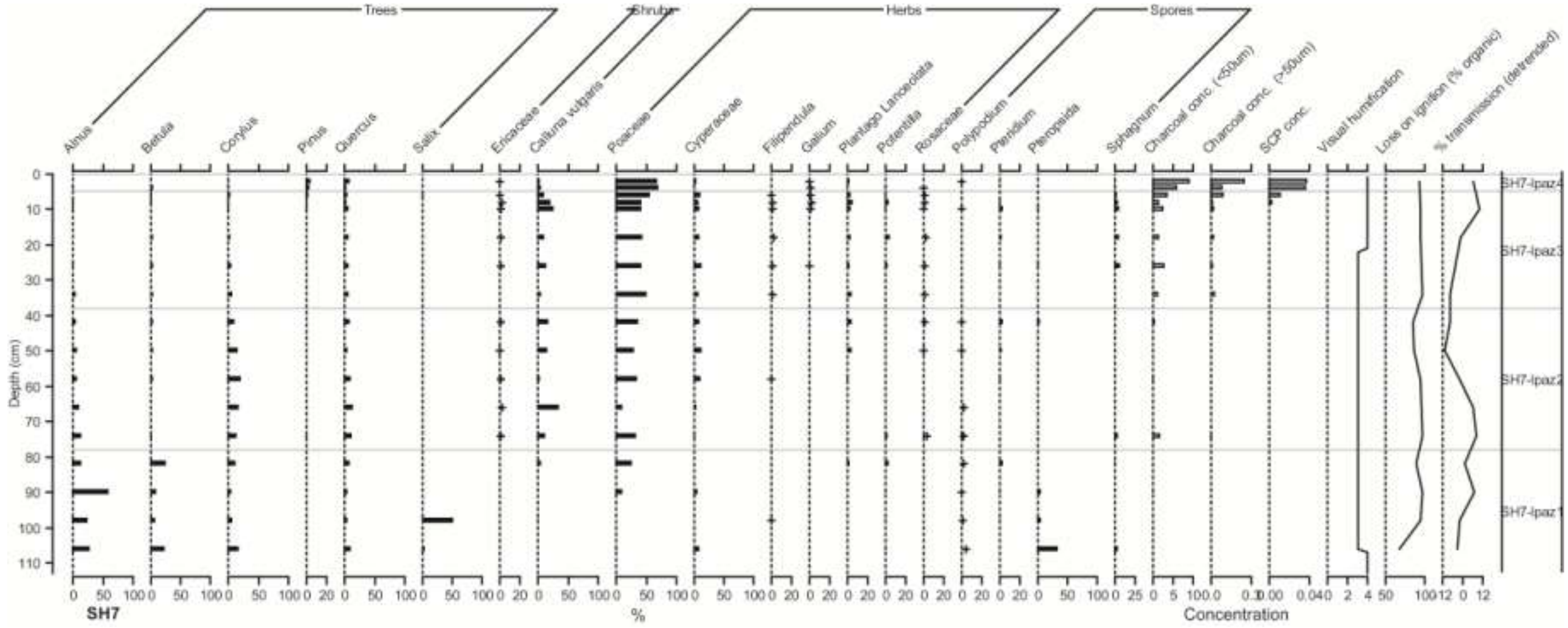


Figure 5.14. Pollen taxa summary data from SH7 showing all taxa equal to or greater than 2% of the total.

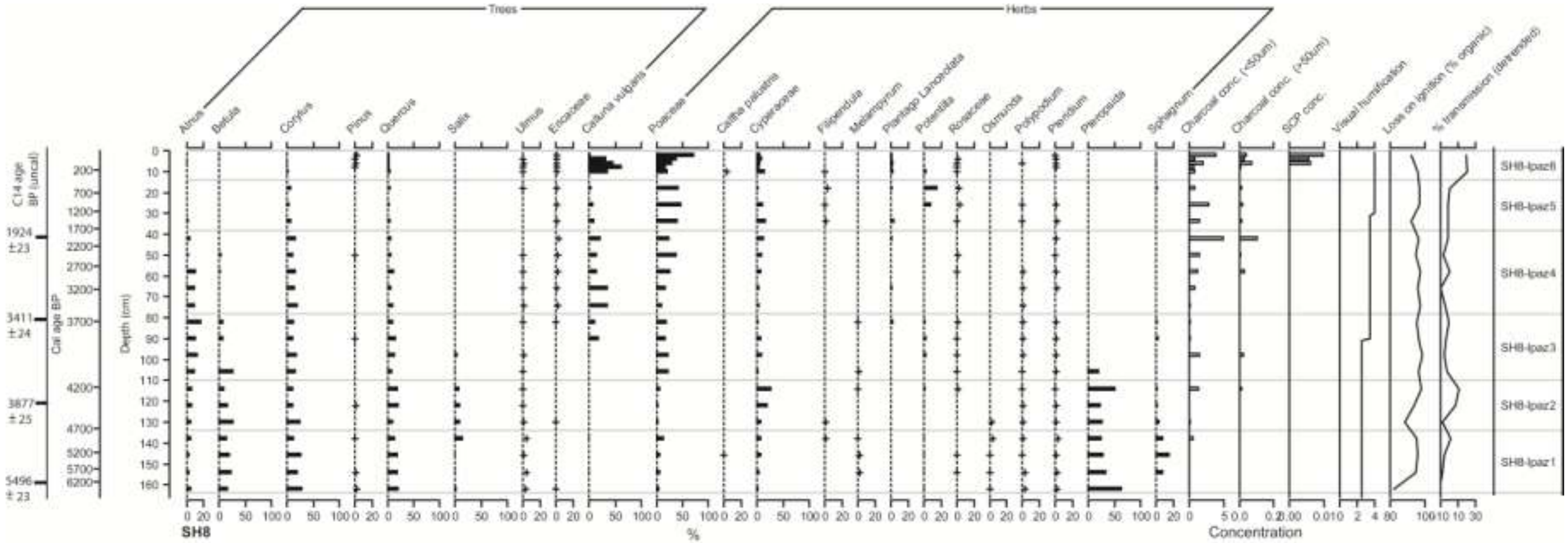


Figure 5.15. Pollen taxa summary data from SH8 showing all taxa equal to or greater than 2% of the total.

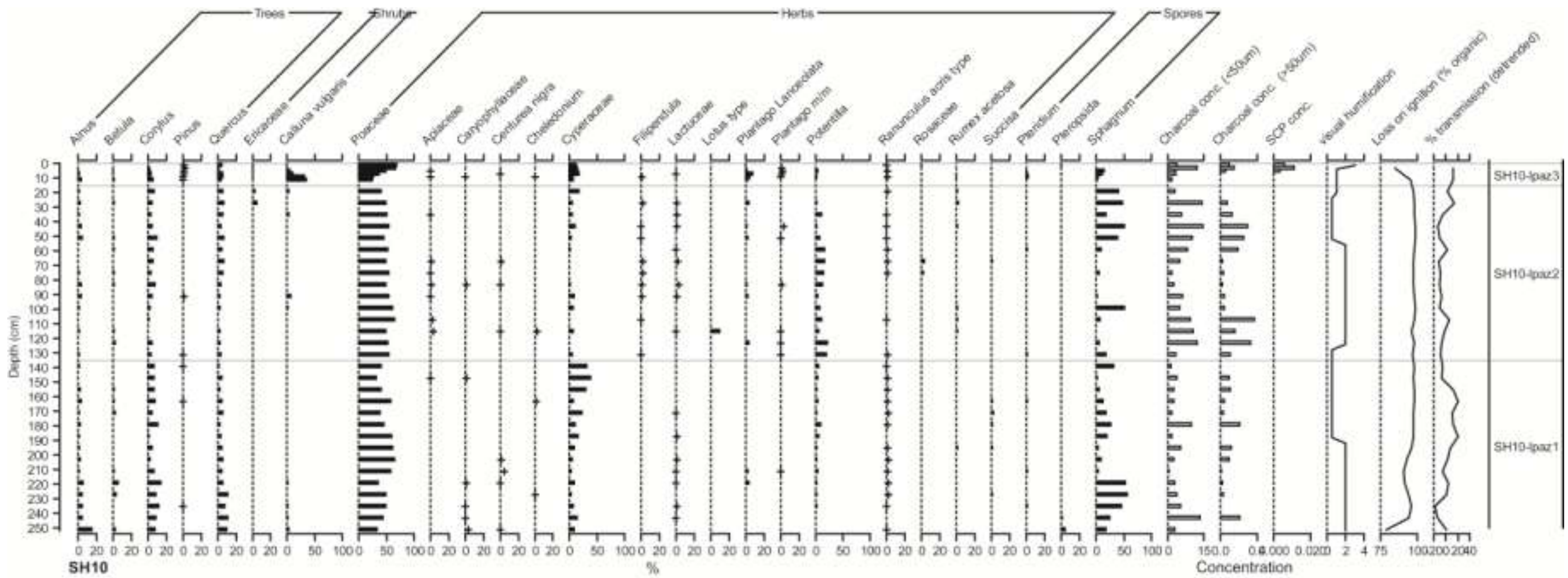


Figure 5.16. Pollen taxa summary data from SH10 showing all taxa equal to or greater than 2% of the total.

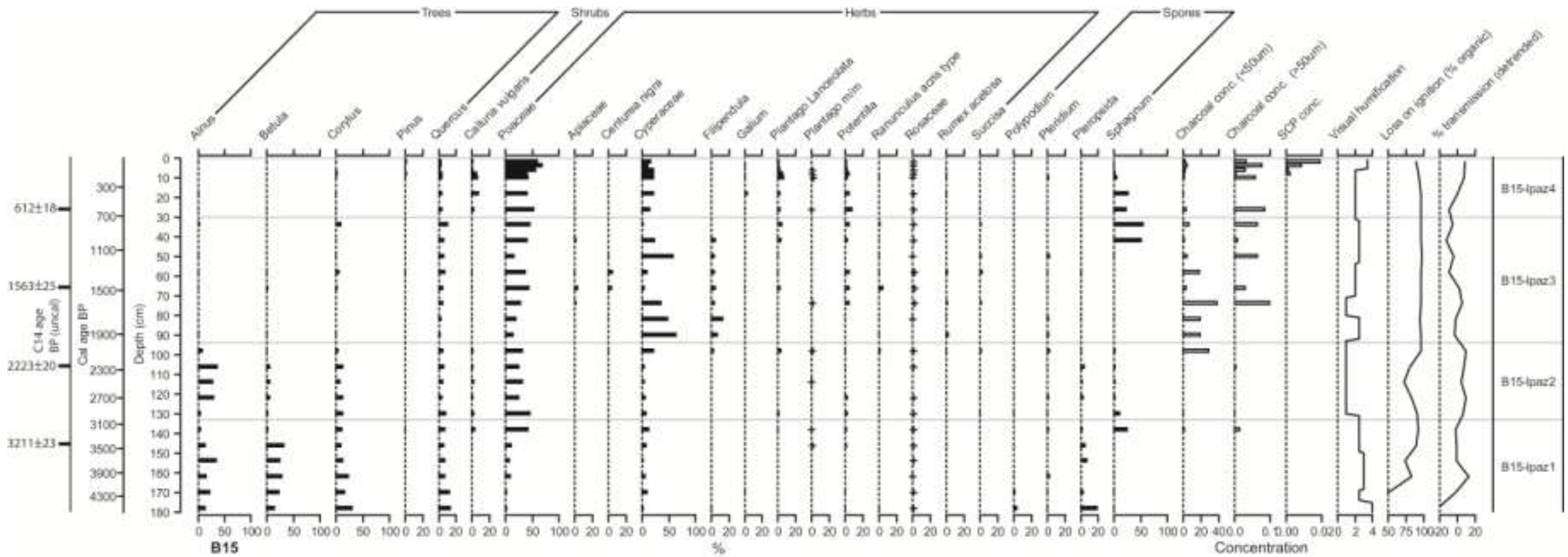


Figure 5.17. Pollen taxa summary data from B15 showing all taxa equal to or greater than 2% of the total.

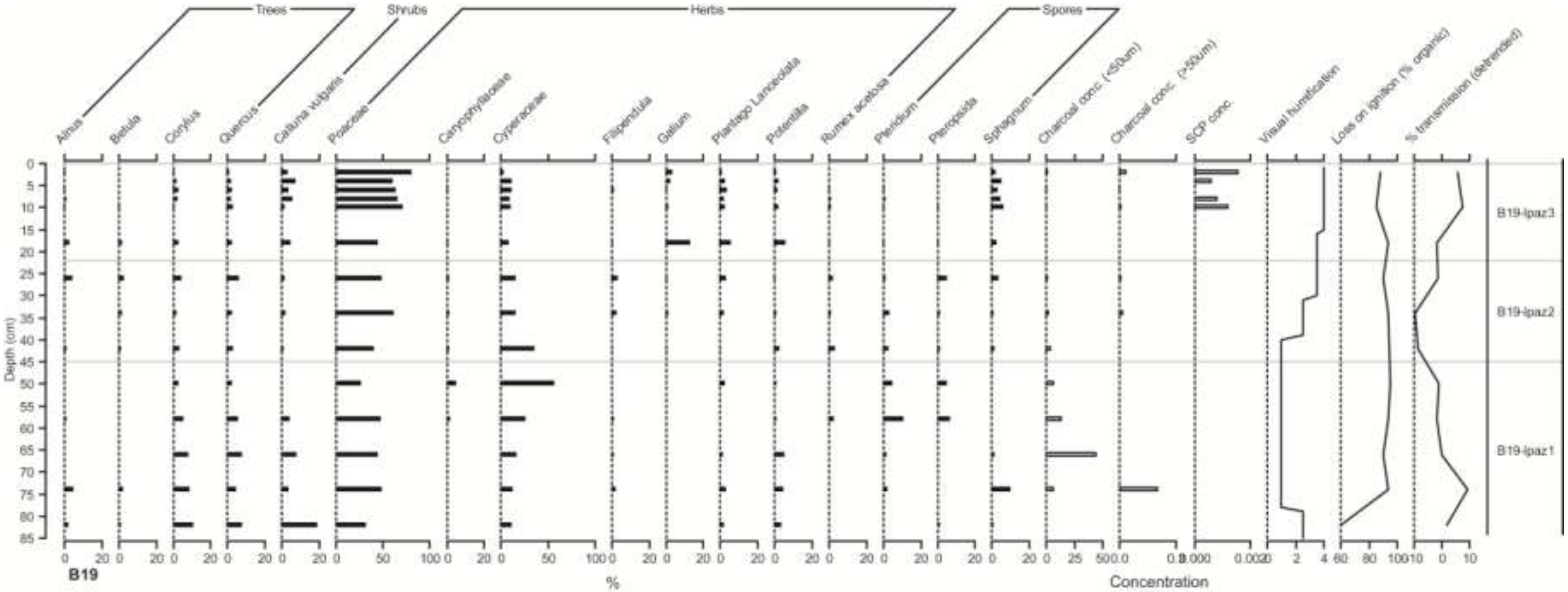


Figure 5.18. Pollen taxa summary data from B19 showing all taxa equal to or greater than 2% of the total.

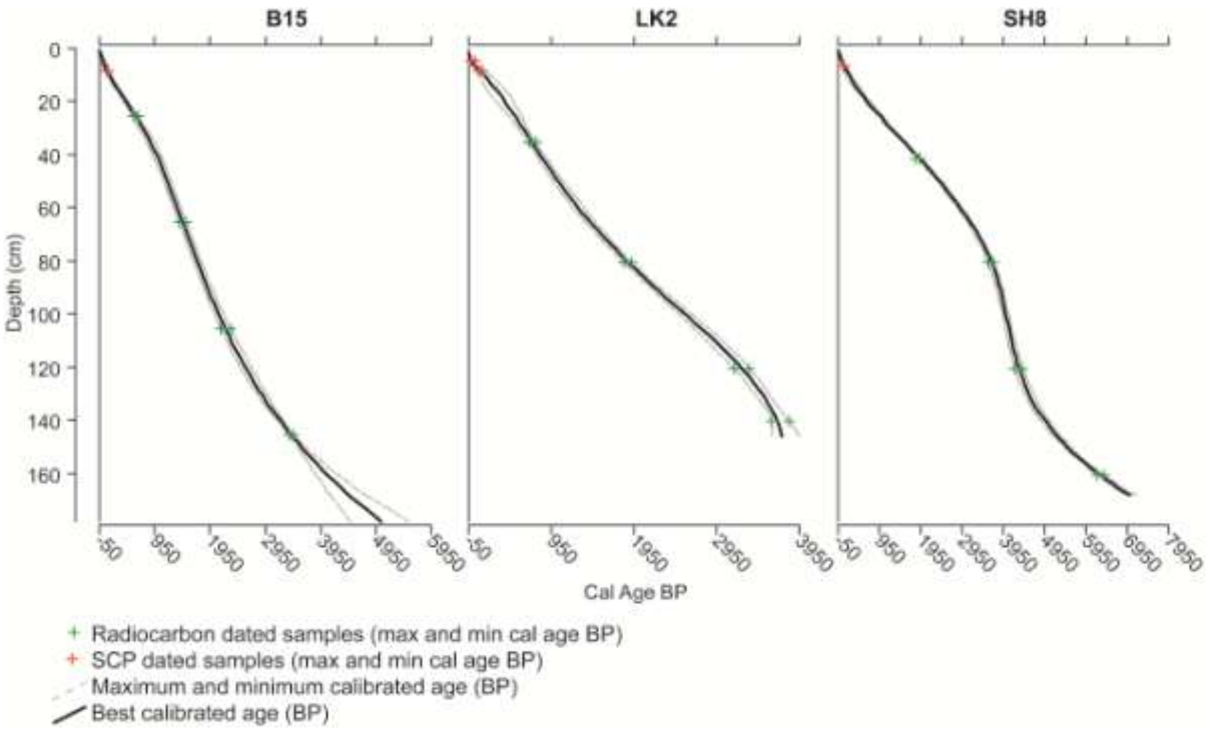


Figure 5.19. Age-depth models for the three radiocarbon dated cores generated in CLAM (Blaaw 2010).

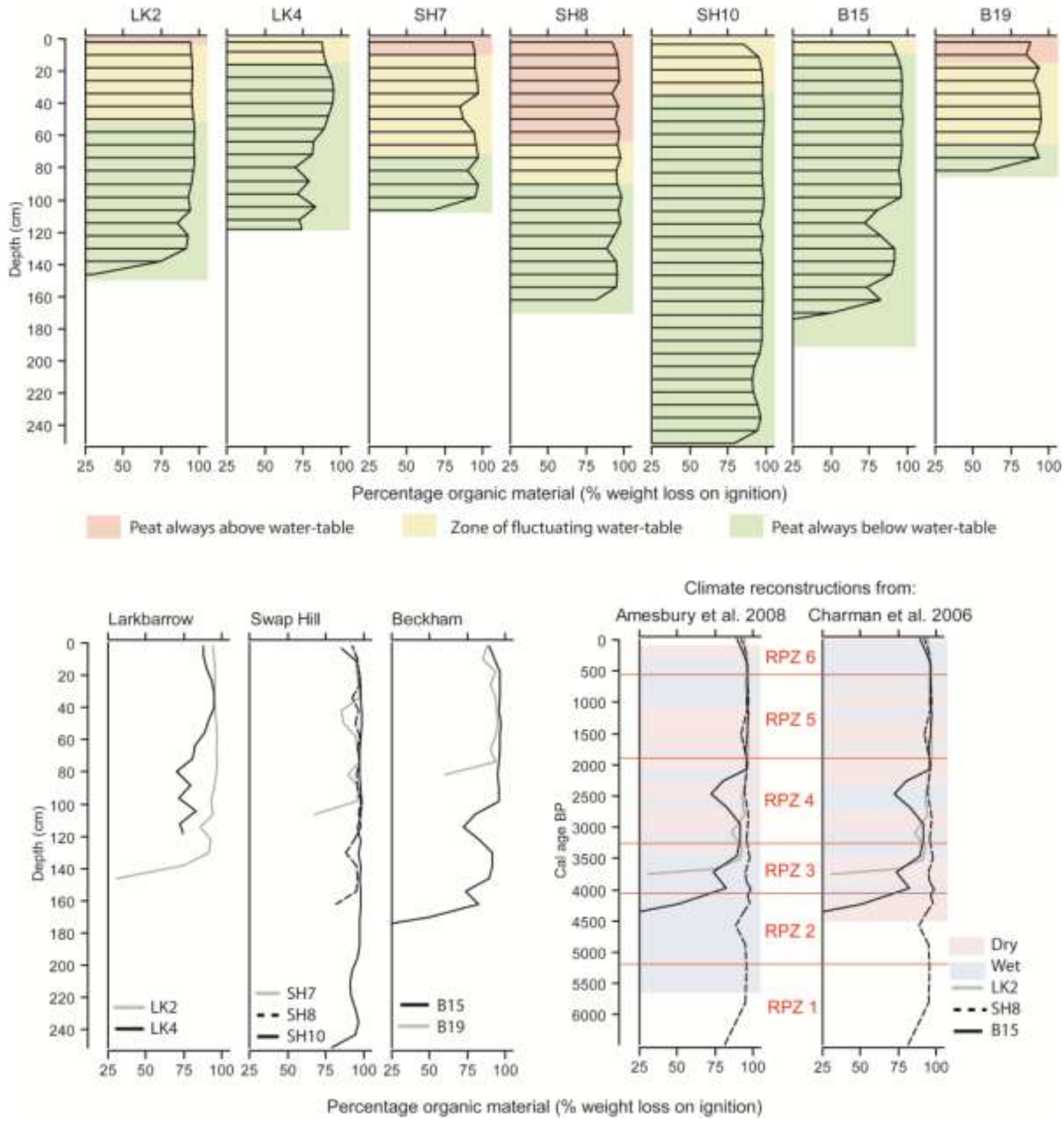


Figure 5.20. Loss on ignition (percentage organic) data. *Top:* Plotted for each core against monitored water-table zones. *Bottom left:* Data plotted by mire. *Bottom right:* Data from radiocarbon dated cores plotted by cal age BP against climate reconstructions from Charman *et al.* (2006) and Amesbury *et al.* (2008).

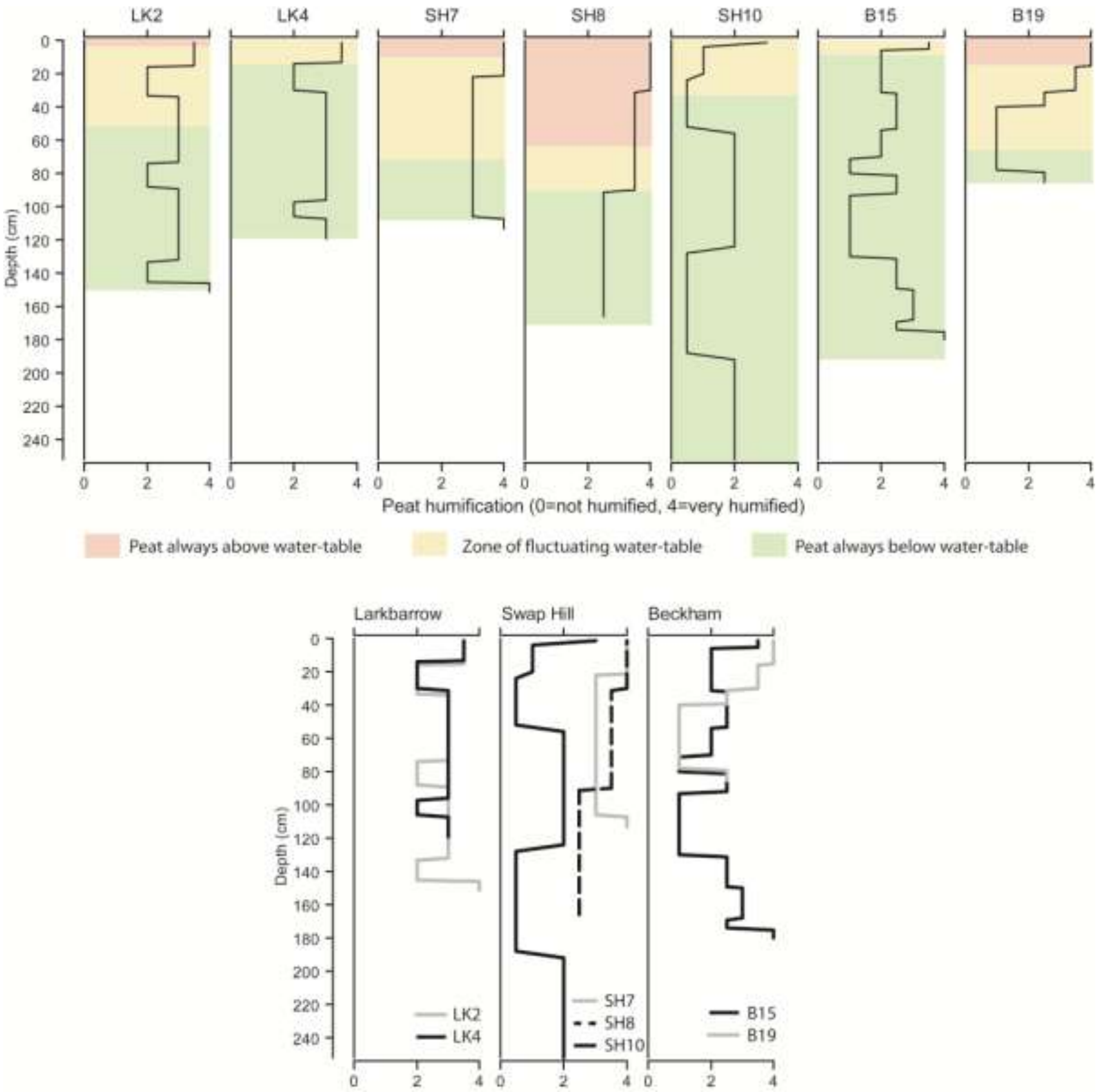


Figure 5.21. Visual humification data (based on Troels-Smith 1955).*Top:* Plotted for each core against monitored water-table zones. *Bottom:* Data plotted by mire.

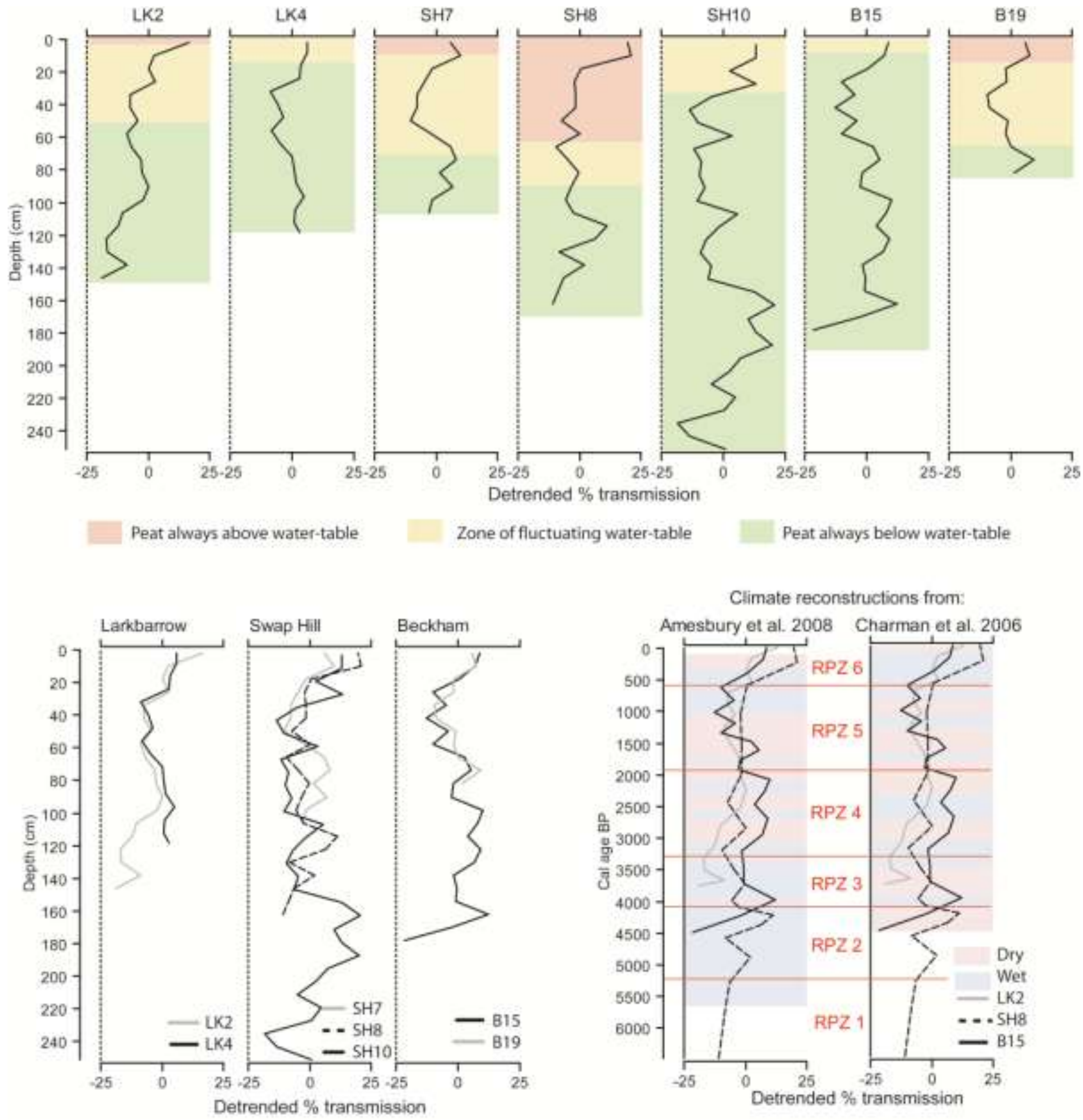


Figure 5.22. Percentage light transmission data. *Top:* Plotted for each core against monitored water-table zones. *Bottom left:* Data plotted by mire. *Bottom right:* Data from radiocarbon dated cores plotted by cal age BP against climate reconstructions from Charman *et al.* (2006) and Amesbury *et al.* (2008).

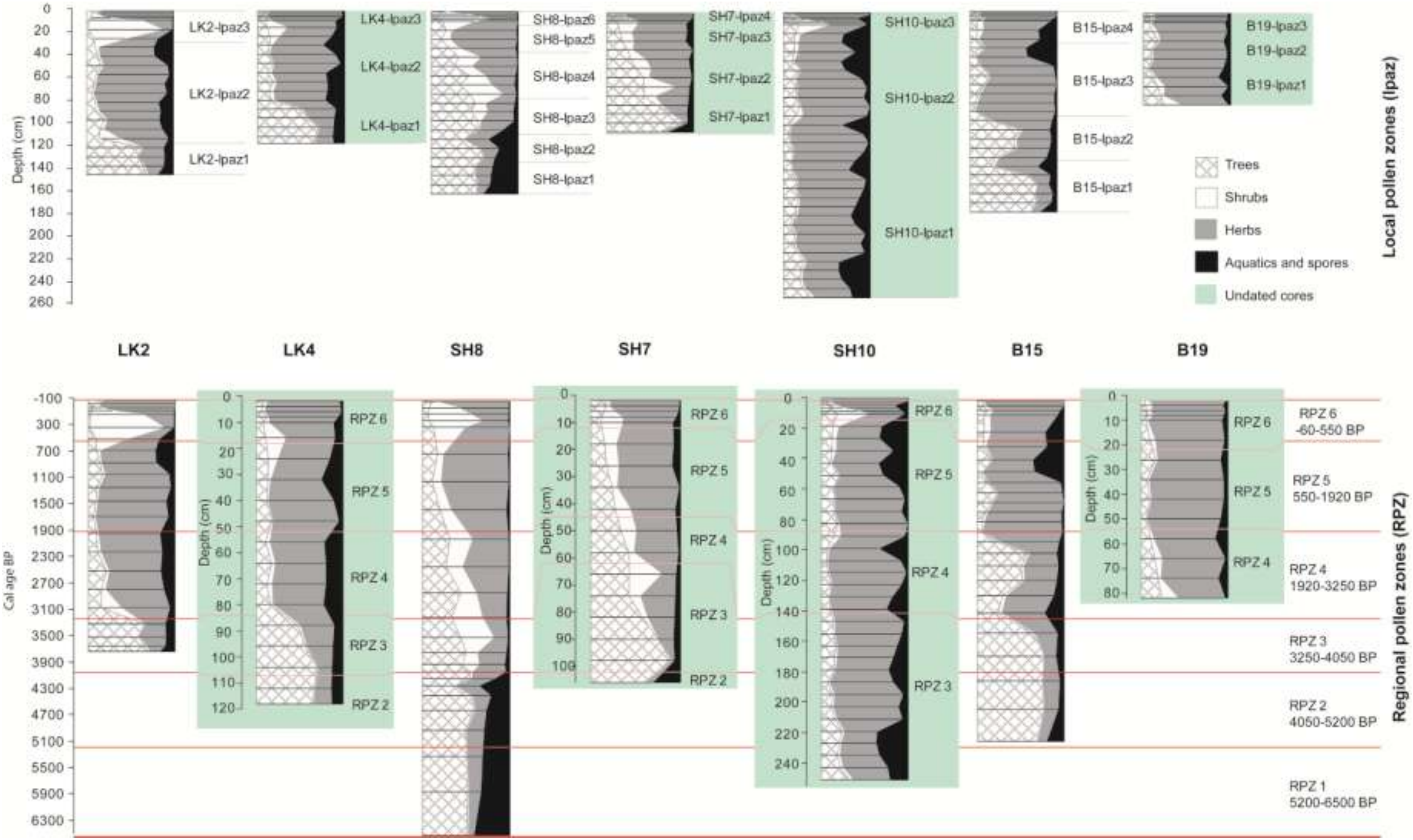


Figure 5.23. Pollen summary data for each core. *Top:* Plotted by depth. *Bottom:* Plotted by cal age BP (for radiocarbon dated cores), with all cores divided into Regional Pollen Zones (RPZs).

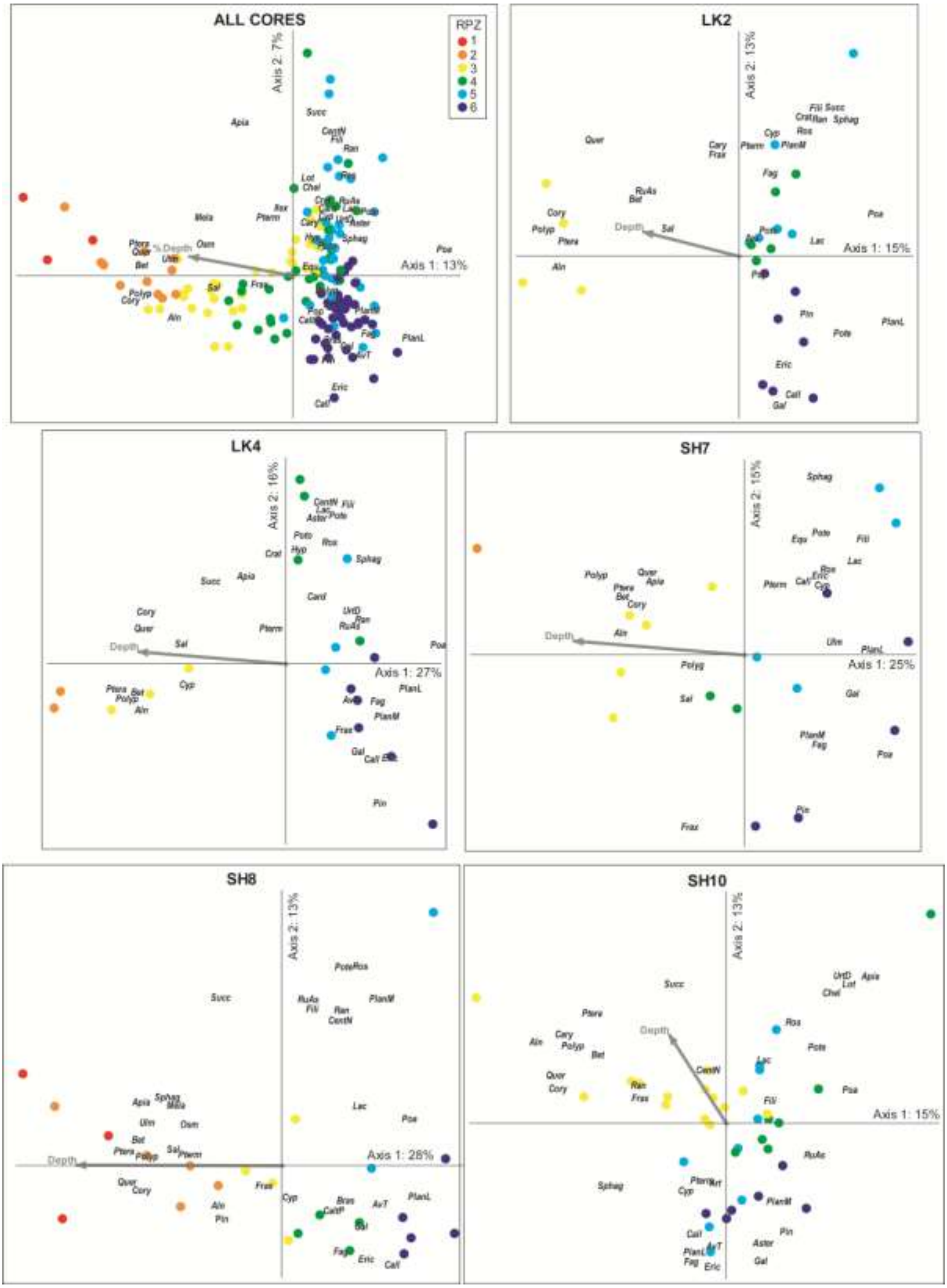


Figure 5.24. PCA scores from pollen taxa summary data for all cores (top left) and individual cores (LK2. LK4, SH7, SH8, and SH10).

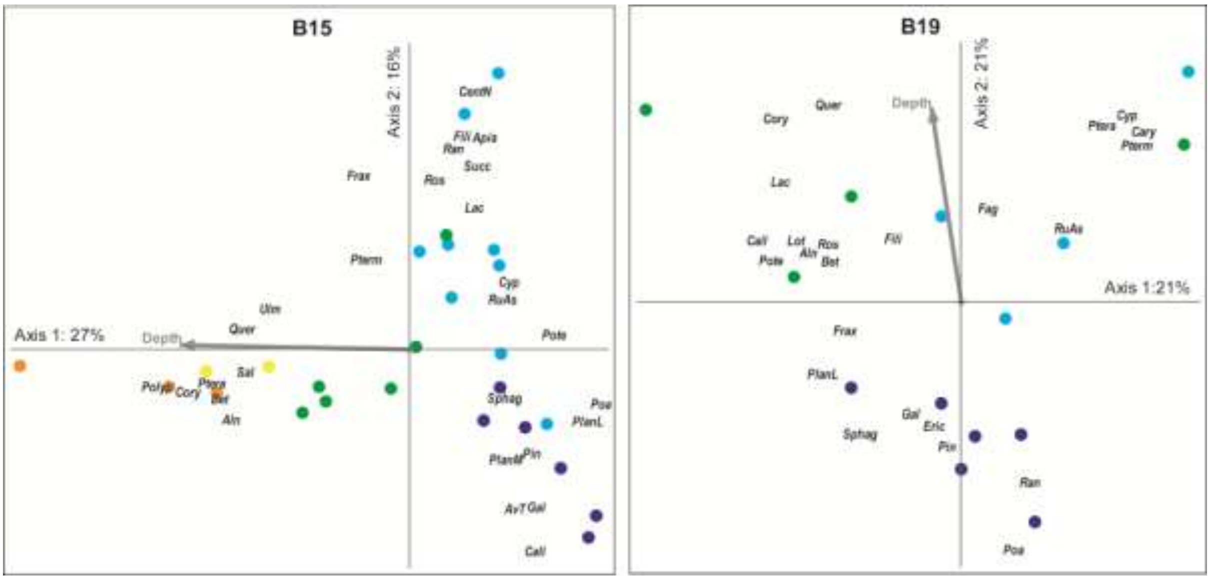


Figure 5.25. PCA scores from pollen taxa summary data for cores B15 and B19.

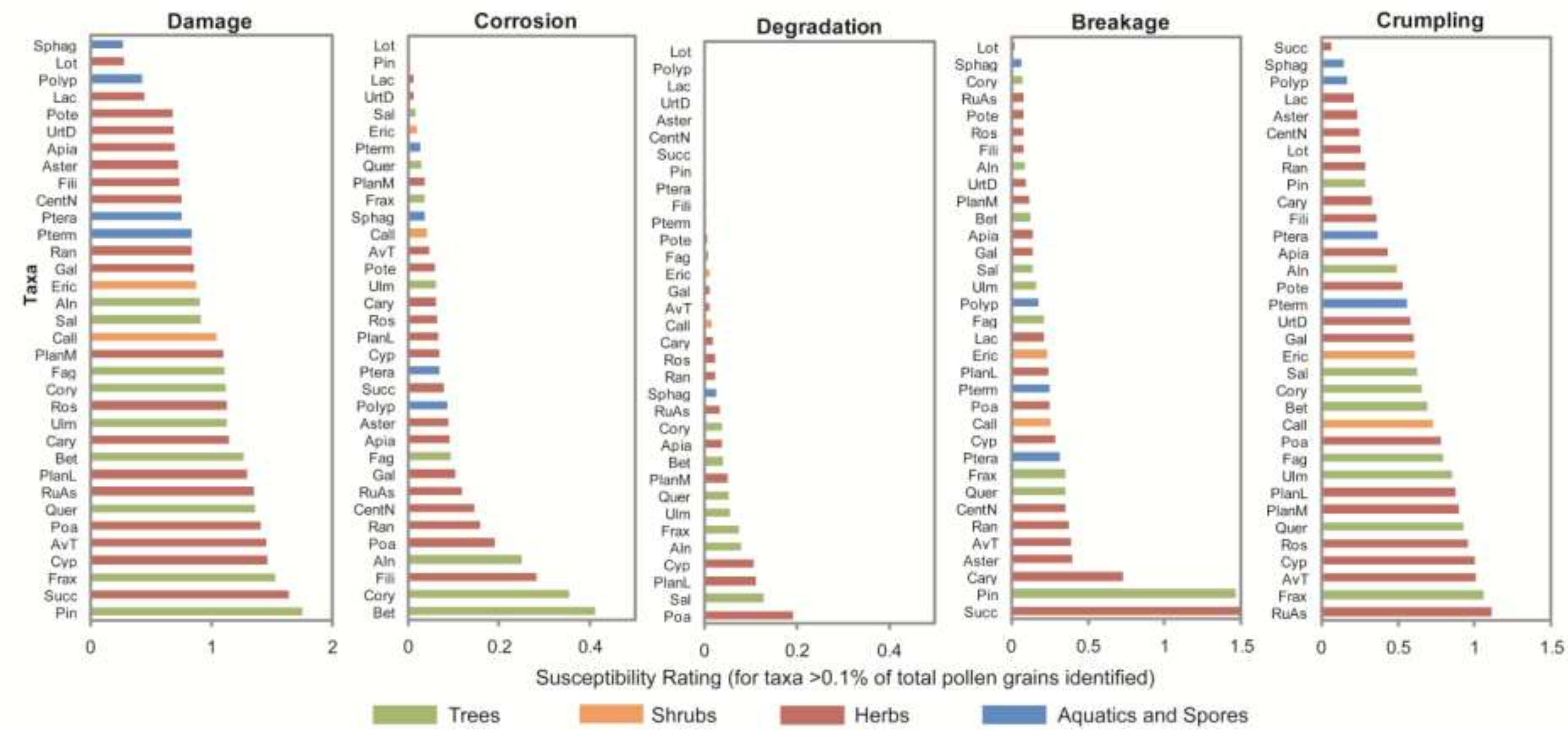


Figure 5.26. Damage susceptibility ratings for all taxa equal to or greater than 0.1% of the total number of pollen grains (for all sampled cores).

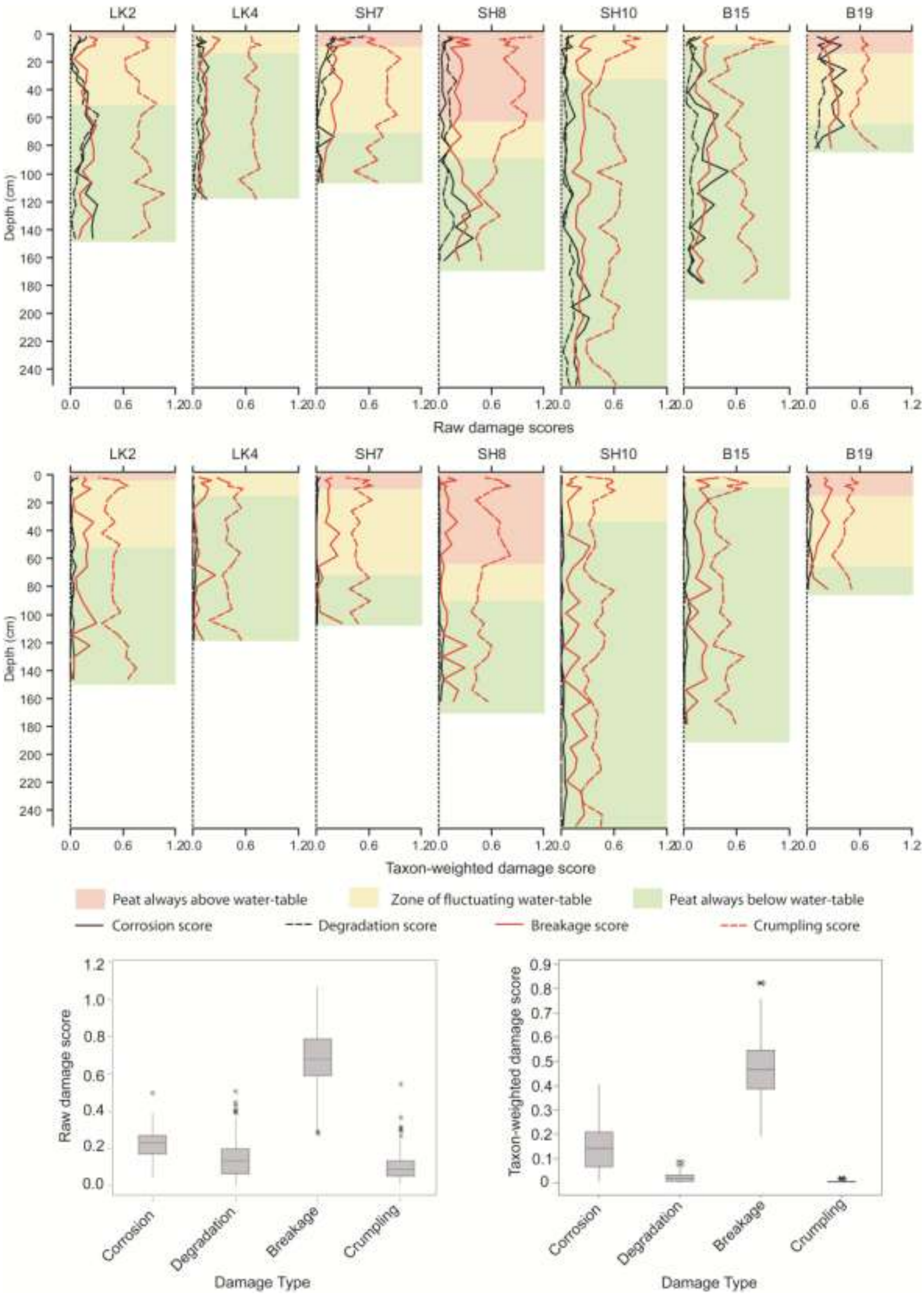


Figure 5.27. Pollen damage scores. *Top:* Stratigraphically plotted raw pollen damage scores against water-table zones. *Centre:* Sratigraphically plotted taxon-weighted damage scores against water-table zones. *Bottom left:* Mean and range raw pollen damage scores for all cores. *Bottom right:* Mean and range taxon-weighted pollen damage scores for all cores.

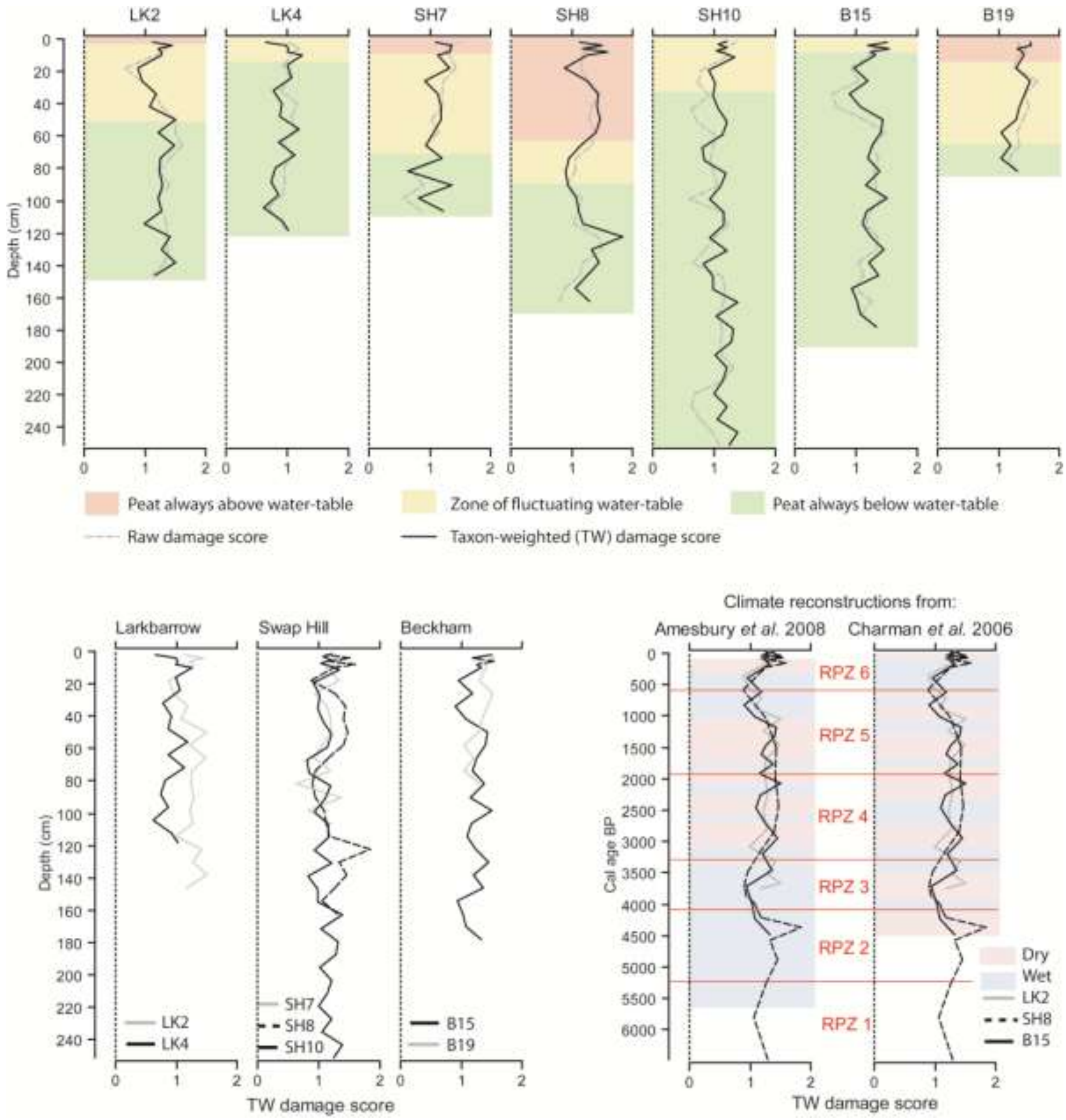


Figure 5.28. Pollen damage scores. *Top:* Plotted for each core against monitored water-table zones. *Bottom left:* Data plotted by mire. *Bottom right:* Data from radiocarbon dated cores plotted by cal age BP against climate reconstructions from Charman *et al.* (2006) and Amesbury *et al.* (2008).

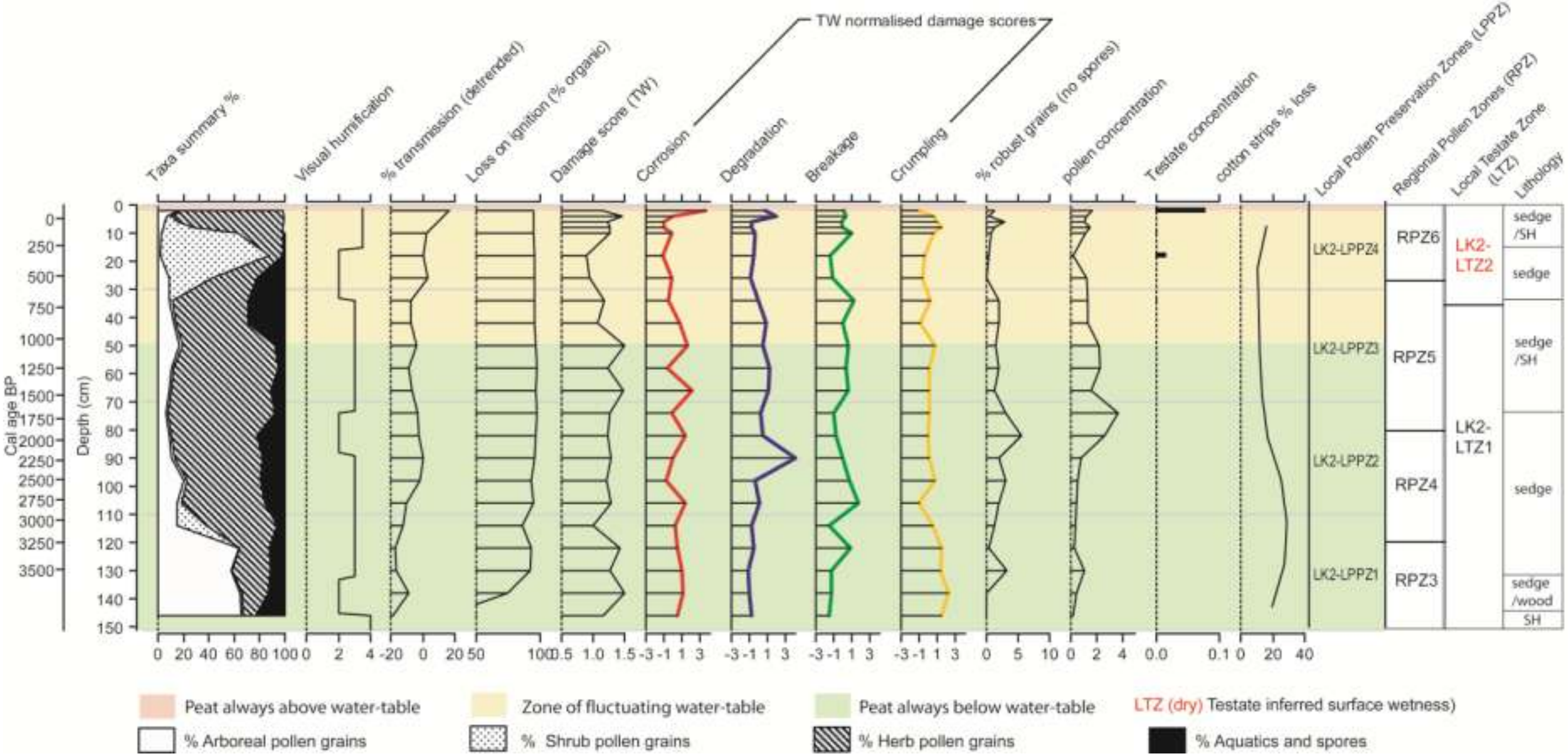


Figure 5.29. LK2 pollen taxa summary data, humification data, pollen damage scores, percentage robust grains, pollen concentration, testate amoeba concentration, cotton strip weight loss, and Local Pollen Preservation Zones (LPPZ) plotted against monitored water-table zones. Also Regional Pollen Zones (RPZ), Local Testate Zones (LTZ), and core lithology.

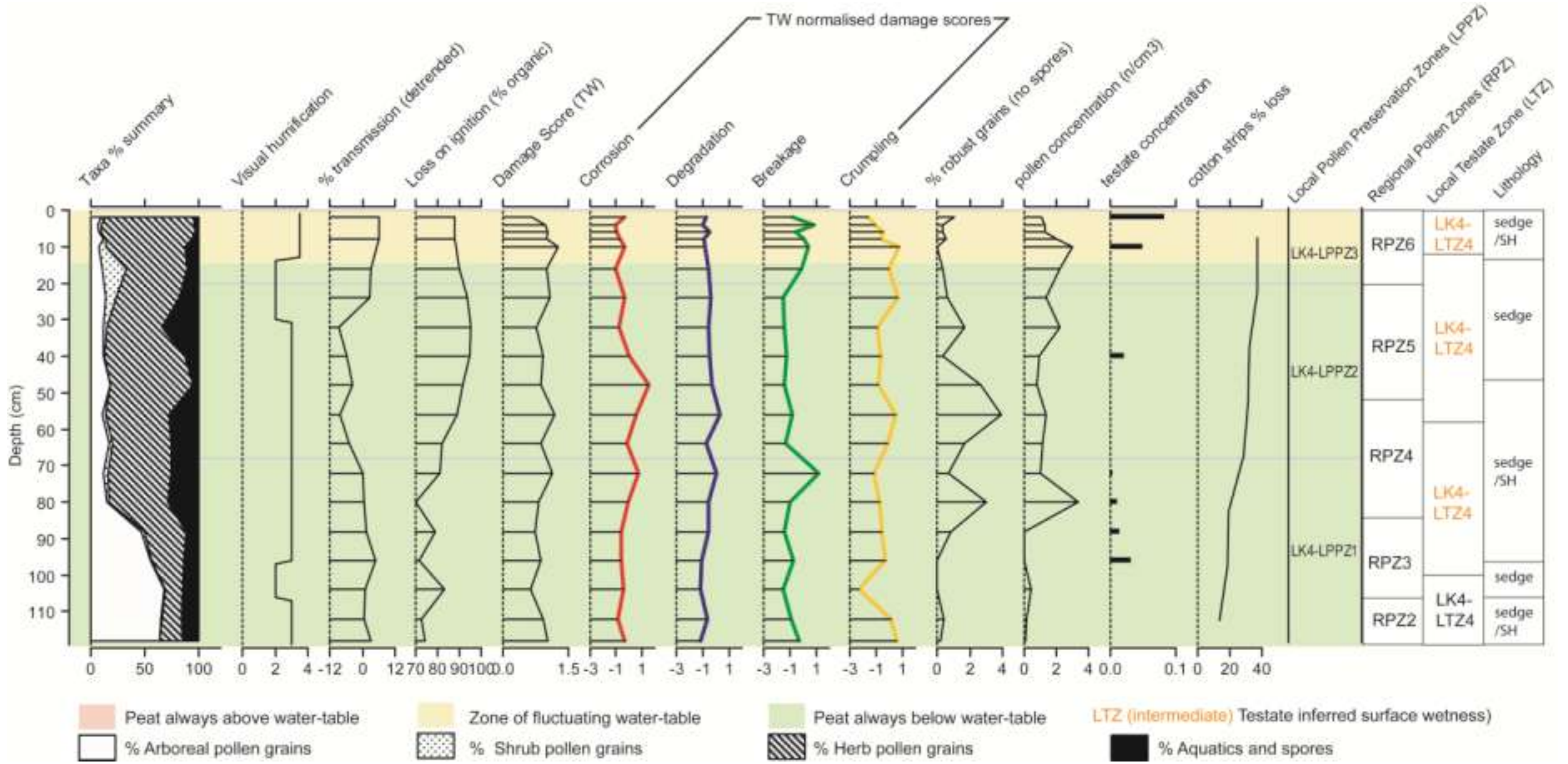


Figure 5.30. LK4 pollen taxa summary data, humification data, pollen damage scores, percentage robust grains, pollen concentration, testate amoeba concentration, cotton strip weight loss, and Local Pollen Preservation Zones (LPPZ) plotted against monitored water-table zones. Also Regional Pollen Zones (RPZ), Local Testate Zones (LTZ), and core lithology.

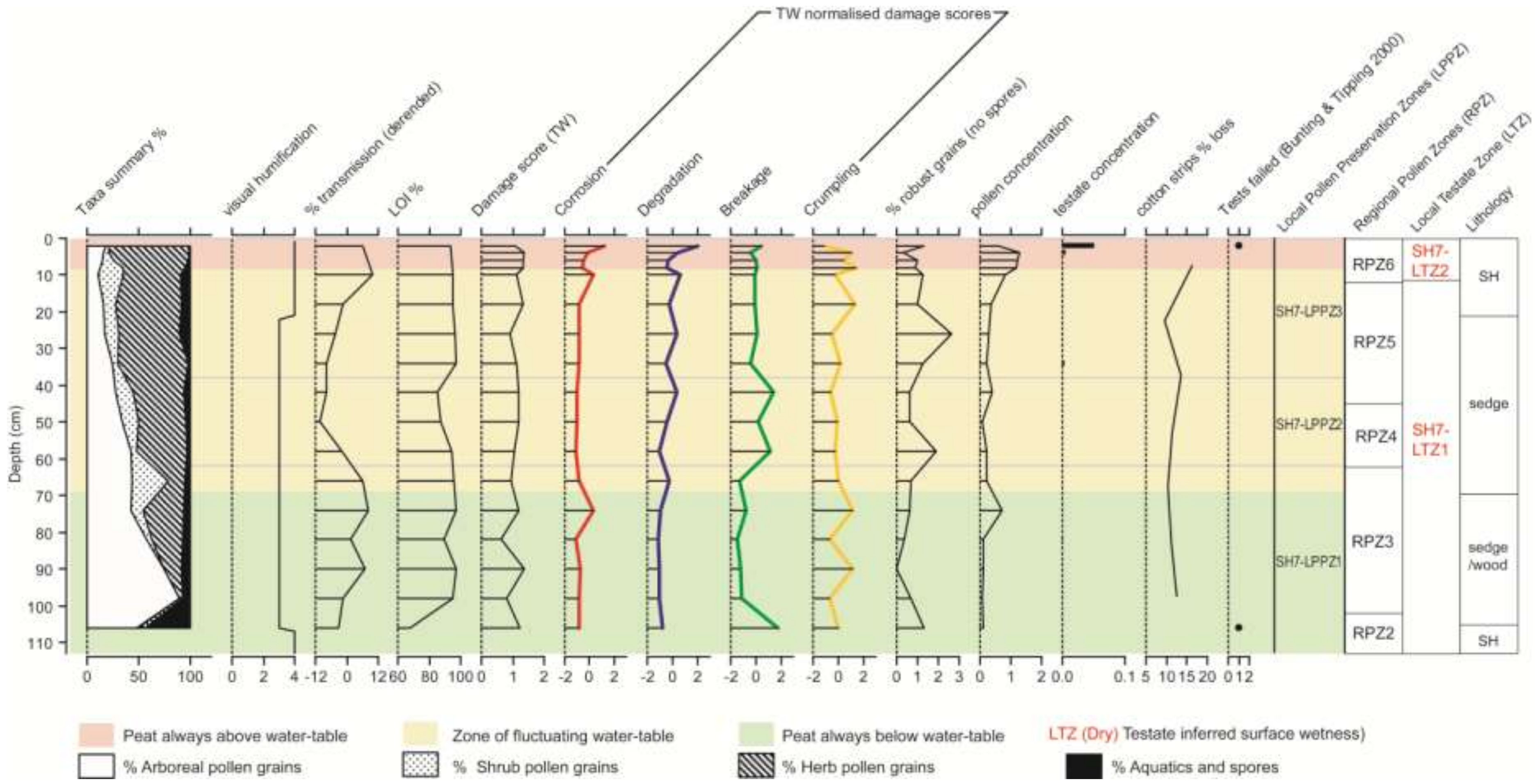


Figure 5.31. SH7 pollen taxa summary data, humification data, pollen damage scores, percentage robust grains, pollen concentration, testate amoeba concentration, cotton strip weight loss, and Local Pollen Preservation Zones (LPPZ) plotted against monitored water-table zones. Also Regional Pollen Zones (RPZ), Local Testate Zone (LTZ), and core lithology.

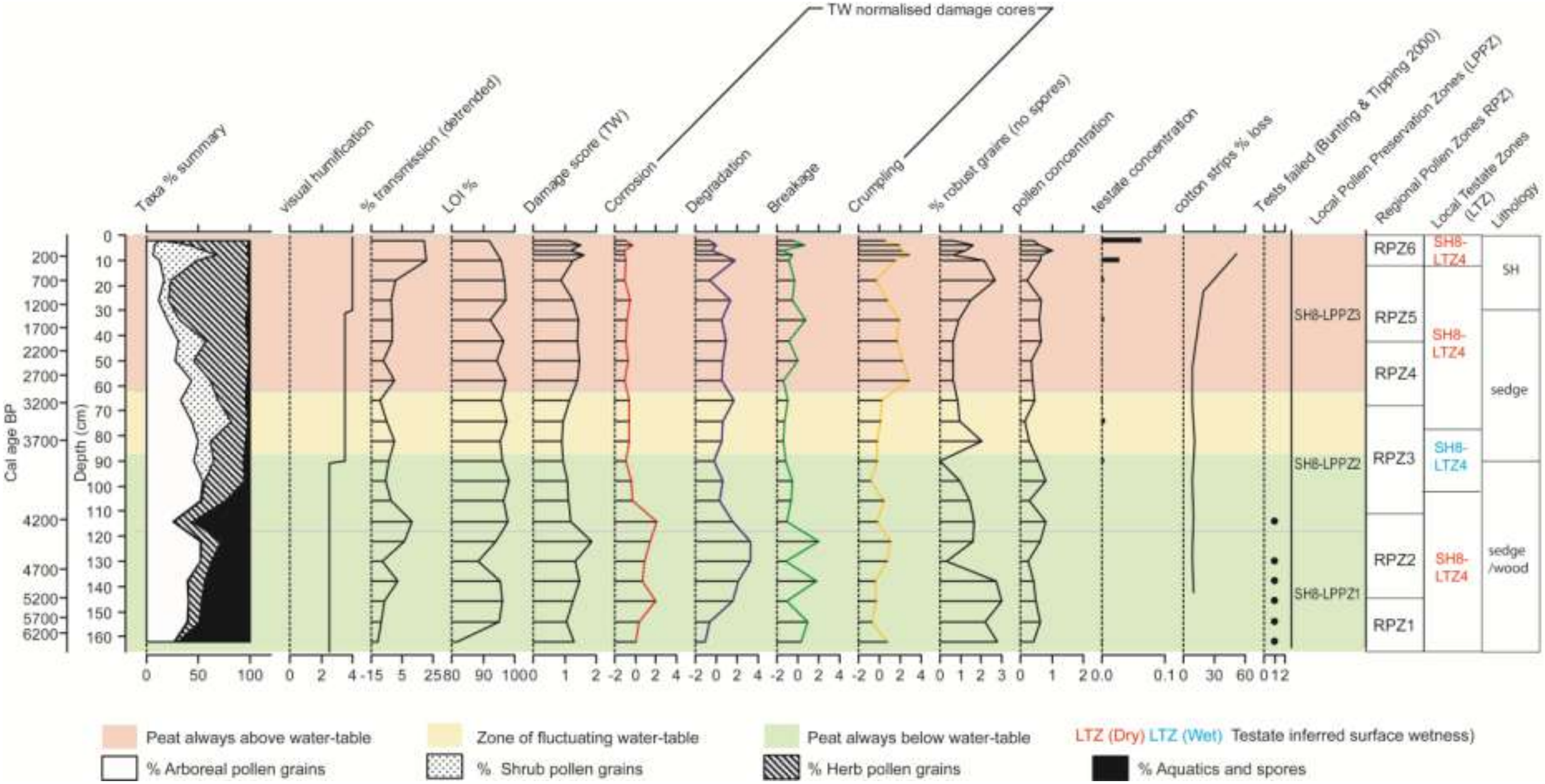


Figure 5.32. SH8 pollen taxa summary data, humification data, pollen damage scores, percentage robust grains, pollen concentration, testate amoeba concentration, cotton strip weight loss, and Local Pollen Preservation Zones (LPPZ) plotted against monitored water-table zones. Also Regional Pollen Zones (RPZ), Local Testate Zones (LTZ), and core lithology.

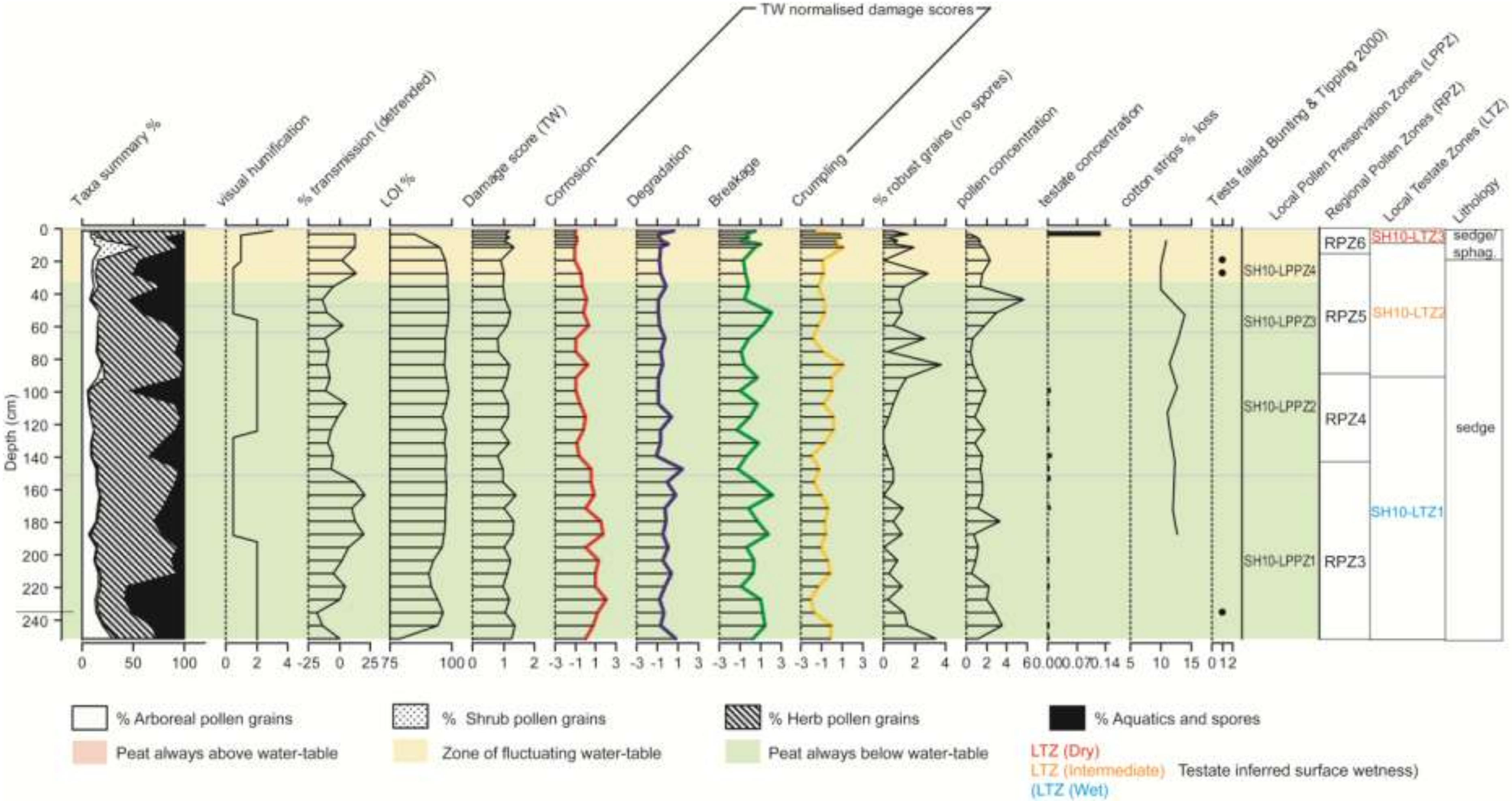


Figure 5.33. SH10 pollen taxa summary data, humification data, pollen damage scores, percentage robust grains, pollen concentration, testate amoeba concentration, cotton strip weight loss, and Local Pollen Preservation Zones (LPPZ) plotted against monitored water-table zones. Also Regional Pollen Zones (RPZ), Local Testate Zones (LTZ), and core lithology.

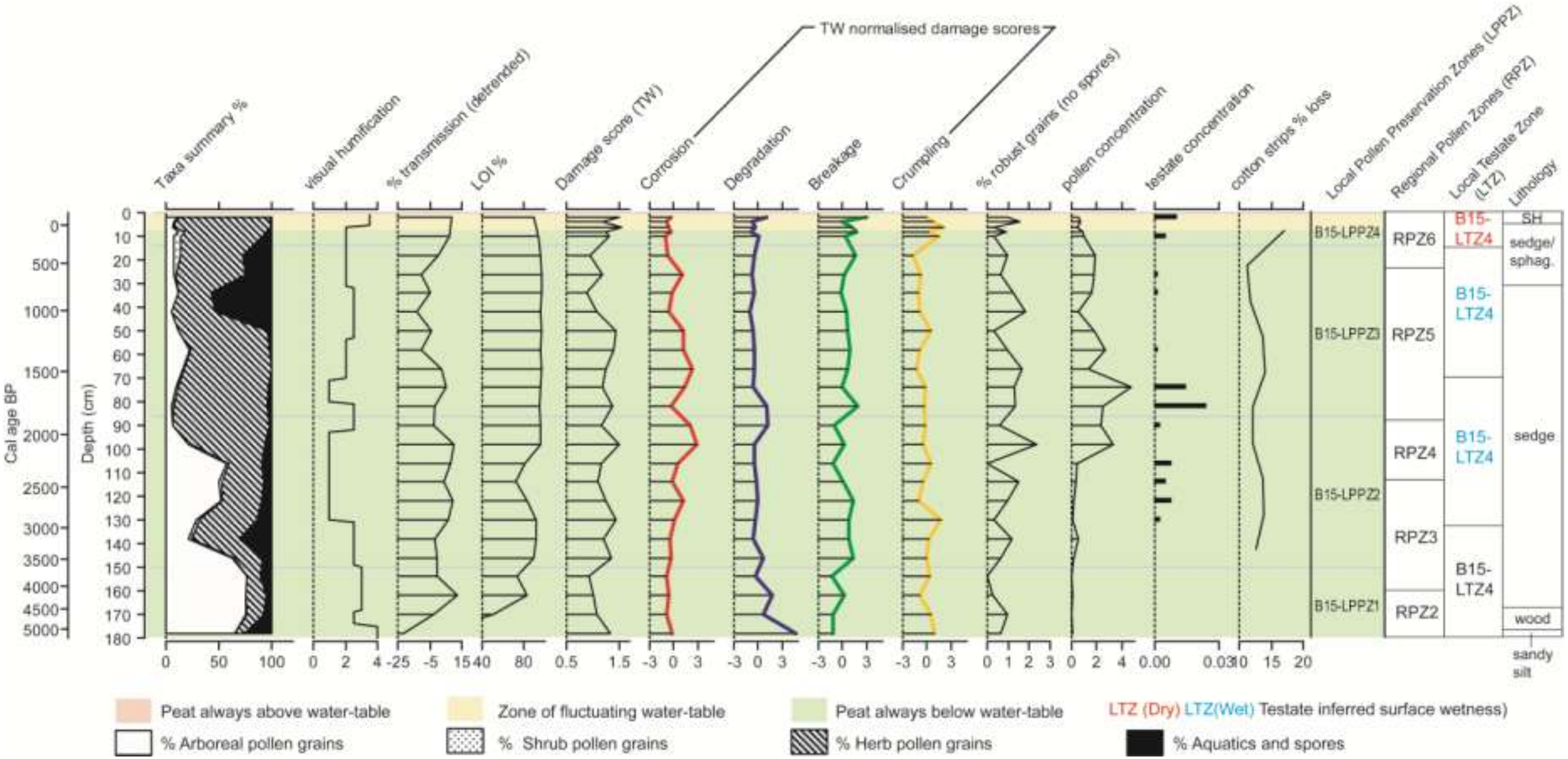


Figure 5.34. B15 pollen taxa summary data, humification data, pollen damage scores, percentage robust grains, pollen concentration, testate amoeba concentration, cotton strip weight loss, and Local Pollen Preservation Zones (LPPZ) plotted against monitored water-table zones. Also Regional Pollen Zones (RPZ), Local Testate Zones (LTZ), and core lithology.

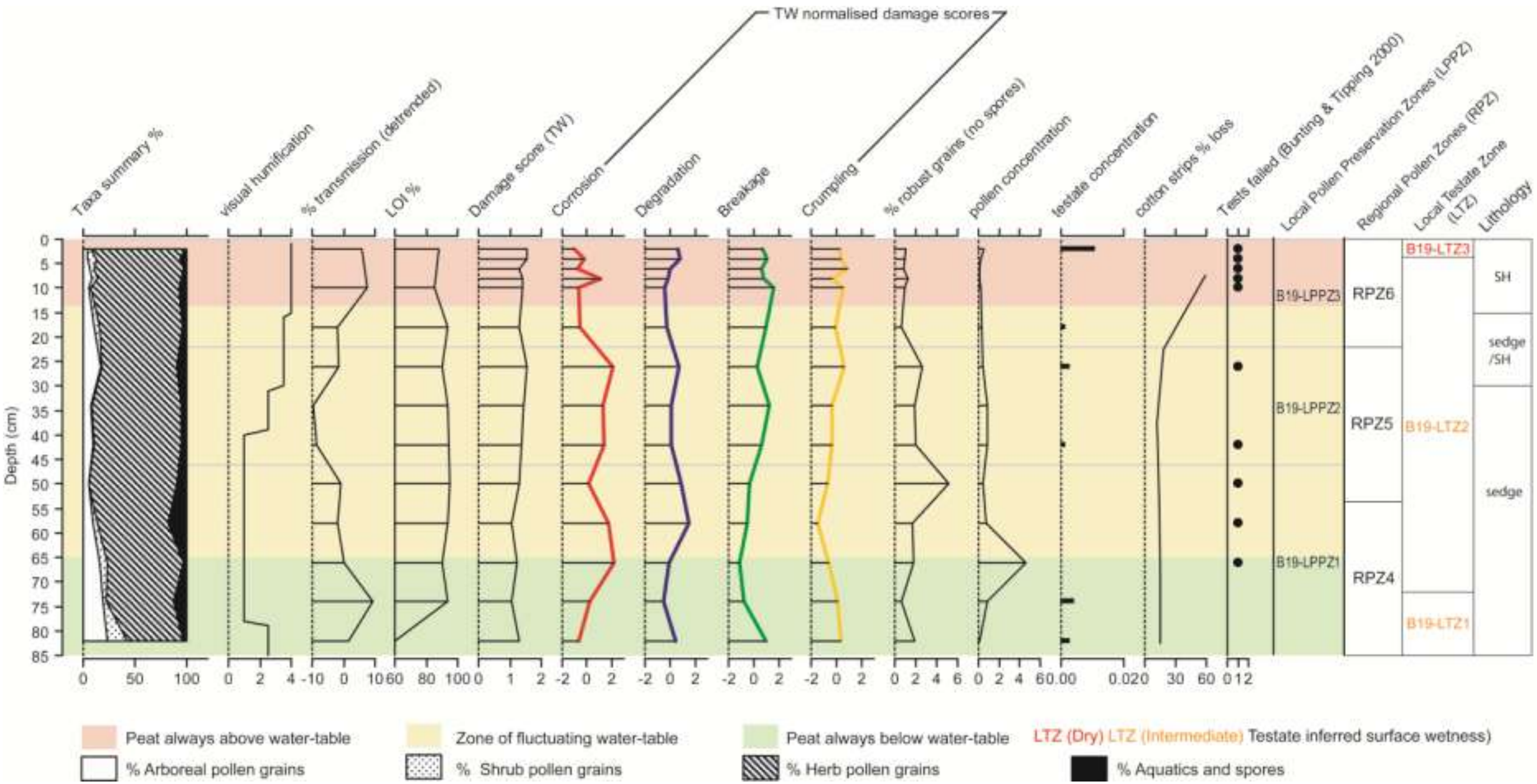


Figure 5.35. B19 pollen taxa summary data, humification data, pollen damage scores, percentage robust grains, pollen concentration, testate amoeba concentration, cotton strip weight loss, and Local Pollen Preservation Zones (LPPZ) plotted against monitored water-table zones. Also Regional Pollen Zones (RPZ), Local Testate Zones (LTZ), and core lithology.

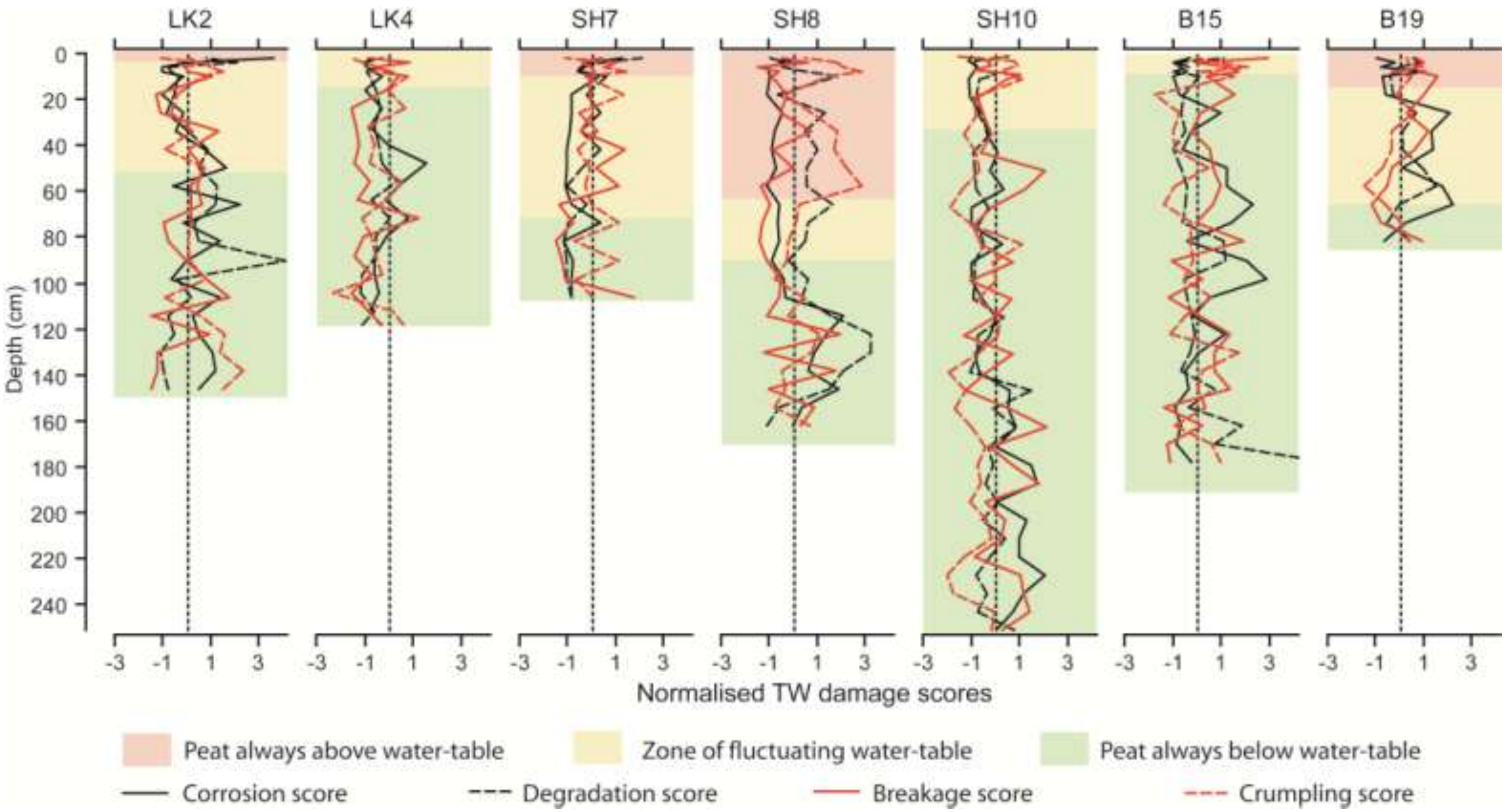


Figure 5.36. Normalised taxon-weighted damage scores plotted by depth against monitored water-table zones.

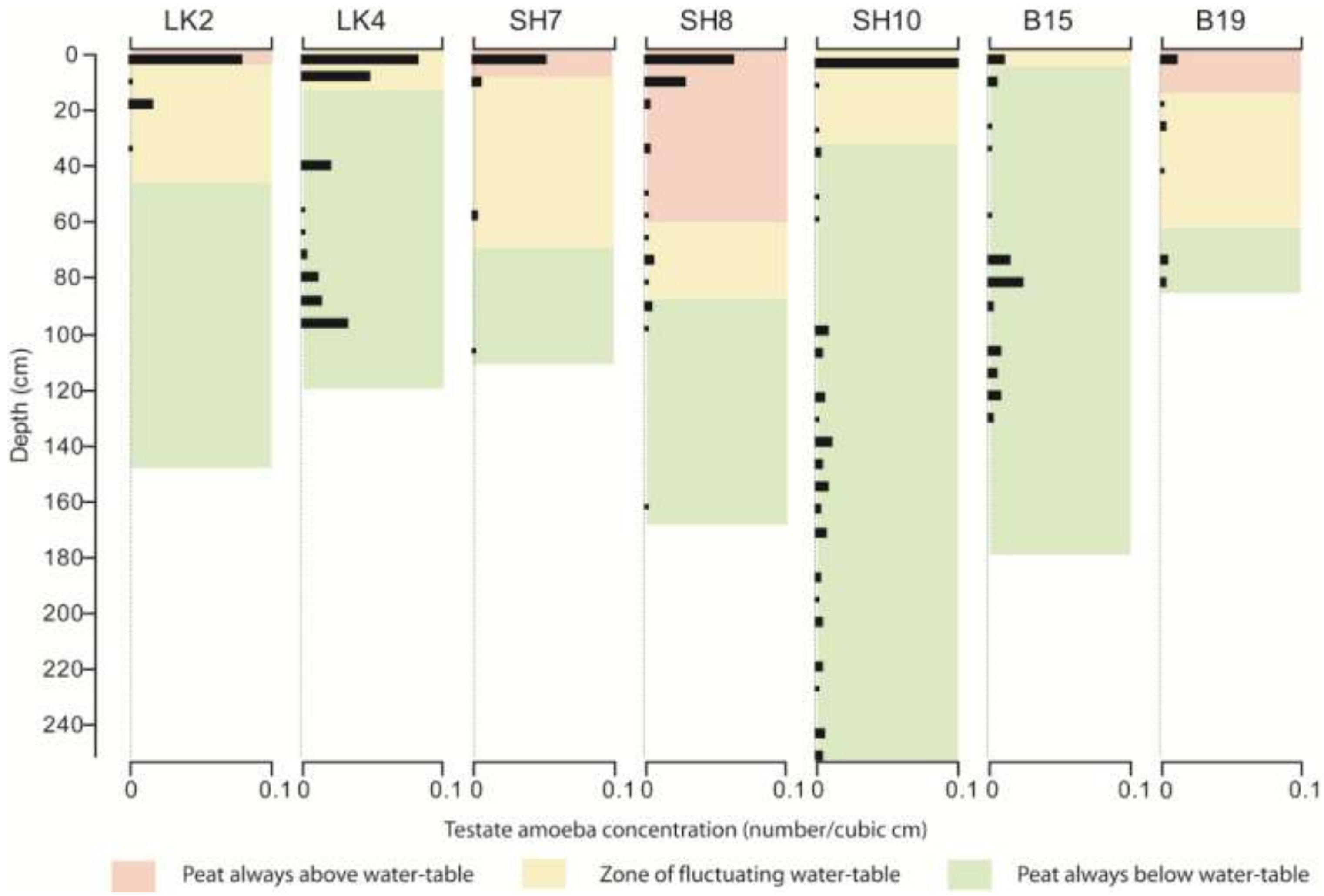


Figure 5.37. Testate amoeba concentration plotted against monitored water-table zones.

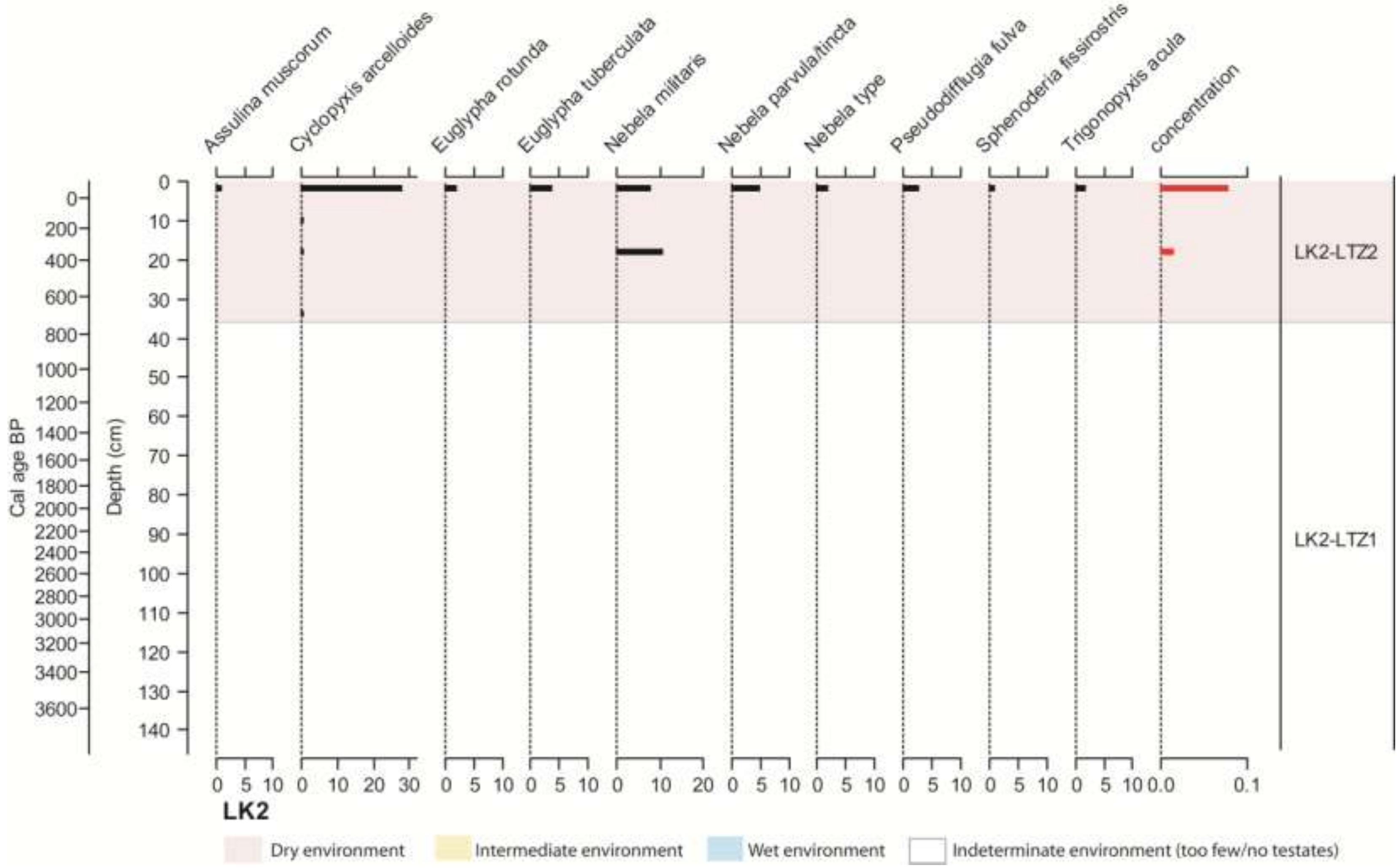


Figure 5.38. Testate amoeba raw count data from LK2 plotted against testate-inferred surface wetness zones.

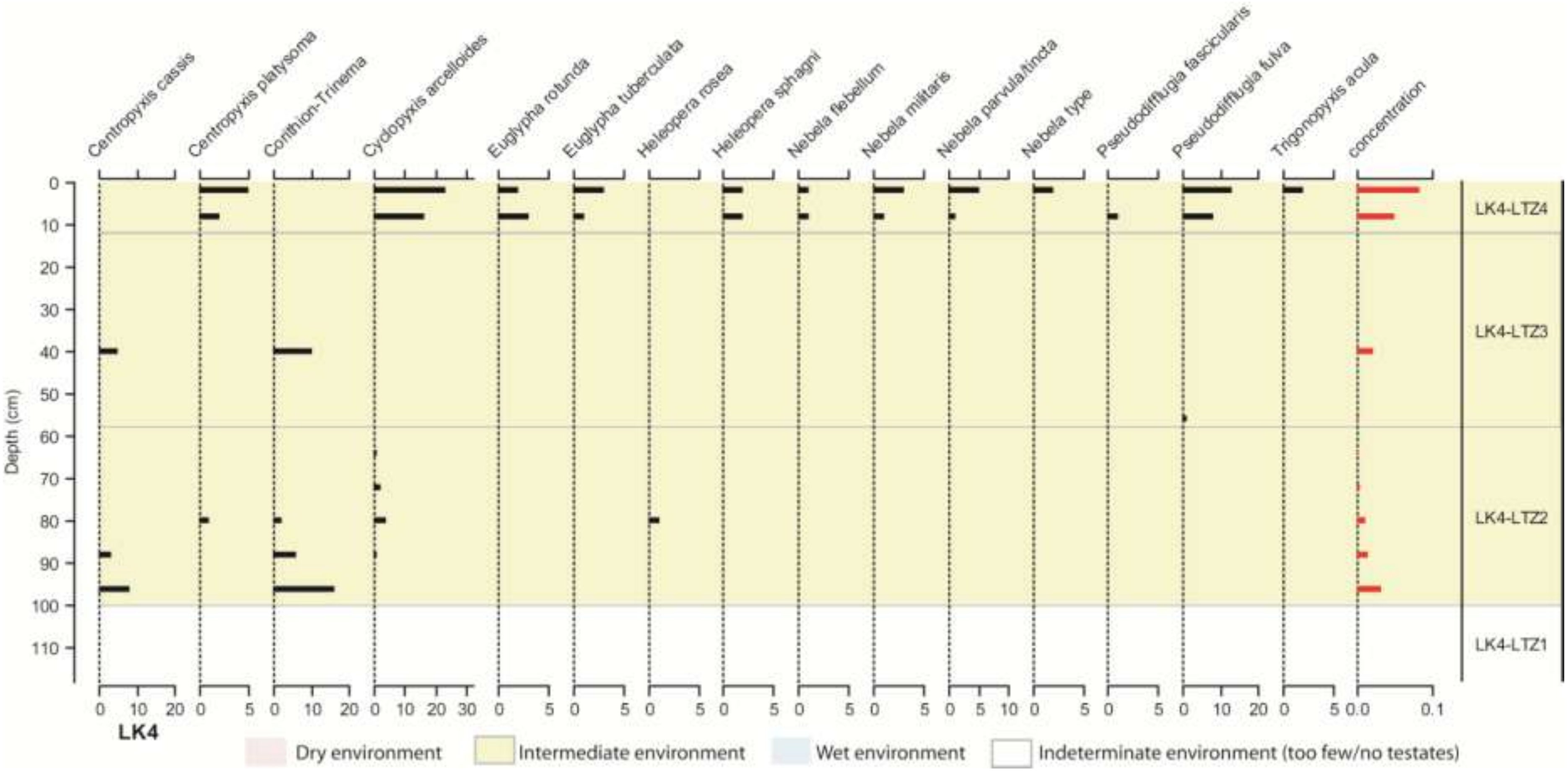


Figure 5.39. Testate amoeba raw count data from LK4 plotted against testate-inferred surface wetness zones.

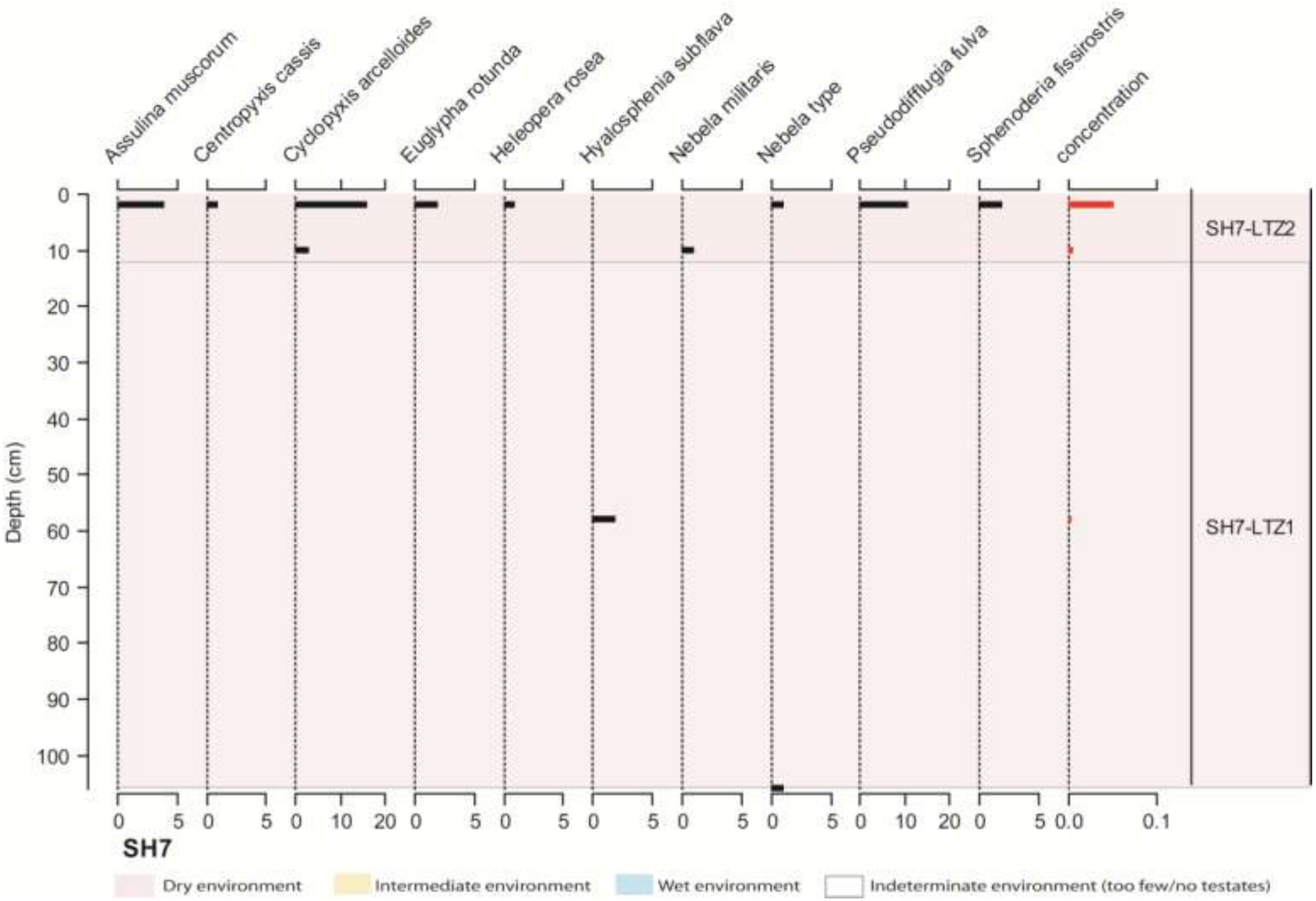


Figure 5.40. Testate amoeba raw count data from SH7 plotted against testate-inferred surface wetness zones.

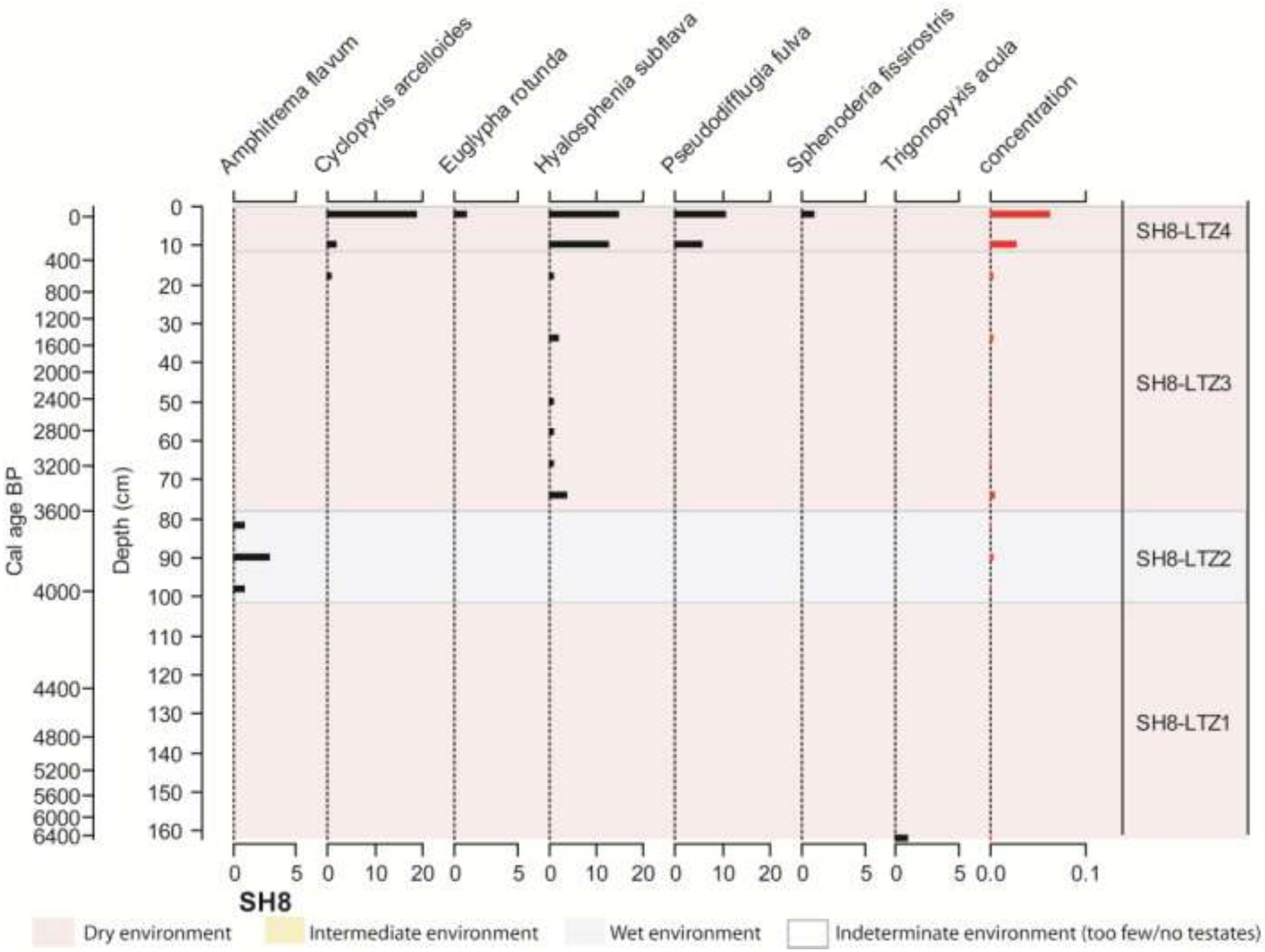


Figure 5.41. Testate amoeba raw count data from SH8 plotted against testate-inferred surface wetness zones.

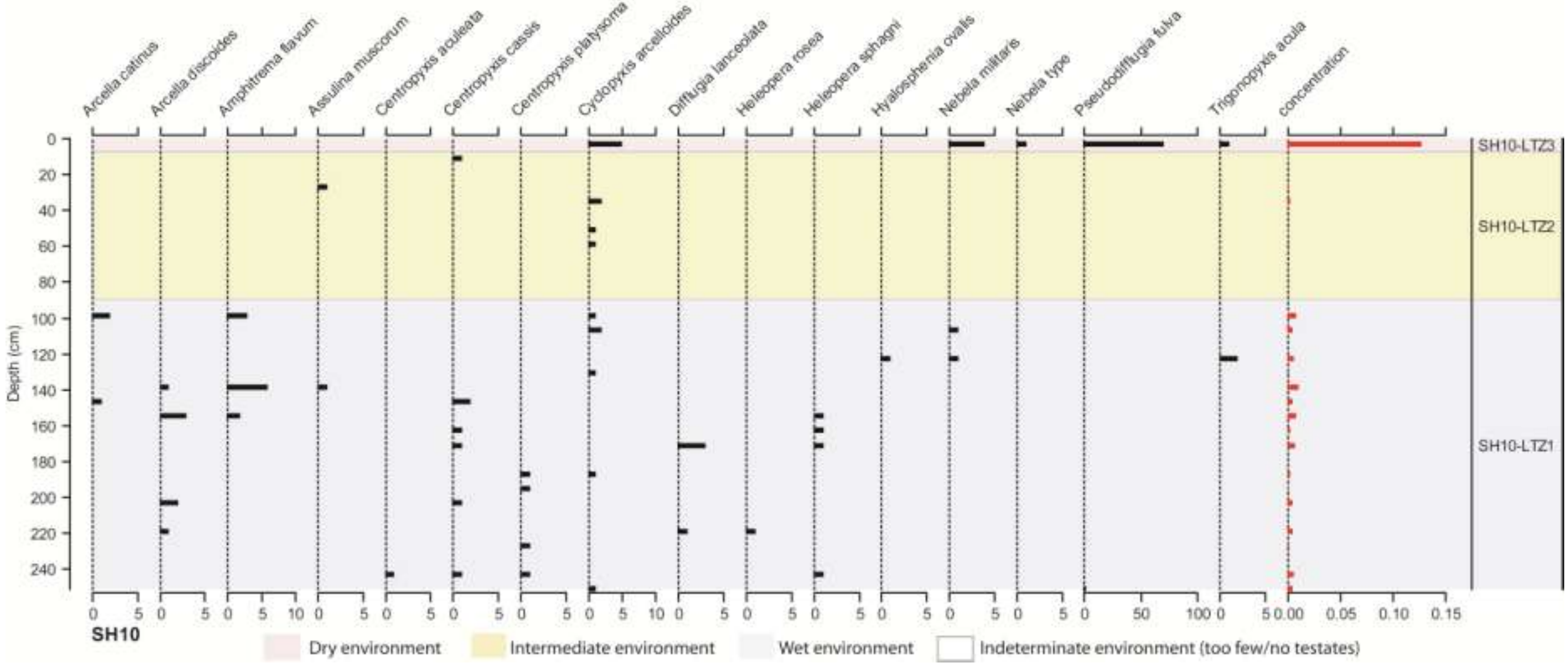


Figure 5.42. Testate amoeba raw count data from SH10 plotted against testate-inferred surface wetness zones.

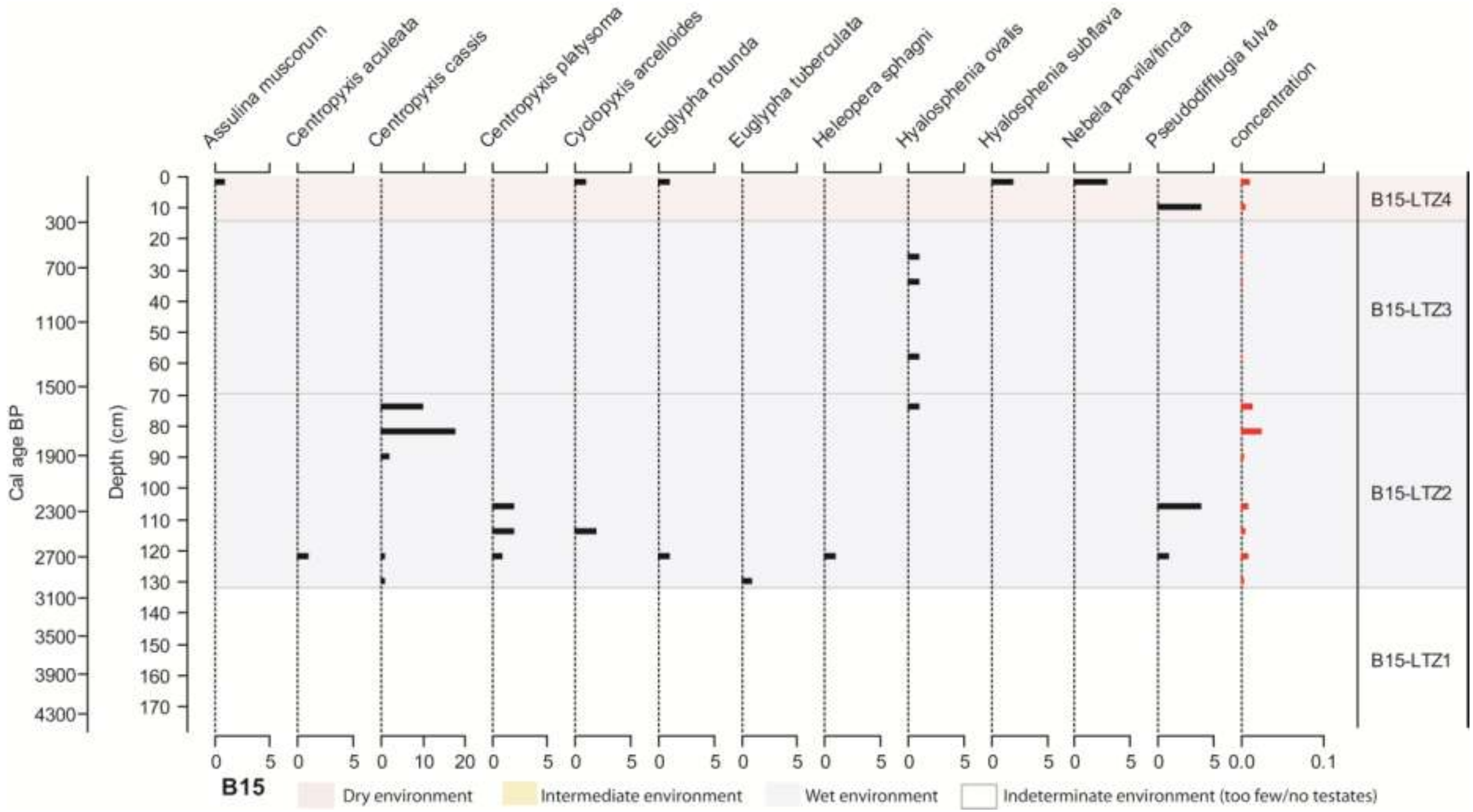


Figure 5.43. Testate amoeba raw count data from B15 plotted against testate-inferred surface wetness zones.

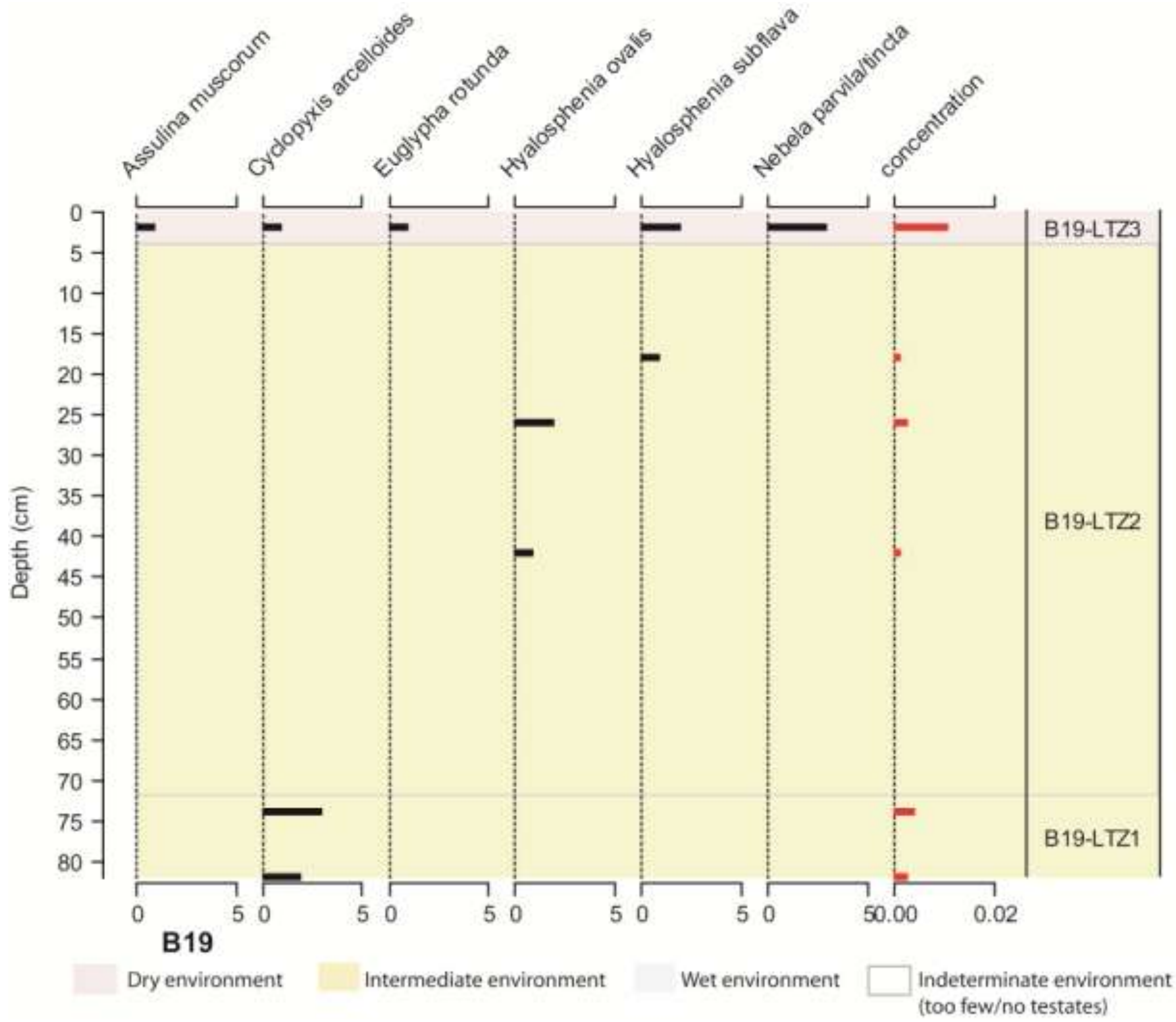


Figure 5.44. Testate amoeba raw count data from B19 plotted against testate-inferred surface wetness zones.

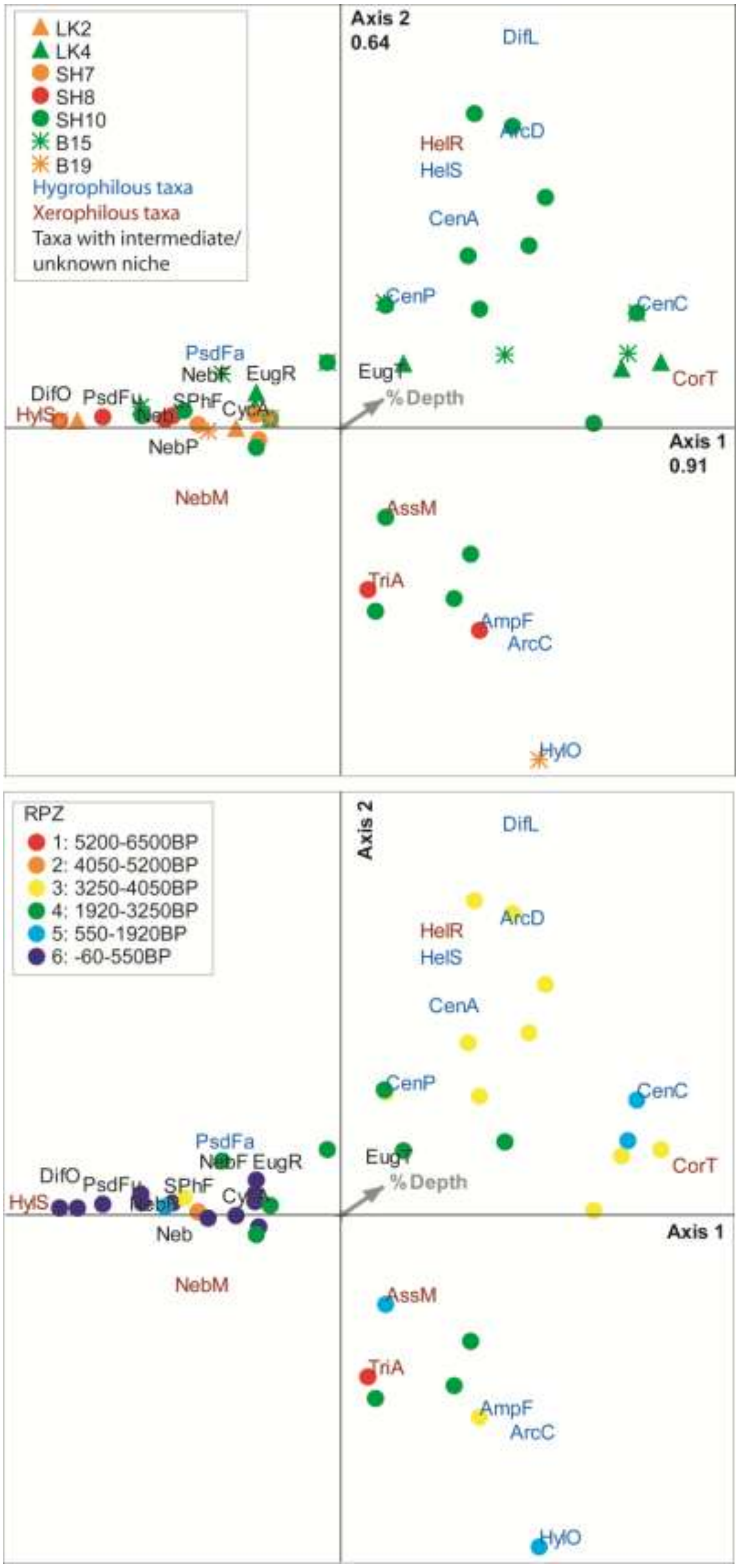


Figure 5.45. DCA scores for all testate amoebae taxa data from all cores. *Top:* Categorised by core. *Bottom:* Categorised by Regional Pollen Zone.

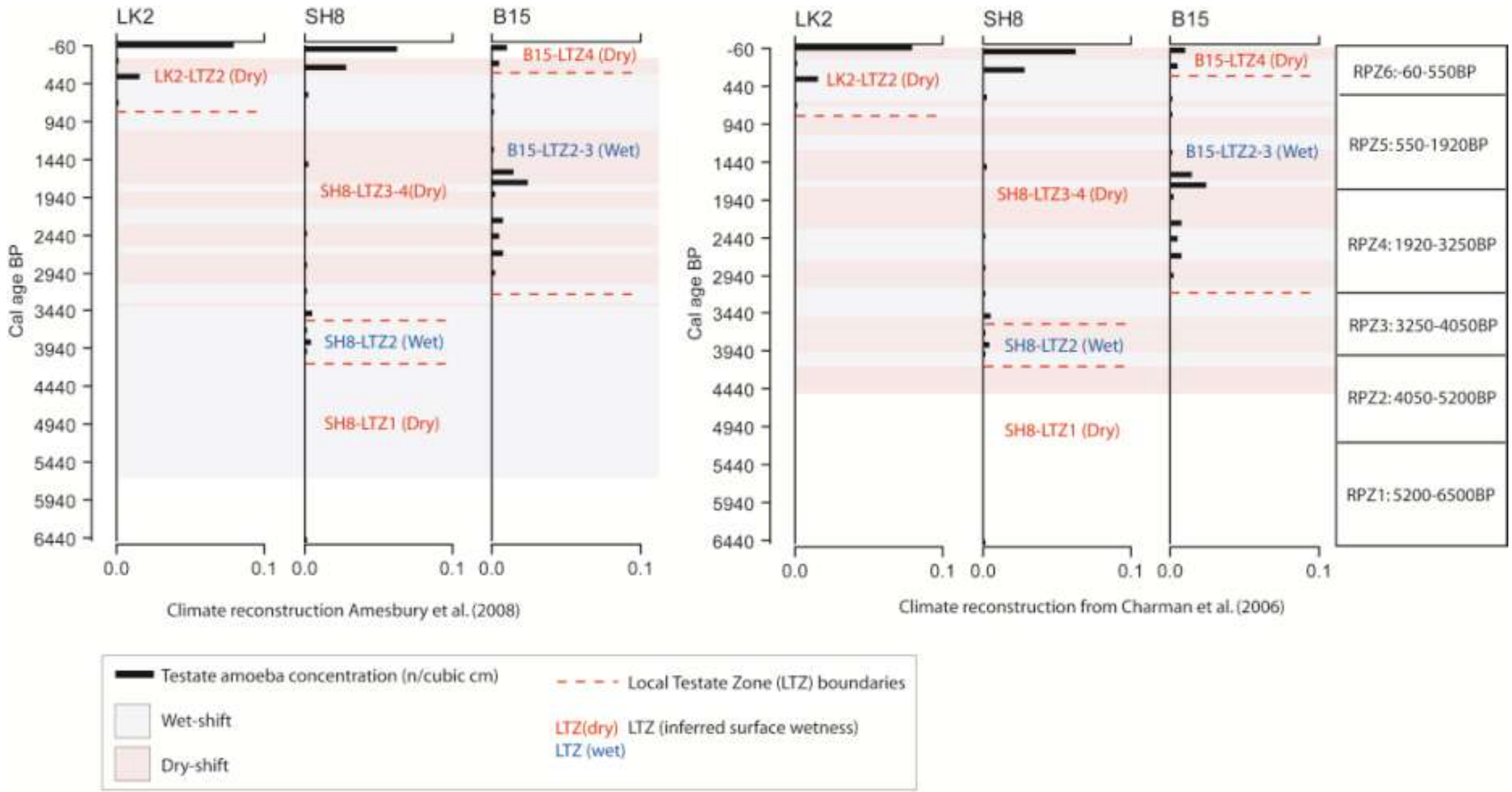


Figure 5.46. Testate amoeba concentration data and Local Testate Zones (LTZ) plotted by cal age BP against climate reconstructions from Charman *et al.* (2006) and Amesbury *et al.* (2008)

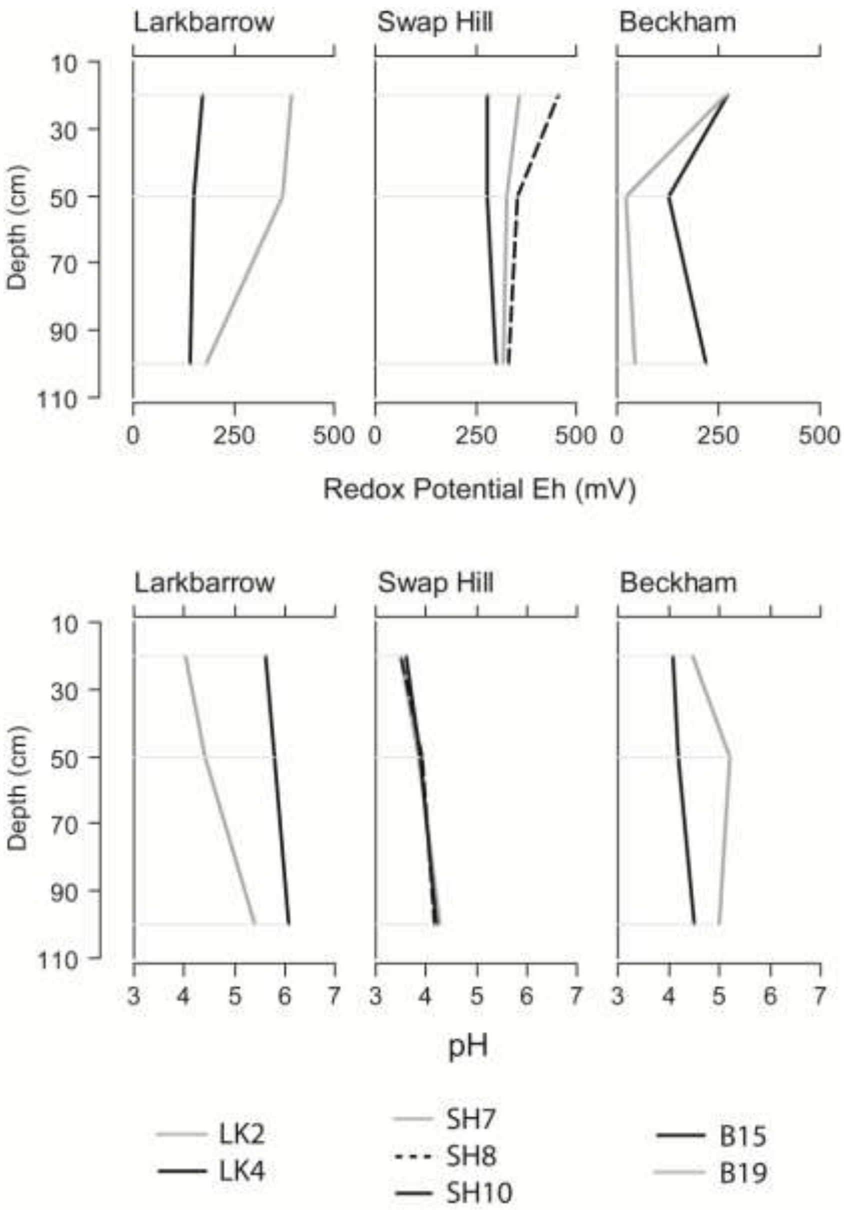


Figure 5.47. Redox (Eh) and pH data recorded in the field from all cores and plotted by mire.

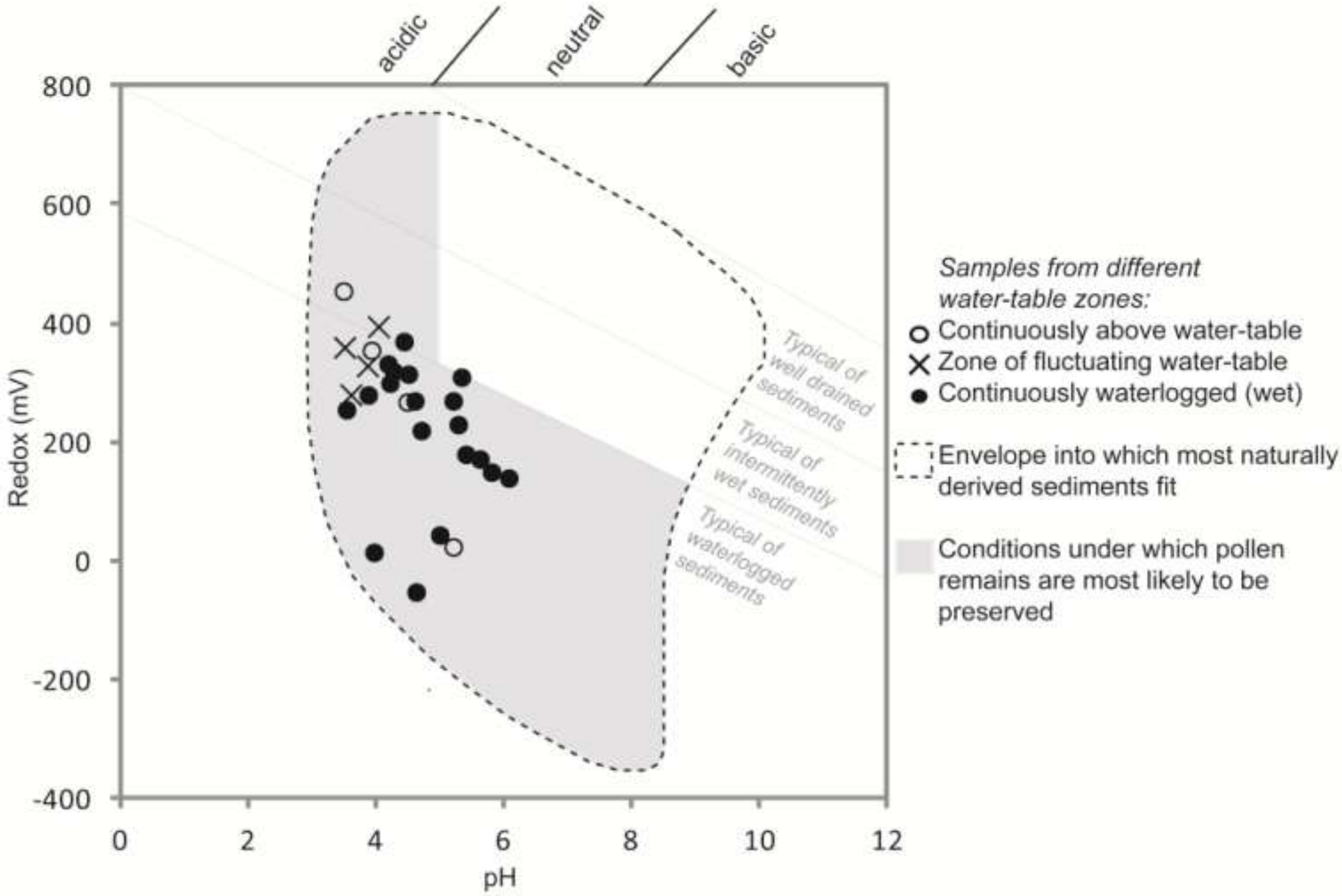


Figure 5.48. Field Eh and pH data (see figure 5.47) plotted against a graph of conditions within natural sediments and the zone of likely pollen preservation. Adapted from Retallack (1984) and Corfield (2007).

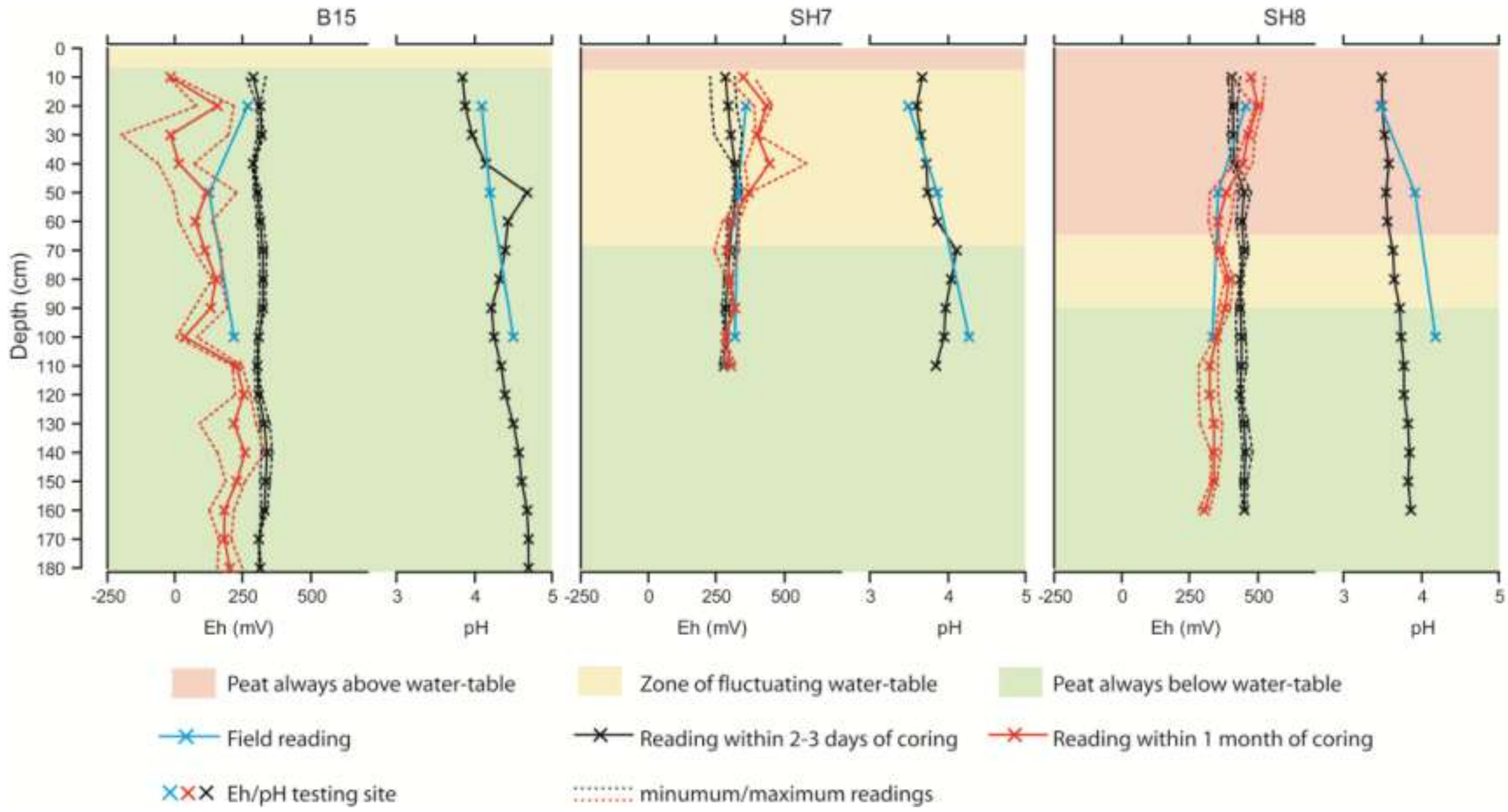


Figure 5.49. Eh and pH readings recorded in the field, and in the lab within 2-3 days and 1 month of core extraction.

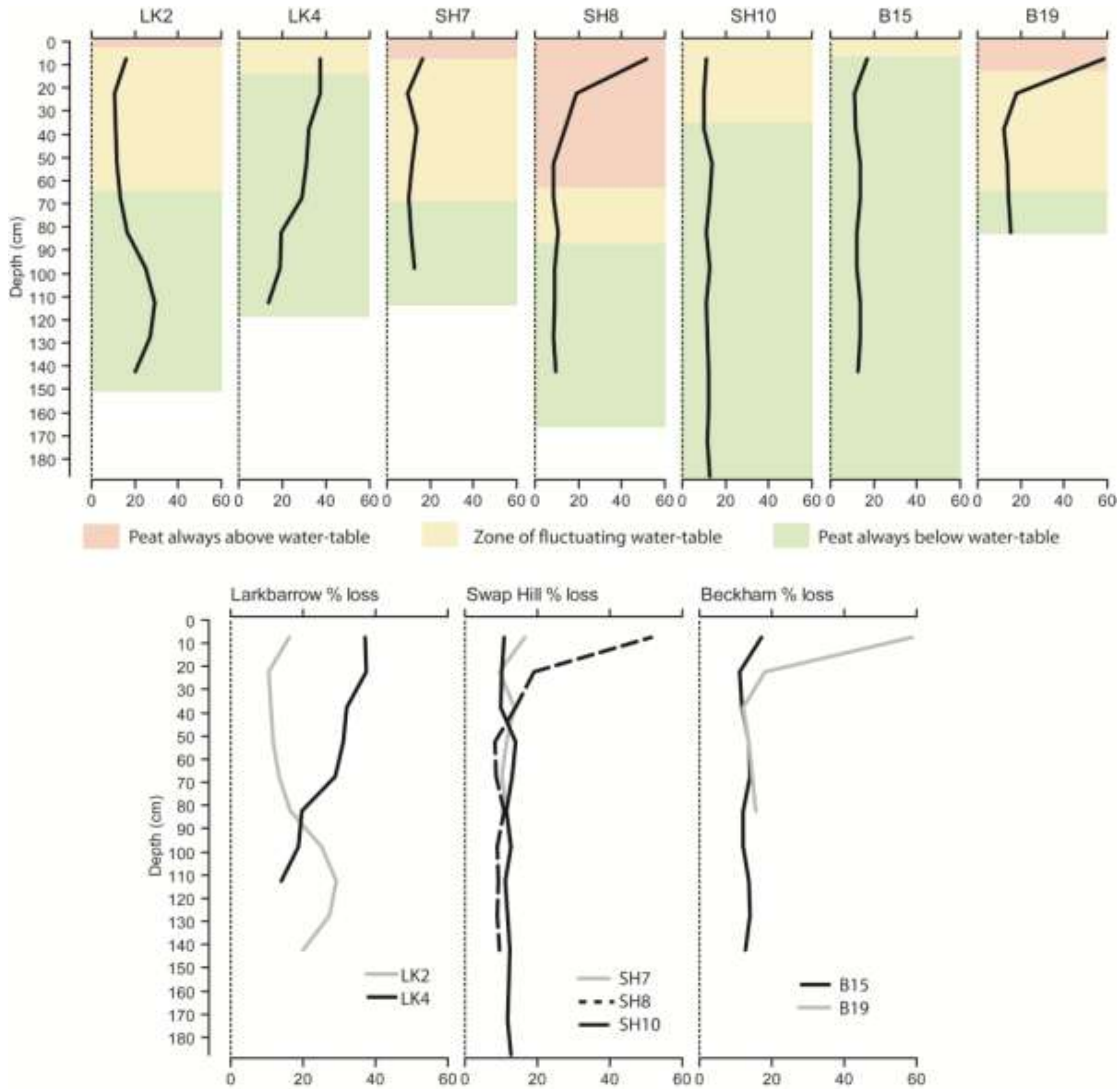


Figure 5.50. Cotton strip percentage weight loss data. *Top:* Plotted against monitored water-table zones. *Bottom:* Plotted by mire.

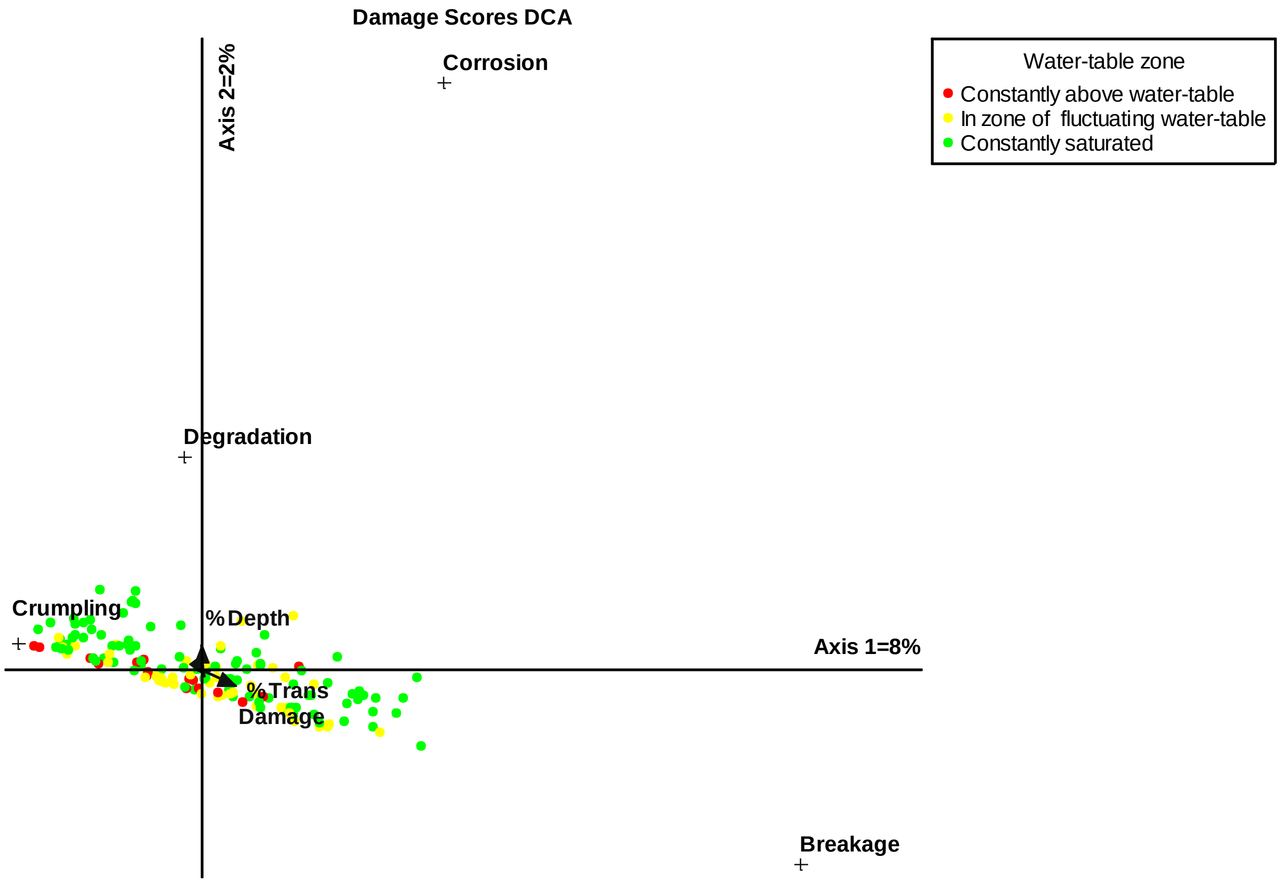


Figure 6.1. DCA scores for all samples (all cores) calculated from TW damage scores

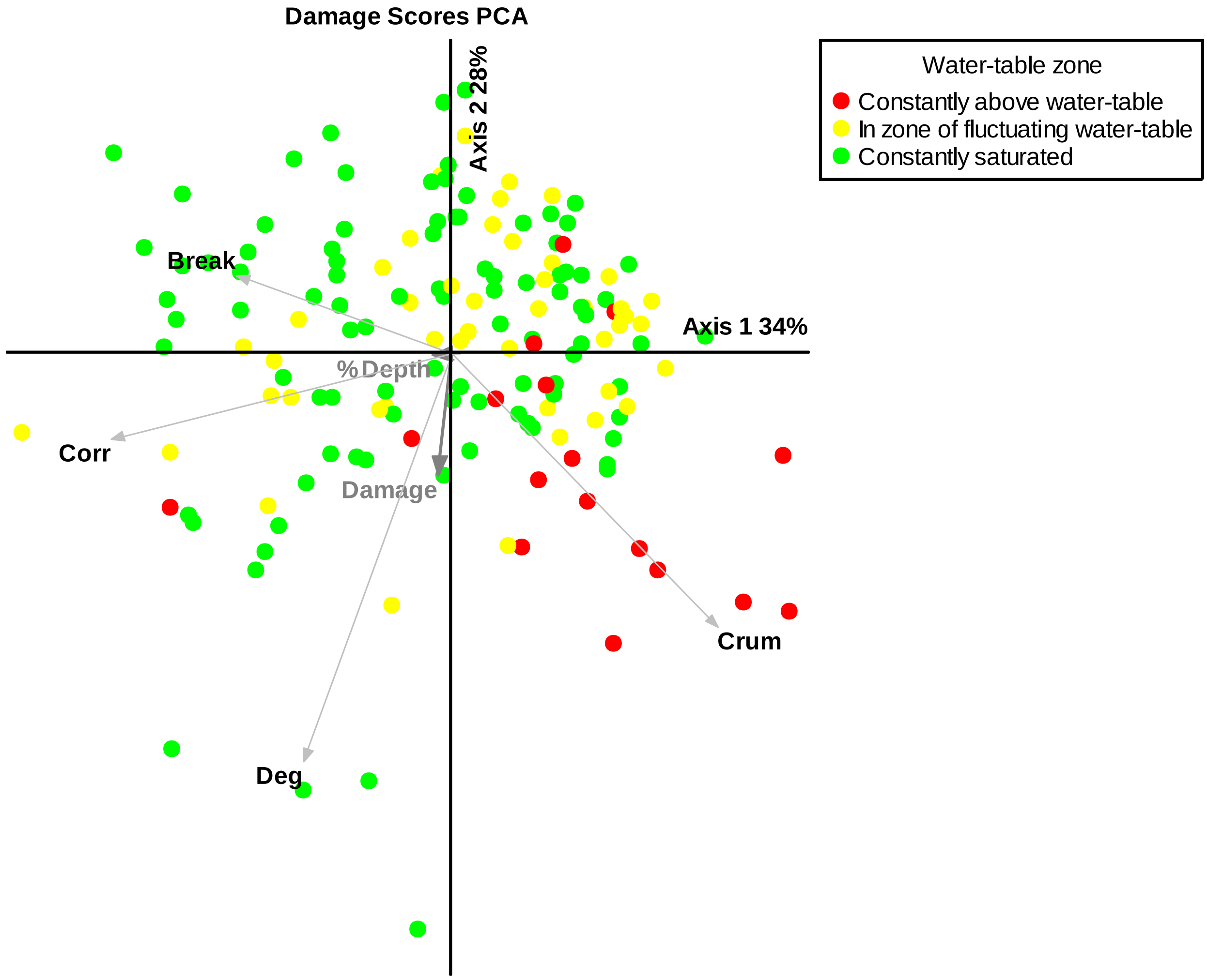


Figure 6.2. PCA scores for all samples (all cores) calculated from TW damage scores and categorised by water-table zone.

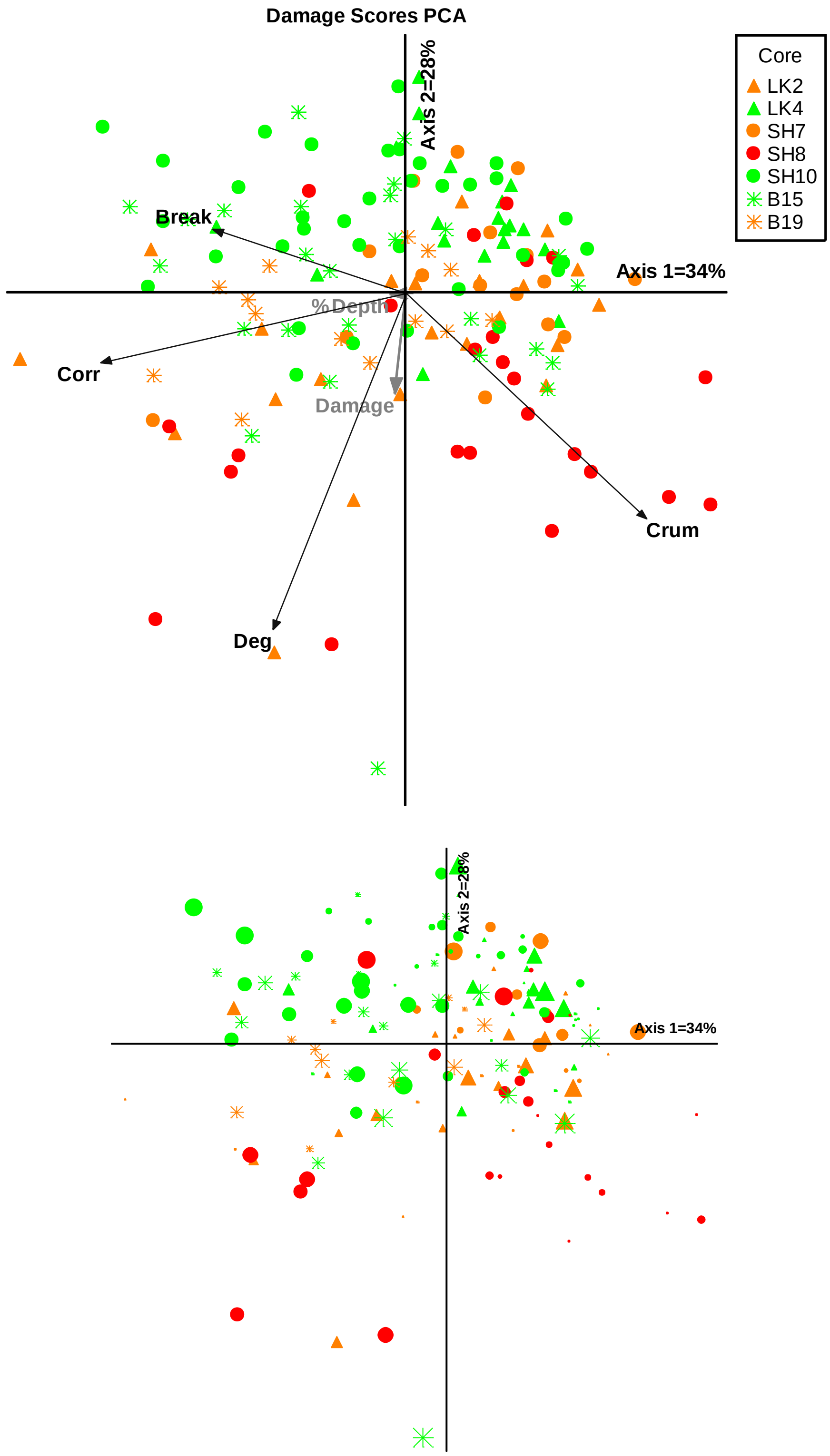


Figure 6.3. PCA scores for all samples (all cores) calculated from damage scores and categorised by core. Cores with constantly high monitored water-table are shown in green, and those with low or fluctuating water-table are shown in red/orange. Bottom: samples scaled by depth (deeper samples are larger).

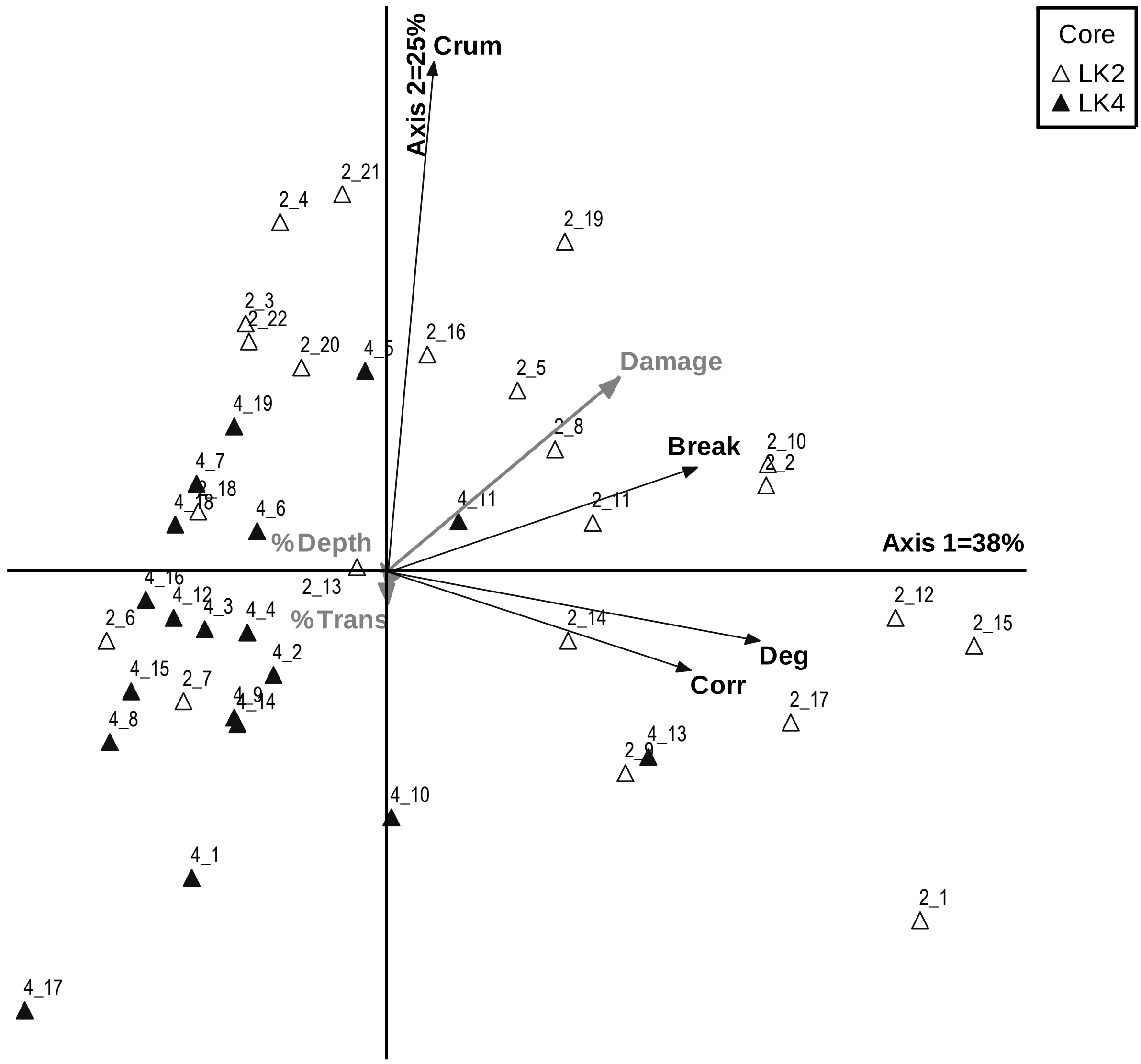


Figure 6.4. PCA scores for all samples from Larkbarrow calculated from damage scores and categorised by core.

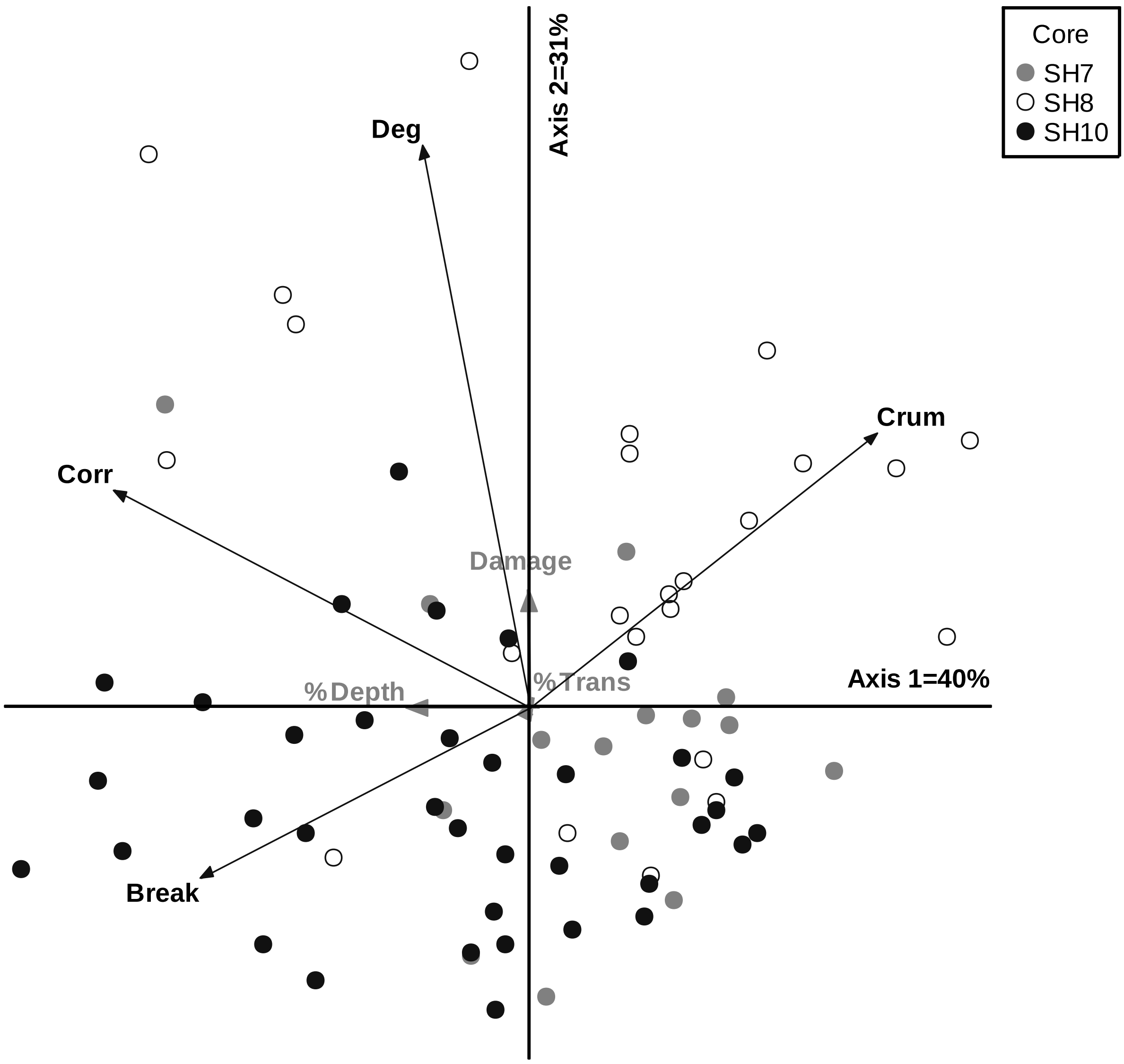


Figure 6.5. PCA scores for all samples from Swap Hill calculated from damage scores and categorised by core.

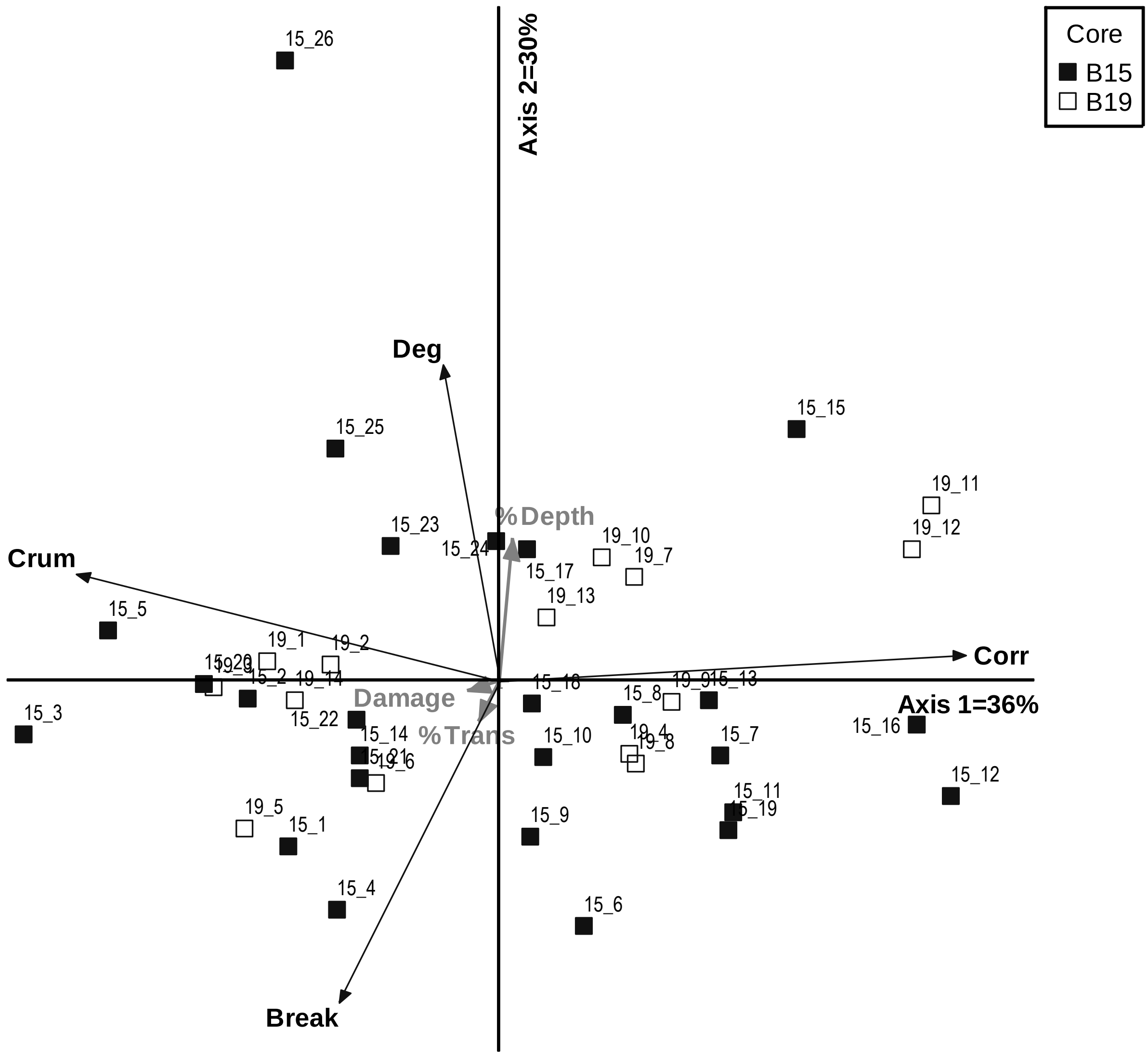


Figure 6.6. PCA scores for all samples from Beckham calculated from damage scores and categorised by core.

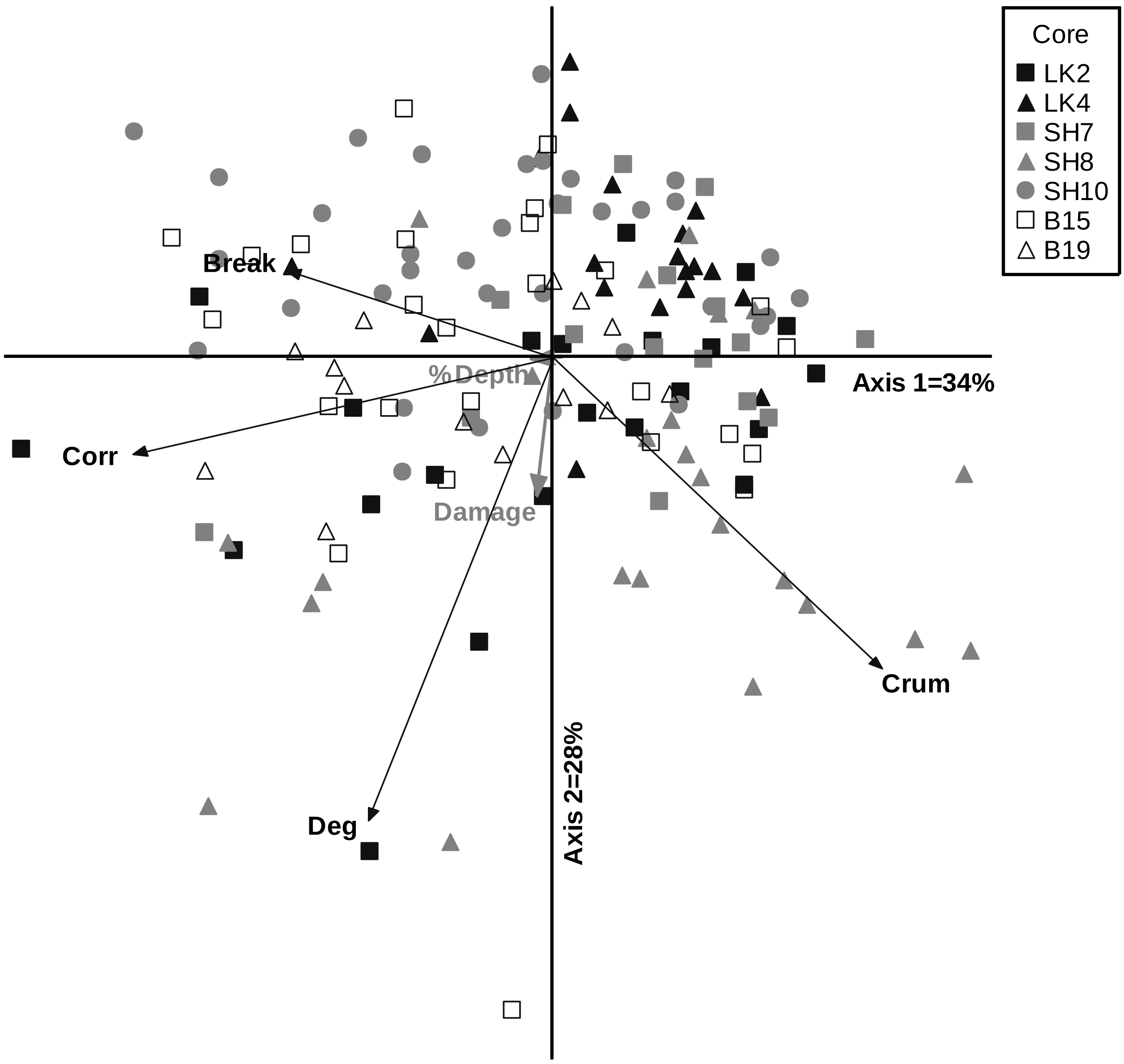


Figure 6.7. PCA scores for all samples (all cores) calculated from damage scores and categorised by mire.

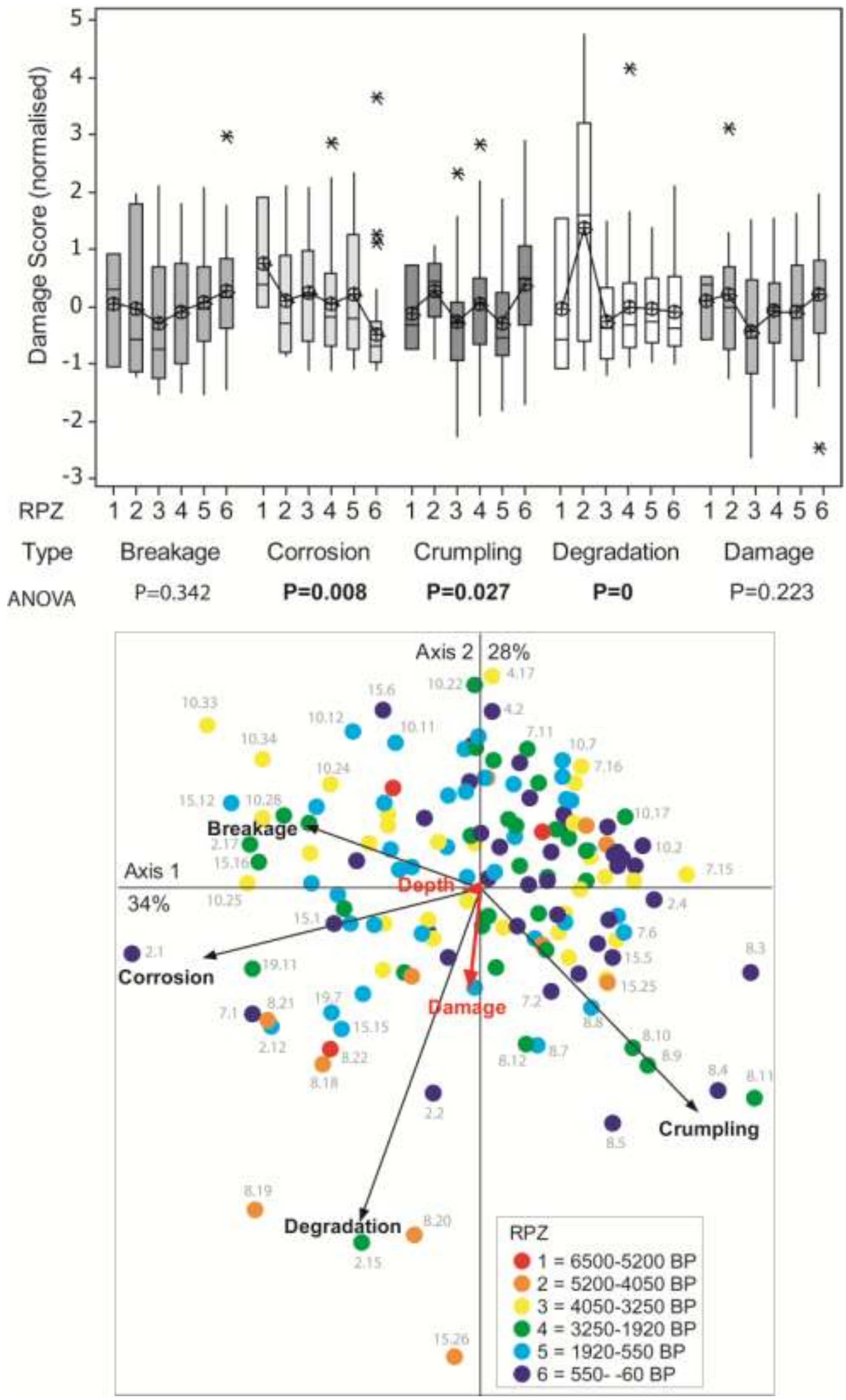


Figure 6.8. *Top:* Covariance of damage scores between Regional Pollen Zones (RPZ). *Bottom:* PCA scores for all samples (all cores) calculated from damage scores and categorised by RPZ. Samples with more extreme PCA scores are labelled with sample numbers.

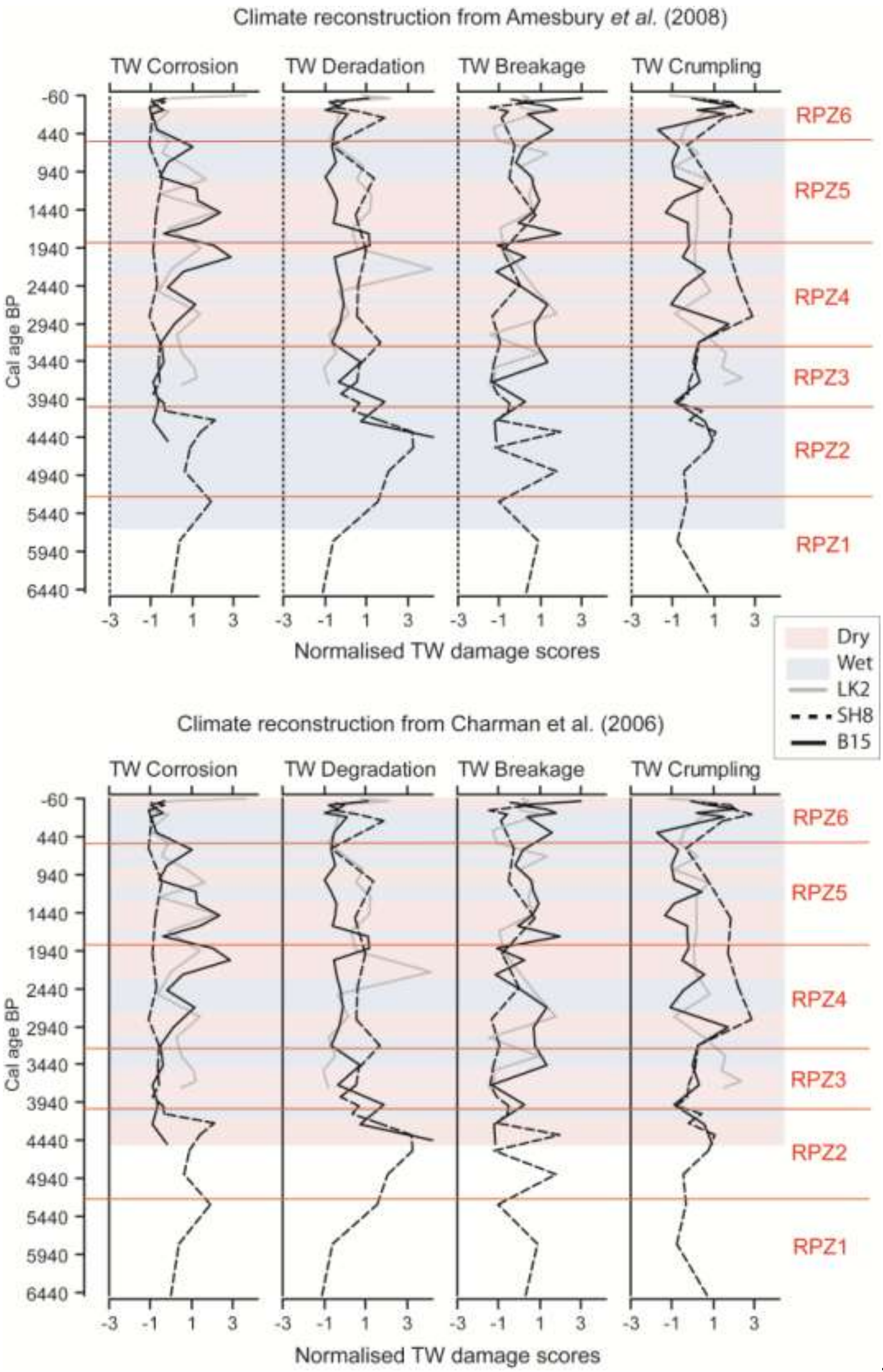


Figure 6.9. Normalised taxon-weighted damage scores plotted with climate reconstructions (Charman *et al.* 2006 and Amesbury *et al.* 2008) and RPZs.

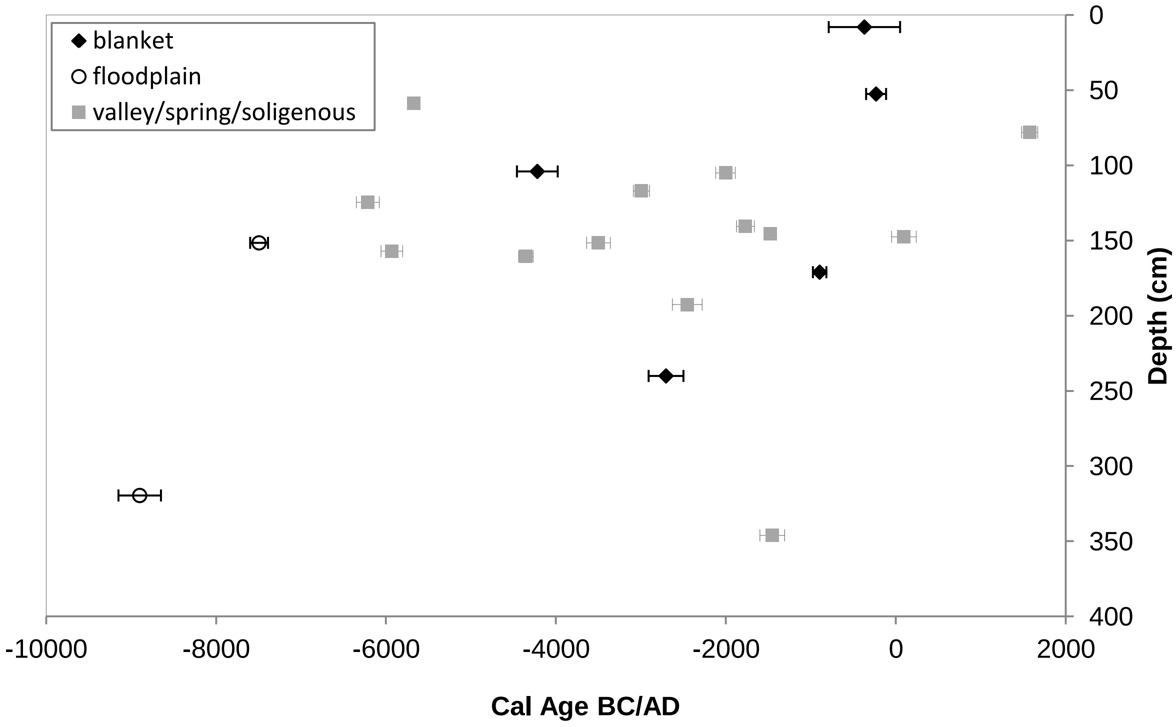


Figure 7.1. Basal radiocarbon dates for peat cores from Exmoor, categorised by mire type.

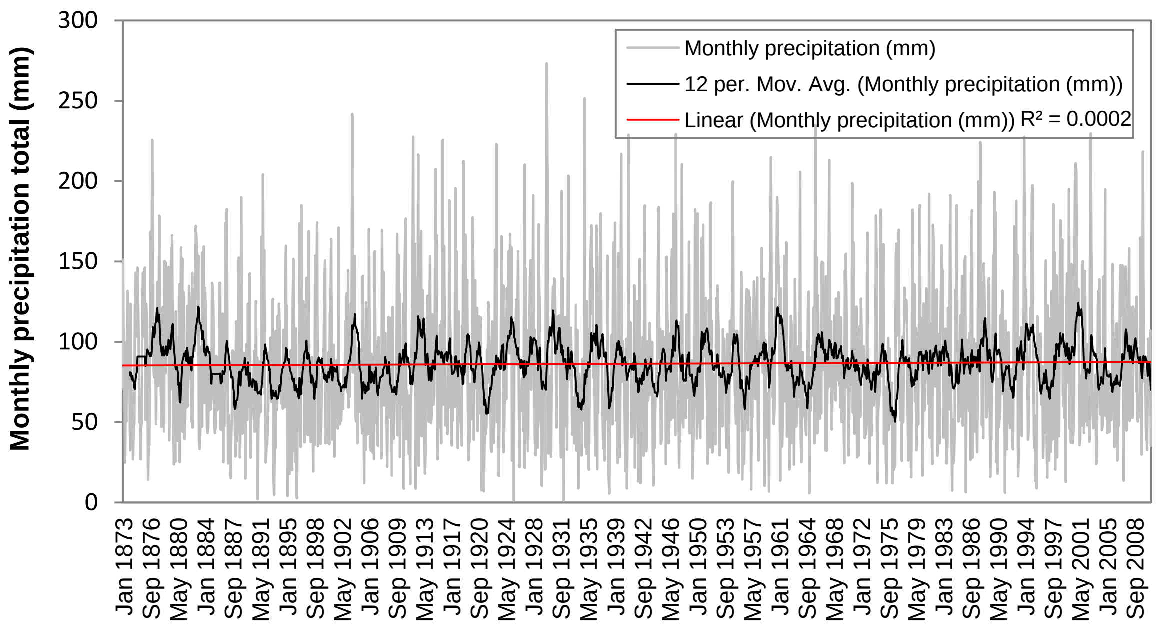


Figure 7.2. Monthly precipitation totals from January 1873 to December 2010 from the Met Office Hadley Centre Observation Dataset for the Southwest England and Wales region. The black line shows a 12-point moving average and the red line is a linear trendline.

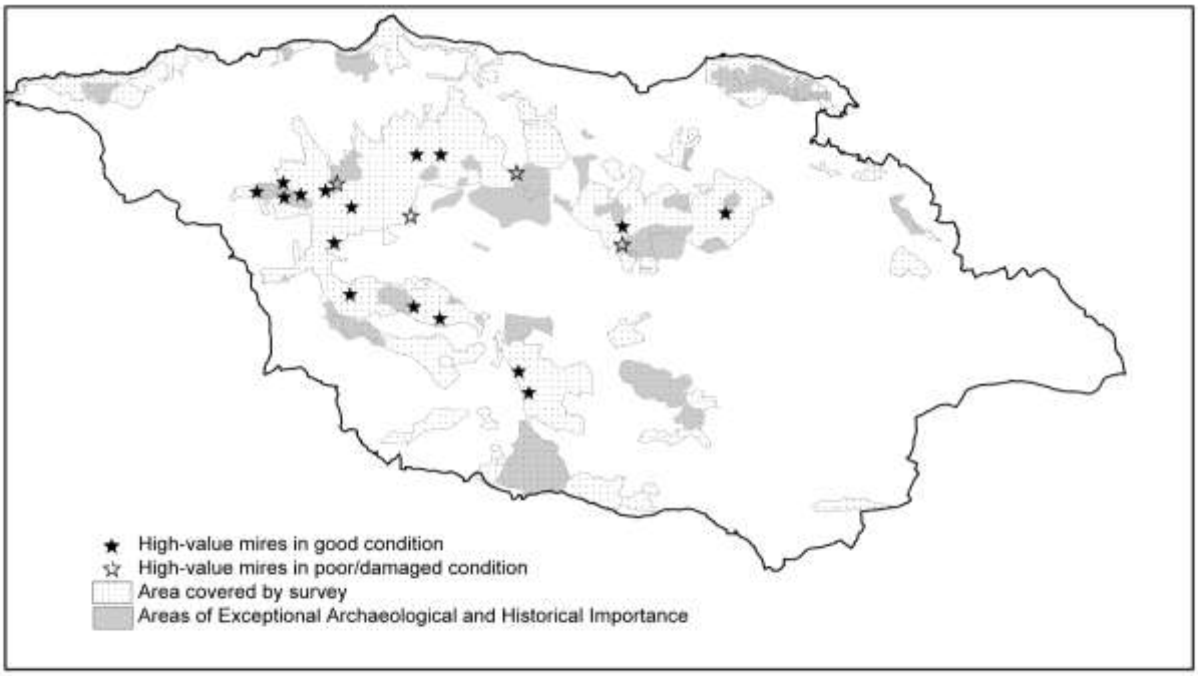


Figure 7.3. Map of Exmoor National Park (see figure 2 for scale) showing: the area covered by the survey; areas designated as exceptionally archaeologically or historically important (AEAHIs: Riley and Wilson-North 2004; Fyfe and Adams 2008); and locations of mires identified as valuable.

APPENDIX 2: TABLES

Type of fossil/remains		Main purpose	Scale of reconstruction
Macrofossils	Plant remains	Local vegetation	On site
	Insects (e.g coleoptera)	Environmental and climatic conditions	Local
	Mammalian remains	Indicators of ecology/human impact	Local/regional, depending on the type of remains
Microfossils	Pollen and spores	Regional/local vegetation	Local/regional, depending on the size of the mire
	Testate amoebae	Surface wetness	On site
	Diatoms	Nutrient status, pH, salinity	On site
	Insect remains (e.g. chironomids)	Summer water temperatures	Local
	Charred particles (charcoal)	Fire histories	Regional
	SCPs	Industrial activity	Regional

Table 2.1 Palaeoenvironmental indicators preserved within peat (Adapted from: Bell and Walker 2005; Charman 2002)

Test	Main purpose	method
Humification	Degree of decay - surface wetness/proxy-climate record	Colourimetry/photospectrometry
Bulk density	Rates of accumulation, estimates of compaction.	Mass loss when sediment is dried
Hydraulic conductivity	Capacity of the peat to allow the passage of water through it	Piezometer head recovery tests (field testing), lab techniques timing water percolation through sediment columns
Visual analyses	Peat stratigraphy	Visual assessment of peat type, colour, texture, humification, inclusions (e.g. Troels-Smith 1955)
pH	Hydrogen ion concentration	pH probe
Redox potential	Electron availability in peat (allows inference of the rate of oxidation and reduction reactions)	Eh probe
Loss on ignition	% organic/calcareous/silicate	Weight after burning at different temperatures
Magnetic susceptibility	Ferromagnetic mineral content, soil horizons (indicating sol formation/pedogenesis)	Bartington magnetic susceptibility meter (Gale and Hoare 1991)
Particle size analysis	Presence/proportion of colluvial/alluvial inwash	Laser particle size analysis
X-ray	Identification of features such as tephra layers	X-rays, tephra identification through light microscopy.

Table 2.2. Testing the physical and chemical properties of peat (Blackford and Chambers 1991; Charman 2002; O'Connor and Evans 2005; Corfield 2007).

Dating method		Main purpose	Material used	Dates encompassed
Radiometric	Radiocarbon (^{14}C)	Organic sediments up to 40,000 years old	Organic remains	40,00 BP to present
	Lead (^{210}Pb)	Recent sediments	Any sediment	1800-present
	Other radionucleotides (^{241}Am, ^{137}Cs, ^{3}H)	Sediments from last 50 years	Any sediment	1950s-present
Time markers	Volcanic ash (tephra)	Markers of volcanic eruptions – chemical components allow the source and date to be identified.	Any sediment	Dependent on study region (date if eruptions and range of volcanic ash clouds)
	Pollen markers	Date known events e.g. Elm decline, pine rise	Acidic conditions	Dependent on date of sediment. e.g UK peat up to approx 10,000 BP
	Fires	May allow correlation between dated and undated sequences	Any sediment	Dependent on date of sediment
	SCPs (spheriodal carbonaceous particles)	Indicates use of heavy industry in Europe	Any sediment	1800s – present (but declining with reduced emissions)
Incremental	Dendrochronology	Can provide *terminus post quem* for peat accumulation using larger timber pieces in peat.	Acidic/ anoxic conditions	Dependent on date of sediment
	Moss growth increments	Counting annual moss growth increments where they are well preserved in peat	Acidic/ anoxic conditions (cold regions)	50-100 years before present in well preserved, accumulating sphagnum peat
Accumulation	Pollen density	Rate of peat accumulation	Acidic conditions	Dependent on date of sediment
	Peat accumulation models	Rate of peat accumulation	Peat	Dependent on date of sediment. e.g UK peat up to approx 10,000 BP

Table 2.3. Methods for dating peat deposits (adapted from Charman 2002).

Mire type	**Morphology/ topography**	**Hydrology**	**Chemistry/ Nutrient status**	**Floristics/ Surface vegetation**
Soligenous mires	Formed on slopes	Associated with moving water, flushes, or springs. (minerotrophic)	Varied base status: fed by surface runoff and groundwater	Small sedge and bryophyte fens NVC: M6;M10;M11 (Rodwell 1991)
Basin mires	Formed in basins or hollows where there is no outflow	No outflow, minimal oscillation of water (ombrotrophic)	Varied base status: fed by rain surface runoff and groundwater	Wide range of communities including small sedge and bryophyte fens, *Molinia* and *Juncus* fens, swap and carr (Rodwell 1991)
Valley mires	Formed in the bottom of valleys, (or at the heads of combes)	Occur along the direction of water flow, usually along the valley axis. (minerotrophic)	Encompass a wide base-status range: fed by surface runoff, groundwater, and streamflow	Wide range of communities including small sedge and bryophyte fens, *Molinia* and *Juncus* fens, swap and carr (Rodwell 1991)
Floodplain mires	Develop on alluvium on floodplains	Develop in areas susceptible to flooding: often follow the sequence of open water, to swamp, to carr (minerotrophic)	Base-rich (alkaline)	Various swamp communities
Raised mires or bogs	Characteristic domed shape. Usually limited in extent, confined by a recognisable boundary (called a rand)	Mire surface isolated from surrounding ground water table, and so entirely rain-fed (ombrotrophic)	Base-poor (acidic), all nutrients derived from atmospheric precipitation.	NVC communities include: M18 *Erica tetralix-Sphagnum papillosum* (Rodwell 1991)
Blanket mires or bogs	Peat covers most of the landscape except steepest slopes. Often form on the watershed between catchments.	Usually develop over impermeable bedrock or podzolised soils. Mainly ombrotrophic.	Base-poor (acidic)	NVC communities include: M17, M19, M20 (Rodwell 1991).

Table 2.4. British upland mire classification (adapted from Rodwell 1991; Blackshall et al. 2001; Charman 2002).

Damage type	Description	Damage to peat
Channel erosion	Erosion of peat due to groundwater flow along drainage ditches or rills	Removal of peat in solution, drying of peat due to water table draw-down
Collapsed sections	Collapsing edges of ditches or peat cuts	Removal of large sections of peat
Peat piping	Erosion of peat along 'pipes' formed by water flowing along cracks in drying peat (Holden and Burt, 2002)	Removal of peat in solution, drying of peat due to water table draw-down
Peat cutting	Historic or modern removal of peat for fuel	Removal of upper layers of peat, drying of peat due to water table draw-down
Trackway erosion	Animal tracks, footpaths or vehicle tracks across mires	Disturbance of the surface of peat matrix. This can lead to rill erosion and removal of peat by groundwater flow
Animal poaching	Animal trampling of mire	As 'trackway erosion'
Drainage ditches	Man-made drainage features which may or may not still show signs of active erosion	Drying of peat due to water table draw-down, and potential peat loss through erosion.

Table 2.5. Threats to mire condition

No.	Name	Relict prehistoric landscapes	Medieval farming systems	Parliamentary enclosure/ reclamation	Military training	Palaeo-environmental
1	Lanacombe	√				
2	Furzehill	√				
3	Chapman and Woodbarrow complex	√				
4	Radworthy		√			
5	Valley of the Rocks	√				
6	Countisbury and Lyn Gorge	√				
7	Shoulsbury	√				
8	Setta Barrow, Five Barrows and Two Barrows	√				√
9	Badgworthy		√			
10	Badgworthy Hill	√				
11	Trout Hill and Pinford	√				√
12	Great Hill and Honeycombe Hill	√				√
13	Porlock Allotment	√				
14	Hawkcombe Head	√				
15	Aldermans Barrow and Madacombe	√				√
16	Codsend and Dunkery	√		√		√
17	Robin and Joaney How	√				
18	Sweetworthy	√	√			
19	Mansley Combe	√	√			
20	Bury Castle	√				
21	Cow Castle	√				
22	Bat’s Castle	√				
23	Brendon Common				√	
24	Blue Gate and Roman Lode			√		
25	Larkbarrow and Tom’s Hill	√		√		√
26	Warren Farm			√		
27	Ley Hill	√	√			
28	Pickedstone		√			
29	Molland Common		√			√
30	Winsford Hill		√			
31	Wheal Eliza			√		
32	North Hill		√			
33	Selworthy WWII ranges				√	
34	Holdstone Down	√		√		
35	Brockwell Pits	√				
36	Kitnor Heath	√				
37	Little Hangman	√				

Table 2.6. Principle components of the archaeology within each Area of Exceptional Archaeological and Historical Importance (AEAHI: Fyfe and Adams 2008). The location of each AEAHI is shown on Figure 2.2.

Period	Date	Key features types	Examples	Issues
Palaeolithic	c. 500,000-10,000 BC	No sites, one findspot	Handaxe fragment	If present, sites likely to be ephemeral and difficult to detect.
Mesolithic	10000-4000 BC	Late Mesolithic flint scatters No Early Mesolithic finds	Hawkcombe Head, Kentisbury Down, Larkbarrow	Mesolithic sites may be hidden under later blanket peat growth (Moore 1993)
Neolithic	4000-2000 BC	standing stones (single/ paired) stone rows stone settings (irregular groups) stone circles Enclosures	The Longstone Honeycombe Hill Lanacombe, Fuzehill Porlock Allotment Badgworthy Hill, Little Hangman 'Tor enclosure'	No long mounds, megalithic tombs, or causewayed enclosures (seen to characterise the Neolithic in Britain No settlement evidence (not uncommon in Britian) Stone settings very small compared to other regions – do they have the same function/purpose? What was the function of Neolithic enclosures? (Can they be dated?)
Bronze Age	2000-700 BC	Round barrows and cairns Ring cairns Burial cairns Field systems Hut circles	Chapman barrows, Five barrows Thorn Hill Barton Down, Culbone Cist Hoar Moor, Codsend Moor, Mansley Combe Holdstone Down, Great Hill	Most of our knowledge from standing monuments (barrows, hut circles, etc.) When did field systems and settlement develop? – dated by analogy to the Middle Bronze Age
Iron Age	700 BC- AD 43	Hillforts Hillslope enclosures	Shoulsbury Castle, Bat's Castle and Gallox Hill Sweetworthy	No obvious 'retreat' from moorlands, as in Dartmoor. Are hillforts a sign of developing hierarchies? (7 hillforts on Exmoor) Were hillslope enclosures (around 50 on Exmoor) all constructed at the same time for the same purpose? Is there any evidence of unenclosed settlement
Roman-British	AD 43-410	Fortlets (Roman lookout posts) Iron mining and processing	Martinhoe, Old Burrow Dulverton, Roman Lode (?), Sherracombe Ford	Roman invasion seems to have had little effect on settlement patterns in Exmoor Exmoor's coastal location and mineral resources was valuable Some finds (coins, lamps) indicate local contact with Roman soldiers/more Romanized regions
Early medieval*	AD 410-1066	Memorial stones	Caractacus, Cavudus, and Culbone Stones	Little archaeological evidence of Saxon/Viking 'invasions' Dispersed settlement patterns-little settlement evidence
Later medieval*	AD 1066-1600	Deserted settlements/fields (DMVs) Castles Monasteries Mineral extraction/processing	Badgworthy, Ley Hill, Grexy Combe Dunster, Hollwell Cleve Abbey Colton pits	Royal Forest extended and 'Forest Law' introduced by Norman Kings. Stock brought to Exmoor for summer grazing (agistment) Dispersed villages and farmsteads – some existing settlements and fields reflect medieval patterns. Remains of DMVs Common in Britain
Post-medieval	AD 1600-1900	Country houses Parliamentary enclosure: farmsteads; sheepfolds; drainage Mineral extraction / processing	Nettlecombe Larkbarrow and Tom's Hill, Lanacombe (sheepfold) Wheal Eliza, Blue Gate	Building and 'improvement' schemes of large estates have had a lasting impact on the landscape. Many of these attempts failed/were unsustainable, but their impact are still clearly visible.
20th century	AD 1900-2000	Military training areas	Brendon Common, Selworthy	Remains of tank training and firing ranges, accommodation, observation posts. Conservation strategies problematic? (only recently seen as worthy of preservation).

Table 2.7. Key archaeological features in Exmoor arranged by period (Grinsall 1970; Riley and Wilson-North 2001)

*Periods defined according to Riley and Wilson-North (2001). *The Early/Later medieval period have been labelled/dated in an unconventional way: owing to the lack of archaeological evidence of archaeological evidence to indicate Saxon/Viking interactions, the period commonly labelled 'Anglo-Saxon' in England, has been called 'Early medieval' and the period usually called medieval, is labelled here as 'Later medieval'*

	Site	Proxy	Site type	Dated	reference
1	Halscombe Allotment	pollen	spring mire	yes	Carter (2002)
2	Hoccombe Combe	pollen	spring mire	no	Wessely (2002)
3	Landacre Bridge	pollen	floodplain mire	no	Badger (2000)
4	Black Hill (Squallacombe)	pollen	blanket peat	no	Albutt (2000)
5	Moles Chamber	pollen,	spring mire	yes	Fyfe (2000)
6	Brightworthy Farm 1	pollen	floodplain mire	yes	Fyfe et al. (2003)
7	Exebridge	pollen	floodplain mire	yes	Fyfe et al. (2003)
8	Gourte Mires	pollen	spring mire	yes	Fyfe et al. (2003a)
9	Anstey's Combe	pollen	spring mire	yes	Fyfe et al. (2003a)
10	Long Breach (Molland)	pollen	spring mire	yes	Fyfe et al. (2003a)
11	Pinkery Canal	pollen	buried soil	no	Crabtree (1995)
12	Porlock Marsh (PM4)	pollen, diatoms	Marsh	yes	Jennings et al (1998)
13	Porlock Forest Bed (FB7)	pollen, diatoms	Marsh	yes	Jennings et al (1998)
14	Porlock Forest Bed (FB4)	pollen, diatoms	Marsh	yes	Jennings et al (1998)
15	Porlock Forest Bed (FB2)	pollen, diatoms	Marsh	yes	Jennings et al (1998)
16	Hoar Moor	pollen	blanket peat	yes	Francis & Slater (1990)
17	Codsend Moor	pollen	blanket peat	yes	Francis & Slater (1992)
18	The Chains	pollen	blanket peat	no	Straker & Crabtree (1995)
19	The Chains	pollen	blanket peat	yes	Merryfield & Moore (1974)
20	Hoar Tor	pollen	blanket peat	no	Merryfield (1977)
21	Alderman's Barrow	pollen	blanket peat	no	Merryfield (1977)
22	Brendon Common	pollen	blanket peat	no	Merryfield (1977)
23	Brightworthy Farm 2	pollen	spring mire	no	Fyfe (2000)
24	Halscombe Allotment	pollen	spring mire	yes	Jennings (1997)
25	Hawkcombe Head	pollen	spring mire	no	Jackson (1997)
26	Hawkcombe Head	pollen	Spring mire	no	Slade (1997)
27	Higher Holworthy	pollen	spring mire	yes	Rippon et al (2006)
28	Twineford Combe Head	pollen	spring mire	yes	Rippon et al (2006)
29	Lanacombe	pollen, macrofossils	blanket peat	yes	Chambers et al (1999)
30	Larkbarrow	pollen, macrofossils	blanket peat	yes	Chambers et al (1999)
31	Roman Lode	pollen, geochemistry	blanket peat	yes	Fyfe (2008)
32	Madacombe	pollen	spring mire	no	Fyfe (2005)
33	Hoscombe	pollen	spring mire	no	Fyfe (2005)
34	Larkbarrow	pollen	spring mire	no	Fyfe (2005)
35	Swap Hill	pollen	spring mire	no	Fyfe (2005)
36	Comerslade	pollen,macrofossils, testate amoebae	spring mire	yes	Fyfe et al (2008)
37	Long Holcombe	pollen, macrofossils, testate amoebae	spring mire	yes	Fyfe et al (2008)
38	North Twitchen Springs	pollen,	spring mire	yes	Fyfe (2003)

Table 2.8. Gazetteer of palaeoenvironmental sites discussed in the text. Numbers correspond to figure 2.3.

Condition category	Deterioration type	Description	Causal processes	Score assigned per grain
1	Well-preserved	No obvious deterioration		0
2	<1/4 corroded			1
3	1/4 -1/2 corroded	Exine pitted, etched or perforated	Biochemical oxidation: fungal/bacterial	2
4	>1/2 corroded			3
5	Partly degraded			1
6	Extensively degraded	Exine thinned, features fused or indeterminate	Chemical oxidation	2
7	Outline only			3
8	Partly broken			1.5
9	Extensively broken	Grain split or fragmented	Physical transport of grain	3
10	Partly crumpled			1.5
11	Extensively crumpled	Grain squashed or folded in more than one plain	Compaction of grain within sediment	3

Table 3.1. Table detailing the condition categories used to classify pollen grains (from Jones *et al.* 2007). See section 2.3.2.2. for further description of condition categories and causal factors.

Treatment	A	B	C	D	E	F	G
Gently heat for 20 minutes							X
Boil for 2 minutes			X			X	
Boil for 5 minutes					X		
Boil for 10 minutes	X	X		X			
5% KoH		X	X				
10% KoH	X						
Sieve (300µm)	X	X	X	X	X	X	X
Micro-sieve (15 µm)	X	X	X	X	X	X	X

Table 3.2. Trialled testate amoeba preparation methodologies (Charman *et al.* 2000; Booth *et al.* 2010)

	Test
1	TLP <300
2	Pollen concentration <3000/cm^3
3	10 taxa or less
4	35% or more of grains degraded or corroded
5	30% or more grain indeterminable
6	6% TLP or more resistant taxa
7	25% or more of TLP+spores is Pteropsida
8	Pteridium/TLP =>0.66
9	spores/TLP = <0.66

Table 3.3. Test criteria for biased/poorly preserved pollen assemblages devised by Bunting and Tipping (2000). Assemblages which meet one or more of these criteria are deemed unreliable (i.e. they fail the reliability test). *N.B. The list of resistant (or robust) taxa used to assess test 6 is also taken from Bunting and Tipping (ibid.).*

	Mire condition	Peat condition	Peat depth	Mire type	Mire area	Elevation
Peat condition	0.06 *Spearman's*					
Peat depth	F=1.76 P=0.083 *ANOVA*	**F=7.64** **P=0.000** ***ANOVA*** (figure 4.17)				
Mire type	0.016 *Spearman's*	-0.021 *Spearman's*	P=0.447 *Kruskal-Wallis* F=0.65 P=0.778 *ANOVA*			
Mire area	P=0.993 *Kruskal-Wallis* F=0.41 P=0.914 *ANOVA*	P=0.483 *Kruskal-Wallis* F=1.05 P=0.402 *ANOVA*	**R=0.376** **P=0.000** ***Pearson's*** (figure 4.9)	**P=0.022** ***Kruskal-Wallis*** F=1.21 P=0.289 *ANOVA* (figure 4.7)		
Elevation	P=0.399 Kruskal-Wallis F=0.97 P=0.465 *ANOVA*	P=0.157 Kruskal-Wallis F=1.41 P=0.21 *ANOVA*	**R=0.105** **P=0.001** ***Pearson's*** (figure 4.10)	**P=0.043** ***Kruskal-Wallis*** ***F=2.01*** ***P=0.034*** ***ANOVA*** (figure 4.7)	R=0.01 P=0.917 *Pearson's*	
Vegetation condition	-0.045 *Spearman's*	-0.19 *Spearman's*	P=0.115 *Kruskal-Wallis* *F=2.89* *P=0.06* *ANOVA*	0.15 *Spearman's*	**P=0.000** ***Kruskal-Wallis*** ***F=34.48*** ***P=0.000*** ***ANOVA*** (figure 4.19)	P=0.48 *Kruskal-Wallis* *F=0.64* *P=0.527* *ANOVA*

Table 4.1. Statistical correlation/covariance between datasets and statistical tests used (reference to the figure in which data is presented as a graph).

Dipwell code	Peat depth (cm)	Water-table minimum (cm)	Water-table maximum (cm)	Water-table level	Amplitude of fluctuation
LK1	63	-30	0	High-fluctuating	Medium
LK2	151	-49	-2	Fluctuating	Large
LK3	181	-29	-2	High-fluctuating	Large-medium
LK4	119	-14	5	High	Small
LK5	123	-27	1	High	Small-medium
LK6	67	-30	3	High	Small-medium
SH7	113	-69	-8	Fluctuating	Large
SH8	166	-88	-62	Low	Small
SH9	141	-87	-34	Low	Medium
SH10	257	-36	3	High	Small
SH11	220	-18	2	High	Small
SH12	113	-57	0	Fluctuating	Large-medium
B13	75	-67	0	Fluctuating	Large
B14	157	-43	0	High-fluctuating	Medium
B15	180	-7	2	High	Small
B16	173	-30	0	High-fluctuating	Small-Medium
B17	153	-43	0	High-fluctuating	Medium
B18	193	-48	0	Fluctuating	Large
B19	85	-65	0	Fluctuating	Large

Table 5.1. The range of water-table fluctuation during the monitoring period for all 19 dipwells.

Core	Local Pollen Zone	Depth (cm)	Major taxa	Description
LK2	LK2-lpaz1	151-118	*Alnus-Betula*	Arboreal taxa dominant. *Alnus* decreases and Poaceae increases through zone.
	LK2-lpaz2	118-30	Poaceae-Cyperaceae	Poaceae dominant. Poaceae and charcoal concentration highest in centre of zone.
	LK2-lpaz3	30-0	*Calluna vulgaris*-Poaceae	*Calluna vulgaris* dominant at start of the zone, falling towards the top. Poaceae decreases at base of the zone and becomes dominant in top 10cm. Charcoal (>50µm) concentration is also high in top 10cm
LK4	LK4-lpaz1	119-84	*Alnus-Betula*	Arboral taxa dominant. *Alnus* and *Betula* decrease towards top of zone and Poaceae increases.
	LK4-lpaz2	84-13	Poaceae-Cyperaceae	Poaceae dominant. Continuous low % of Cyperaceae, *Corylus* and *Quercus.* Charcoal concentration fluctuates
	LK4-lpaz3	13-0	Poaceae	Poaceae dominant throughout zone. High charcoal (>50µm) concentration.
SH7	SH7-lpaz1	113-78	*Alnus-Betula-Salix*	Arboreal taxa dominant. *Alnus* increases and then decreases though zone. Peak in *Salix* at centre of zone. Poaceae begins to increase at top of zone.
	SH7-lpaz2	78-38	Poaceae-*Calluna vulgaris-Corylus*	Poaceae and *Calluna vulgaris* fluctuate throughout zone. Cyperaceae increases towards the top of zone.
	SH7-lpaz3	38-5	Poaceae-*Calluna vulgaris*	Poaceae dominant. *Calluna vulgaris* and charcoal concentration increase towards top of zone.
	SH7-lpaz4	5-0	Poaceae	Poaceae dominant. High charcoal concentration.
SH8	SH8-lpaz1	166-134	*Betula-Corylus-Quercus*	Arboreal taxa dominant. *Betula, Quercus* and *Corylus* are at high levels throughout this period. Salix increases at the very top of the zone. *Pteropsida* levels are also high.
	SH8-lpaz2	134-110	*Betula-Corylus-Quercus*-Cyperaceae	*Betula, Quercus* and *Corylus* levels remain fairly high, with constant at around 10%. Cyperacece increases towards the top of the zone. *Pteropsida* levels remain high.
	SH8-lpaz3	110-78	*Alnus-Betula-*Poaceae-*Corylus*	Alnus increases and Poaceae high thoughout zone. *Betula* decreases. *Quercus* and *Corylus* stable at around 10% each. Sharp drop in *Pteropsida* at start of zone. Increase in *Calluna vulgaris* at top of zone.
	SH8-lpaz4	78-38	Poaceae-*Calluna vulgaris-Alnus-Corylus*	Poaceae and *Calluna vulgaris* dominant and fluctuating : *Calluna vulgaris* peaks near the base of the zone and Poaceae near the top. *Alnus* levels decrease. Charcoal concentrion increases markedly.
	SH8-lpaz5	30-14	Poaceae	Poaceae dominant at 40-50%. *Calluna vulgaris* decreases. Very low levels of arboreal taxa. Charcoal concentration fluctuates.
	SH8-lpaz6	14-0	Poaceae-*Calluna vulgaris*	Poaceae and *Calluna vulgaris* dominant and fluctuating thoughout zone: *Calluna vulgaris* peaks and then falls; Poaceae peaks toward the surface. Charcoal concentration fluctuates.
SH10	SH10-lpaz1	257-135	Poaceae-Cyperaceae	Poaceae dominant but fluctuating. Cyperaceae increases towards top of zone. Charcoal concentration fluctuating. Sphagnum peaks near base.
	SH10-lpaz2	135-15	Poaceae	Poaceae dominant. Cyperaceae decreases. Reduced levels of arboreal taxa. Levels of *Potentilla* elevated (10-20%) but decreasing at top of zone. Charcoal concentration higher but highly fluctuating. Sphagnum peaks near the top, but fluctuates throughout zone.
	SH10-lpaz3	15-0	Poaceae-*Calluna vulgaris*	Poaceae and *Calluna vulgaris* dominant: *Calluna vulgaris* peaks towards the base of the zone, Poaceae towards the top. Lower Sphagnum levels.
B15	B15-lpaz1	178-133	*Alnus-Betula-Corylus-Quercus*	Arboreal taxa dominant. *Alnus*, *Betula* and *Corylus* decrease towards top of zone, and Poaceae increases.
	B15-lpaz2	133-94	*Alnus-Poaceae*	*Alnus* peaks in centre of the zone, Poaceae high, but lower in centre of zone. Cyperaceae and charcoal concentration increases at top of zone.
	B15-lpaz3	94-30	Poaceae-Cyperaceae	Cyperaceae and Poaceae dominant and fluctuating throughout zone. Arboral taxa very low. *Filipendula* peaks towards base of zone (10%) and gradually decreases. Sphagnum increases at top of zone. Peaks in charcoal concentration, but fluctuating.
	B15-lpaz4	30-0	Poaceae	Poaceae dominant. Increase in *Calluna vulgaris* at centre of zone. Cyperaceae stable throughout zone. Sphagnum decreases. Charcoal concentration high at base and near surface.
B19	B19-lpaz1	85-45	Poaceae-Cyperaceae-*Calluna vulgaris*	Poaceae dominant. *Calluna vulgaris* decreases throughout zone, and Cyperaceae increases. Constant levels of *Corylus* and *Quercus* (5-10%). Peak in charcoal concentration towards centre of the zone.
	B19-lpaz2	45-22	Poaceae-Cyperaceae	Poaceae dominant, Cyperaceae decreases through the zone.
	B19-lpaz3	22-0	Poaceae	Poaceae dominant. Peak in some herbaceous taxa near base of zone (*Galium, Plantago lanceolata*). Slight increase in *Calluna vulgaris*.

Table 5.2. Local pollen assemblage zones (lpaz)

Core	Depth	Humicity	*Nigor*	*Siccitas*	*Elasticitas*	Stratification	Inclusions	Peat type
LK2	0-15	3.5	3	2	1	1		sedge/SH
	15-33	2	2	2	1	0		sedge
	33-73	3	3	1	1	0		Sedge/SH
	73-88	2	2	1	1	0		sedge
	88-110	3	3	1	1	0		sedge
	110-116	3	4	1	1	0		sedge
	116-132	3	3	1	1	0		sedge
	132-145	2	3	2	2	2		sedge/wood
	145-151	4	2	1	0	2	sand	SH
LK4	0-13	3.5	4	2	1	1		sedge/SH
	13-30	2	3	1	1	0		sedge
	30-47	3	3.5	1	1	0		sedge
	47-86.5	3	3.5	1	1	0		sedge/SH
	86.5-88	3	2	1	1	2		sedge/SH
	88-96	3	3.5	1	1	0		sedge/SH
	96-106	2	3	1	1	0		Sedge
	106-119	3	3.5	1	1	0		sedge/SH
SH7	0-21	4	3	3	1	0	roots 30%	SH
	21-70	3	3	2	2	0		sedge
	70-106	3	3	2.5	2	0		sedge/wood
	106-113	4	4	2.5	1	0		SH
SH8	0-30	4	4	2.5	1	0		SH
	30-90	3.5	4	1	1.5	0		sedge
	90-166	2.5	3.5	1.5	1.5	0	wood 1-2cm	sedge/wood
SH10	0-3	4	4	2	1	1		sedge
	3-20	1	2	1	2	0		Sedge/sphag.
	20-55	0-1	3	1	3	1		sedge
	55-125	2	4	1	2	0		sedge
	125-190	0-1	2-3	1	3	0		sedge
	190-257	2	3	1	1	0		sedge
B15	0-5	3.5	3.5	3	1	0	roots 20%	SH
	5-31	2	2.5	2	3	0		sedge/sphag.
	31-53	2.5	3	3	3	0		sedge
	53-70	2	2.5	3	3	0		sedge
	70-80	1	2.5	3	4	0		sedge
	80-92	2.5	3	3	3	0		sedge
	92-130	1	3	3	4	0		sedge
	130-149	2.5	3	3	3	0		sedge
	149-168	3	3.5	3	2	0	sand/gravel	sedge
	168-178	2.5	3	3	2	0		wood
	178-180							sandy silt
B19	0-15	4	4	3.5	0	0		SH
	15-30	3.5	4	3	1	0		sedge/SH
	30-39	2.5	4	2	2	0		sedge
	39-78	1	3	3	3	0		sedge
	78-85	2.5	4	2	5	0		sedge

Table 5.3. Core lithologies

Site	Code	Depth (cm)	Uncalibrated ^{14}C age BP	Calibrated age range BP	Calibrated age range BC/AD
LK2	LK2.1	**35-36**	810±22	**763-682**	**1187-1268 AD**
LK2	LK2.2	**80-81**	1932±23	**1927-1825**	**23-125 AD**
LK2	LK2.3	**120-121**	3039±30	**3351-3162**	**1401-1212 BC**
LK2	LK2.4	**140-141**	3432±25	**3824-3616**	**1874-1666 BC**
SH8	SH8.1	**40-41**	1924±23	**1924-1822**	**26-128 AD**
SH8	SH8.2	**80-81**	3411±24	**3716-3584**	**1766-1634 BC**
SH8	SH8.3	**120-121**	3877±25	**4413-4237**	**2463-2287 BC**
SH8	SH8.4	**160-161**	5496±23	**6387-6218**	**4437-4268 BC**
B15	BK15.1	**25-26**	621±18	**656-555**	**1294-1395 AD**
B15	BK15.2	**65-66**	1563±25	**1523-1398**	**427-552 AD**
B15	BK15.3	**105-106**	2223±20	**2328-2154**	**378-204 BC**
B15	BK15.4	**145-146**	3211±23	**3466-3382**	**1516-1432 BC**

Table 5.4. Radiocarbon dated samples

Regional Pollen Zone	Age BP *(BC/AD)*	Cores present	Major Taxa	Description
RPZ1	5200-6500 BP *(3250-4550 BC)*	SH8	*Betula-Corylus*	Arboreal taxa dominant: high *Betula* and *Corylus*
RPZ2	4050-5200 BP *(2100-3250 BC)*	LK4, SH7, SH8, B15	*Betula-Corylus-Alnus*	Arboreal taxa dominant: high *Betula* and *Corylus;* increasing *Alnus* and Cyperaceae.
RPZ3	3250-4050 BP (1300-2100 BC)	LK2, LK4, SH7, SH8, SH10, B15	*Betula-Corylus-Alnus*-Poaceae	Arboral taxa dominant: Increasing *Alnus*. Poaceae increasing towards top of zone.
RPZ4	1920-3250 BP *(AD30-1300 BC)*	All cores	Poaceae	Poaceae dominant. Cyperaceae increasing towards top of zone. Marked increase in charcoal concentration.
RPZ5	550-1920 BP *(AD 1400-30)*	All cores	Poaceae-Cyperaceae	Poaceae dominant. Increased but fluctuating Cyperaceae. Increase in herabeous taxa such as *Potentilla* and *Plantage Lanceolata*. High charcoal concentration.
RPZ6	-60-550 BP *(AD 2010-1400)*	All cores	*Calluna vulgaris*-Poaceae-Cyperaceae.	Increase in Calluna vulgaris towards centre of zone. Decrease then increase in Poaceae towards surface. Low charcoal at the beginning of zone, increasing near the surface.

Table 5.5. Regional Pollen Zones (RPZs).

Core	Local Pollen Preservation Zone (LPPZ)	Depth (cm)	Description of zone
LK2	LK2-LPPZ1	151-110	High crumpling and corrosion at base. Increased breakage towards top of zone. Low % transmission (high humification). Rapid increase in LOI, but decrease at top of zone.
	LK2-LPPZ2	110-70	Peak in breakahe and crumpling near base of zone. Peak in degradation in centre of zone. Peak in roust grains and pollen concentration at the top of zone. % transmission highest (humification lowest) in centre of zone. LOI high and stable.
	LK2-LPPZ3	70-30	Highest corrosion score, but damage scores in general fairly high and stable fall in robust grains and pollen concentration. Some fluctuation in humification, but % organic high and stable through zone.
	LK2-LPPZ4	30-0	Damage scores high and fluctuating: beakage and crumpling scores peak near centre of zone, and corrosion and degradation scores peak near the surface. % transmission peaks at the top of the core (humification lowest). Testate concentration also high at the top of the core.
LK4	LK4-LPPZ1	119-68	Crumpling scores high with a sharp drop between 90 and 110. Corrosion, degradation, and breakage score increase towards the top of the zone with a marked peak in breakage score. Low and fluctuating % organic through.Humification is fairly low throughout the zone (high % transmission), increasing at the top of the zone. Peaks in robust grains and pollen concentration near the top of the zone.
	LK4-LPPZ2	68-20	Corrosion and crumpling score peak towards the centre of the zone. Damage score fairly stable. Loos on ignition increases through the zone. Humification increases through the zone, and then decreases rapidly towards the top of the zone. High % of robust grains in the centre of the zone.
	LK4-LPPZ3	20-0	Crumpling and breakage scores high at the base of the zone and decreasing towards the top. Corrosion and degradation scores increase slightly towards the top of the core. Pollen concentration peaks towards centre of the zone. Humification lowest at the top of core (% transmission high). Testate concentration high near the surface.
SH7	SH7-LPPZ1	113-62	Breakage score peak at the base of the zone. Crumpling score high and fluctuating. % transmission increases (humification decreases through the zone).
	SH7-LPPZ2	62-38	Breakage scores peak in this zone and degradation increases throughout zone. LOI and % transmission dips between the centre and top of zone.
	SH7-LPPZ3	38-0	Crumpling scores increase until 8cm from the top of the core and then decrease. Corrosio, degradation, and to a lesser extent breakage score, increase rapidly at the top of the zone. % tansmission higher (humification lowe) towards the surface of the core.
SH8	SH8-LPPZ1	166-118	All damage scores peak at the top of the zone. % transmission increases (humification decreases) throughout the zone. Percentage of robust grains very and % organics high and decreases rapidly at the top of zone, before increasing again.
	SH8-LPPZ2	118-62	All types of damage decrease , and humifcation increases throughout the zone.
	SH8-LPPZ3	62-0	Crumpling scores are high at the base and near the top of the zone. Breakage, degradation, and corrosion peak near the surface (corrosion peaks nearer the surface then crumpling). % transmission is also very high (humification very low) near the surface. Testate concentration highest near the surface.
SH10	SH10-LPPZ1	257-161	Damage scores fluctuating thoughout zone. Overall damage fairly stable. % transmission increases (humification decreases) towards the top if the zone.
	SH10-LPPZ2	151-63	Damage scores fairly stable, but breakage and crumpling scores drop rapidly at the top if the zone. % organic stable, but % transmission fluctuating. % robust grains peaks at the top of the zone.
	SH10-LPPZ3	63-47	Breakage scores peak in the centre of the zone, and pollen concentration increases through zone.
	SH10-LPPZ4	47-0	Breakage and crumpling score peak around 10cm from the top of the core. Degradation scores peak at the top of the core. Pollen concentration peaks at the base of the zone. LOI and humification decreases (% transmission increases) towards the top of the core .
B15	B15-LPPZ1	178-150	Degradation score high at the base of the zone and decreases throughout the zone. % organic and % transmission increases (humification decreases) through zone.
	B15-LPPZ2	150-86	Damage scores fairly stable throughout the zone, with increase in breakage, corrosion, and degradation scores at the top of the zone. % organic dips near the centre of the zone. Pollen concentration increases rapidly at the top of the zone.
	B15-LPPZ3	86-14	Damage scores fairly stable throughout the zone. Pollen concentration and testate concentration peak near the base of the zone.
	B15-LPPZ4	14-0	Crumpling scores peak a 6cm from top of the core. Degradation and breakage scores peak at the top of the zone. % organics and humification decrease (% transmission increases) through the zone.
B19	B19-LPPZ1	85-46	Degradation, crumpling and breakage scores decrease and then increase through the zone. Corrosion scores peak in the centre of the zone. % transmission decreases (humification increases) through the zone. Pollen concentration peaks in the centre of the zone and % robust grains towards the top.
	B19-LPPZ2	46-22	All damage scores increase slightly through the zone. % tansmission is lowest (humification is highest) in the centre of the zone.
	B19-LPPZ3	22-0	Dmage scores fluctuate thoughout the zone. Breakage, crumpling and corrosion scores peak between 8 and 10cm from the peat surface, while degradation scores increasetowards the peat surface. % organic decreases lightly throughout the zone, and % transmission increases (humification decreases).

Table 5.6. Local Pollen Preservation Zones (LPPZ) for each core.

Testate taxon	Code	Environment/Niche v.wet	wet	intermediate	dry	unknown
Amphitrema flavum	AmpF	X	X			
Arcella catinus	ArcC		X			
Arcella discoides	ArcD	X				
Assulina muscorum	AssM			X	X	
Centropyxis aculeata	CenA	X				
Centropyxis cassis	CenC	X	X			
Centropyxis platysoma	CenP	X	X			
Corithion-Trinema	CorT			X	X	
Cyclopyxis arcelloides	CycA		X	X	X	
Difflugia lanceolata	DifL	X				
Difflugia oblonga	DifO			X		
Euglypha rotunda	EugR			X		
Euglypha tuberculata	EugT			X		
Heleopera rosea	HelR				X	
Heleopera sphagni	HelS		X	X		
Hyalosphenia ovalis	HylO		X			
Hyalosphenia subflava	HylS				X	
Nebela flebellum	NebF			X		
Nebela militaris	NebM				X	
Nebela parvula/tincta	NebP					X
Nebela type	Neb			X		
Pseudodifflugia fascicularis	PsdFa		X	X		
Pseudodifflugia fulva	PsdFu					X
Sphenoderia fissirostris	SPhF					X
Trigonopyxis acula	TriA				X	

Table 5.7. Testate amoeba taxa with codes (used in DCA plots) and the environmental range of each taxon (following Charman *et al.* 2000)

Core	Local Testate Zone	Depth (cm)	Major taxa *(see codes above)*	Description
LK2	LK2-LTZ1	151-36		No testates
	LK2-LTZ2	36-0	CycA, NebM	High testate concentration. NebM suggests a dry environment
LK4	LK4-LTZ1	119-100		No testates
	LK4-LTZ2	100-58	CorT, CenC, CycA	Fairly high testate concentration. Testates from a mix of environments from dry (CorT) to wet (CenC).
	LK4-LTZ3	58-12	CorT, CenC	Sample at 40cm with fairly high concentration, low concentration in other samples. Testates from a mix of environments from dry (CorT) to wet (CenC).
	LK4-LTZ4	12-0	CycA, PsdFu, NebP	High testate concentration. Taxa present represent a mix of environmental niches, or niches are unknown
SH7	SH7-LTZ1	113-12	HylS, Neb	Only 2 samples with testates (at 58 and 106cm). Taxa indicate dry to intermediate environment during peat formation.
	SH7-LTZ2	12-0	CycA, PsdFu	High testate concentration. Taxa indicate an intermediate environment.
SH8	SH8-LTZ1	166-102	TriA	Only lowest sample has testates. Taxon indicates dry environment.
	SH8-LTZ2	102-78	AmpF	Low testate concentration. Taxon present indicates wet environment
	SH8-LTZ3	78-12	HylS	Low testate concentration. Taxon present indicates a dry environment
	SH8-LTZ4	12-0	CycA,HylS,PsdFu	High testate concentration. Taxa indicte a dry to intermediate environment.
SH10	SH10-LTZ1	257-90	PsdFu, AmpF, CycA, ArcD, DifL	Low-medium testate concentration. High species diversity (in comparison to other samples). Species assemblage indicates a wet to very wet environment.
	SH10-LTZ2	90-7	AssM, CenC, CycA	Low testate concentration. Taxa present are from a range of environmental niches from wet (CenC) to intermediate-dry (AssM).
	SH10-LTZ3	7-0	CycA, NebM, PsdFu	High testate concentration. Taxa indicate a dry-intermediate environment
B15	B15-LTZ1	178-132		No testates
	B15-LTZ2	132-70	CenC, PsdFu, CenP	Medium testate concentration. Taxa indicate a wet environment.
	B15-LTZ3	70-14	HylO	Low testate concentration. Taxon present indicates a wet environment.
	B15-LTZ4	14-0	PsdFu, NebP,HylS	Medium-low testate concentration. Taxa indicate a dry to intermediate environment.
B19	B19-LTZ1	85-72	CycA	Medium testate concentration. Taxon present has a wide environmental niche (wet-dry)
	B19-LTZ2	72-4	HylO, HylS	Low testate concentration. Taxa present have a mix of environmental niches (HylO=wet, HylS=dry).
	B19-LTZ3	4-0	HylS, NebP	High testate concentration. Taxa indicates an intermediate-dry environment.

Table 5.8. Local Testate Amoebae Zones (LTZs)

Core	Depth (cm)	Tests 1	2	3	4	5	6	7	8	9
SH7	2				**D**					
SH7	106							**W**		
SH8	114							**W**		
SH8	130							**W**		
SH8	138							**W**		
SH8	146							**W**		
SH8	154							**W**		
SH8	162							**W**		
SH10	19	**F**								
SH10	27	**F**								
SH10	235	**W**								
B19	2				**D**					
B19	4				**D**					
B19	6				**D**					
B19	8				**D**					
B19	10				**D**					
B19	26				**F**					
B19	42				**F**					
B19	50	**F**								
B19	58	**F**								
B19	66				**F**					

D = Sample from peat always above the water-table (dry)
F=Sample from peat in zone of fluctuating water-table
W= Sample from peat always below the water-table (wet)

Table 6.1. Results of tests for sample reliability (Bunting and Tipping 2000).
See table 3.3 for details of the test criteria. Only samples which did not meet the reliability criteria for ('failed') one test or more are shown (21 out of 258 samples in total).

	% Trans.	Dam. score	Corr. score	Deg. score	Break. score	Crum. score	% Time	% Rob.
TW Damage score	0.131 0.102							
TW Corrosion score	-0.084 0.292	**0.285 0.000**						
TW Degradation score	-0.005 0.948	**0.375 0.000**	**0.222 0.005**					
TW Breakage score	0.103 0.197	**0.522 0.000**	0.130 0.105	0.048 0.548				
TW Crumpling score	0.116 0.145	**0.563 0.000**	**-0.248 0.002**	0.104 0.194	-0.116 0.148			
% time peat saturated	**-0.383 0.000**	**-0.318 0.000**	**0.205 0.010**	-0.148 0.063	-0.042 0.599	**-0.401 0.000**		
% robust grains	-0.153 0.055	0.090 0.261	**0.214 0.007**	0.146 0.067	0.028 0.722	-0.032 0.692	0.024 0.760	
Pollen concentration	-0.056 0.488	-0.005 0.951	**0.321 0.000**	-0.147 0.065	0.056 0.485	**-0.256 0.001**	**0.216 0.006**	0.118 0.142

Table 6.2. Pearson's correlation coefficients r-values (upper) and p-values (lower). Shaded cells show statistically significant relationships at a 5% significance level.

Climate Reconstruction	Variable	ALL CORES	LK2	SH8	B15
Amesbury *et al.* (2008)	TW damage score	**6.91** **0.011**	0.06 0.806	**4.58** **0.047**	**5.74** **0.026**
	TW corrosion score	0.92 0.342	0.02 0.885	4.29 0.055	**9.18** **0.006**
	TW degradation score	1.3 0.259	0.06 0.81	2.75 0.111	0.75 0.407
	TW breakage score	3.2 0.079	0.94 0.347	0 0.993	2.4 0.137
	TW crumpling score	1.25 0.268	0.87 0.364	**57.53** **0**	0.27 0.609
	% Transmission	3.82 0.055	0.52 0.483	2.88 0.108	1.99 0.173
Charman *et al.* (2006)	TW damage score	2.4 0.126	1.45 0.242	0.9 0.356	0.31 0.583
	TW corrosion score	**8.45** **0.005**	**15.79** **0.001**	1.77 0.201	0.78 0.386
	TW degradation score	2.27 0.137	1.6 0.221	0.2 0.657	1.14 0.297
	TW breakage score	0.96 0.33	0.37 0.552	2.61 0.121	3.76 0.064
	TW crumpling score	0.18 0.671	0.1 0.75	0.02 0.886	1.13 0.298
	% Transmission	0.02 0.887	0 0.978	0.06 0.817	0.06 0.806

Table 6.3. Covariance between the damage scores categorised by wet- or dry-shifts according to two climate reconstructions (upper figure = ANOVA F-value, lower figure = ANOVA P-Value). Cells are shaded where there is a significant difference between scores from wet- and dry-shifts.

	Mire number	Moorland unit	Good veg. condition Indicator spp.	*Erioporum vaginatum* or Eric.aceous spp. Over 75%	Weeds/disturbance/eutrophication indicators over 1%	Poor veg. Condition Indicators over 1%	Vegetation condition	Within AEAHI	SAMsWithin1km	**depth points**	**Veg. Condition points**	**SAM points**	**AEAHI points**	**peat condition points**	**points total**	**Mire condition**	**threats causing peat loss**	**Good condition and valuable**	**Poor condition and valuable**
1	97	15	10				Good	X	4	2	1	1	1	1	6	3			
2	126	12	6				Good		1	2	1	1	0	1	5	4	4		**X**
3	111	15	11				Good	X	1	1	1	1	1	1	5	1.5	1	**X**	
4	52	8	6				Mixed	X	3	2	0	1	1	1	5	1.5	0	**X**	
5	109	15	8				Good		1	2	1	1	0	1	5	1.5	0	**X**	
6	96	15	14				Good	X	5	1	1	1	1	1	5	3.5			
7	98	15	8				Good	X	2	1	1	1	1	1	5	3			
8	65	5	6				Good		1	2	1	1	0	1	5	3			
9	153	14	9				Good	X	5	1	1	1	1	1	5	2.5			
10	142	4	8				Good	X	2	0	1	1	1	1	4	5	4		**X**
11	76	6	8			X	Mixed	X	2	1	0	1	1	1	4	4.5	4		**X**
12	148	10	4				Poor	X	1	1	0	1	1	1	4	4	2		**X**
13	135	11	10				Good		2	1	1	1	0	1	4	2	2	**X**	
14	134	11	8			X	Mixed	X	3	1	0	1	1	1	4	2	1	**X**	
15	133	11	8				Good	X	2	0	1	1	1	1	4	2	1	**X**	
16	58	5	10				Good		3	1	1	1	0	1	4	2	1	**X**	
17	147	18	10				Good		1	1	1	1	0	1	4	2	1	**X**	
18	60	5	12	X			Good		0	2	1	0	0	1	4	2	1	**X**	
19	116	15	3			X	Poor		2	2	0	1	0	1	4	1.5	1	**X**	
20	136	9	4	X		X	Poor		8	1	0	2	0	1	4	2	0	**X**	
21	14	12	7				Good		1	1	1	1	0	1	4	2	0	**X**	
22	131	11	6				Good		1	1	1	1	0	1	4	2	0	**X**	
23	44	12	9				Good		2	1	1	1	0	1	4	1	1	**X**	
24	28	12	8				Good		3	1	1	1	0	1	4	1.5	0	**X**	
25	155	18	4			X	Poor		1	2	0	1	0	1	4	1	0	**X**	
26	64	5	5				Mixed	X	1	1	0	1	1	1	4	3.5			
27	102	15	10		X	X	Mixed		2	2	0	1	0	1	4	3.5			
28	45	8	13			X	Mixed		2	2	0	1	0	1	4	3.5			
29	126	12	4			X	Poor		2	2	0	1	0	1	4	3.5			
30	48	8	8			X	Mixed	X	3	1	0	1	1	1	4	3			
31	99	15	5				Poor	X	2	1	0	1	1	1	4	3			
32	127	12	2			X	Poor		6	1	0	2	0	1	4	3			
33	82	6	6				Good		2	1	1	1	0	1	4	3			
34	41	12	1			X	Poor		5	2	0	1	0	1	4	2.5			
35	140	4	9			X	Good		2	1	1	1	0	1	4	2.5			
36	139	4	7			X	Good		2	1	1	1	0	1	4	2.5			
37	151	18	3			X	Poor		2	2	0	1	0	1	4	2.5			

Table 7.1. Mires designated as important using the flexible valuation system (see section 7.4.2)

APPENDIX 3: PUBLICATIONS

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