APPLICATION OF PALAEOECOLOGICAL TECHNIQUES TO INFORM BLANKET MIRE CONSERVATION IN YORKSHIRE, UK.

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Abstract

In a recent discussion of research priorities for palaeoecology, it was suggested that palaeoecological data can be applied and used to inform nature conservation practice. The present study exemplifies this approach. It was conducted on three degraded blanket mires in Yorkshire, UK, in collaboration with a field-based moorland restoration agency. High-resolution, multiproxy palaeoecological analyses on peat cores from Mossdale Moor, Oxenhope Moor and West Arkengarthdale reconstructed mid- to late-Holocene vegetation changes. Humification, pollen, plant macrofossil and charcoal analyses carried out throughout the peat profile at each site show marked changes in species composition and indicate their potential causes. Results suggest that human clearance in the Mesolithic–Neolithic transition may have initiated peat growth at Mossdale Moor, making this landscape ‘semi-natural’ in its origin. Further human-induced changes are identified at 1300 cal. years BP at Mossdale Moor, 2100 cal. BP at Oxenhope Moor and c. 3250 cal. BP at West Arkengarthdale, most likely deliberate clearance by fire. Increased anthropogenic activity is identified at each site since the industrial revolution where monocots and *Eriophorum vaginatum* increase, consistent with rises in charcoal at Mossdale Moor and West Arkengarthdale. These are interpreted as recent (<300 years) management practices using burning to encourage browse on the moor. Climatic deteriorations have also been identified, with wetter conditions at 5000 cal. BP and 4400 cal. BP at West Arkengarthdale and Oxenhope Moor, c. 2400 cal. BP at Mossdale Moor and West Arkengarthdale and the Little Ice Age at each site. It is intended that these long-term ecological histories of the sites, derived using palaeoecological techniques, will be used to inform conservation practice and can help set feasible targets for restoration and conservation.

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Chapter 1: Introduction

1.1 Peatland Formations and Their Value

Globally, peatlands cover 3–4% of Earth's surface (Gore, 1983); with most beginning their formation during the Holocene epoch and containing a record of vegetation development within their deposits. In North-west Europe, two major ombrotrophic peatland formations (mires) are raised bogs and blanket bogs. The latter are found in coastal zones of Western Ireland and Norway, but in the UK they are usually found at altitudes above 400 m and in areas currently in receipt of >1250 mm rainfall annually. The area covered by blanket mire alone in the UK is approximately 25,000 km, 10% of the world total (Tallis, 1997). The distribution of peat and peaty soils in the UK can be seen in Figure 1.1.

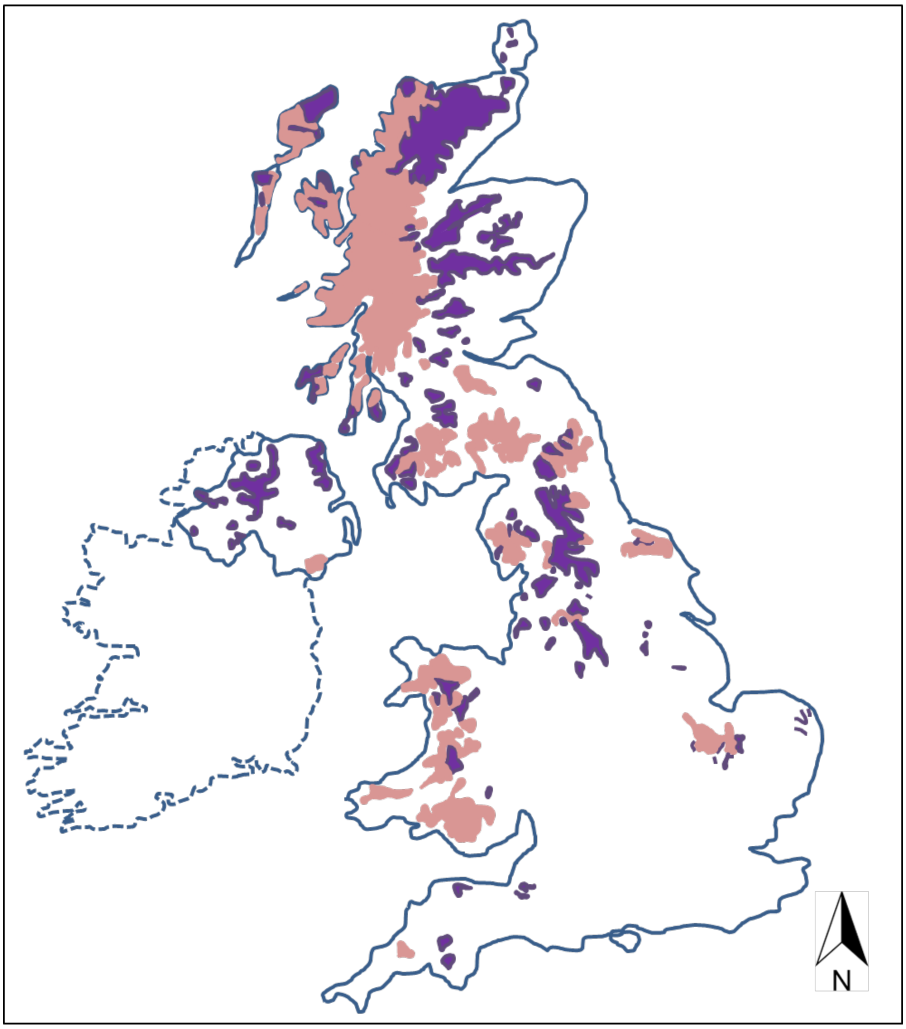


Figure 1. 1: Distribution of peat and peaty soils in the United Kingdom. Deep peat soils (purple) and shallow peaty soils (pink). Adapted from Montanarella *et al.* (2006).

Barber (1993) describes peatlands as being the most vulnerable to irreversible damage of all natural ecosystems, as they cannot return to their previous state following significant interference by humans. Peatlands represent a dynamic habitat for many unique species (including various *Sphagnum* mosses and species such as *Vaccinium oxycoccus*) as well as playing an important role as a pool and store for carbon (Gorham, 1991), contributing to the equilibration of the water cycle and containing information in the remains of plants, animals, and atmospheric particles deposited and stored in the peat profile (Chapman *et al.*, 2003).

1.2 Peatland Degradation

Blanket mires are particularly vulnerable to degradation and this has become widespread in parts of the UK uplands. Degradation and erosion of these areas has significant ecological effects including loss of habitat and biodiversity (Yeo, 1997). There are also economic effects depending on use of the land, such as loss of land suitable for grazing and shooting, a reduction in reservoir catchment capacity and discolouration of drinking water (Yeloff *et al.*, 2006, Holden *et al.*, 2007). Peatland ecosystems in the UK are considered to be of national and international importance (Lindsay *et al.*, 1988, Bain *et al.*, 2011) because they provide terrestrial carbon storage, maintenance of biodiversity and protection of water resources (Drew *et al.*, 2013). It is predicted that they will show heightened sensitivity to disturbance as a result of climatic change and increasing erosion over the coming decades (Davies and Bunting, 2010). The vegetation considered typical of undisturbed peatlands is no longer supported across much of the UK. Instead, degraded blanket mires are dominated by graminoids such as *Eriophorum vaginatum* with amounts of ericoids and *Sphagna* being significantly reduced (Chambers *et al.*, 2007c).

Peatlands play a role in regulating the atmospheric concentration of carbon dioxide and methane (Klinger *et al.*, 1996) by steadily accumulating carbon (Webster *et al.*, 2013). Human disturbance of these ecosystems is depleting carbon stores and causing a transfer of carbon as either methane or carbon dioxide to the atmosphere, which may be contributing to climate change (Garnett *et al.*, 2000). It is estimated that there is up to 10,000 years' worth of atmospheric carbon stored in peatlands (Sjörs, 1980) and terrestrial ecosystems alone contain three times more carbon than the atmosphere and are capable of storing much more carbon than the same area of trees. For example, an area of peat 1.5 metres deep has been estimated to store 20 times as much carbon as the equivalent area of conifer plantation (Garnett *et al.*, 2000). Pristine peatland ecosystems have been described as carbon stores owing to high water levels resulting in mostly anoxic conditions (Worrall *et al.*, 2010) leading to limited decomposition of organic matter by reduced oxygen availability, causing peat and carbon accumulation. Pristine peatlands have also been defined by the IUCN as areas in which “there is no management at the time during, or preceding, the study that could affect the peat. Pristine does not mean that the site has been unaffected by external factors such as climate change or atmospheric deposition” (Worrall *et al.*, 2010).

Peat has been harvested on an industrial scale for both energy and horticultural purposes commonly in both Europe and North America, the effects of which are destructive to the mire ecosystem. All vegetation is removed, completely altering the hydrology of the system and terminating peat growth. Even once harvesting has stopped, the cut area of peat continues to be a release of carbon as it gradually decomposes and is exposed to erosion by rain and wind. Stopping a harvested peatland from being a source of carbon dioxide requires the re-establishment of vegetation, which is difficult owing to the harsh conditions unsuitable for the colonisation of plants, such as dry surface soil and high temperature fluctuations (Soini *et al.*, 2010).

1.3 Possible Causes of Peatland Degradation

1.3.1 Peat Erosion

Peat erosion, which can lead to extensive removal of peat, is a significant problem. According to Yeloff *et al.* (2006), blanket peat erosion is a three-stage process beginning with a disruption of the vegetation cover, leaving peat exposed. This is followed by reduced cohesiveness of the exposed peat caused by frost action and drought, leaving the peat surface layer easily eroded by wind, water or oxidation. Peat can be eroded easily owing to its low density and long-term records have shown that degradation of peatland systems is determined by heavy rain, wind and fast snowmelt. Mass movements and surface recession after periods of drought can also lead to the formation of gullies as well as causing peat failures; a significant factor in the natural erosion of blanket peat. This can lead to the deposition of large amounts of peat into local streams (Ramchunder *et al.*, 2009).

The initial disruption of the vegetation cover can be caused by natural events or processes such as bog bursts (failures of hydrological and structural integrity of parts of mire caused by a variety of factors (Caseldine and Geary, 2005)) but can also be caused by anthropogenic impacts such as air pollution, fire, over-grazing, peat cutting, artificial drainage and trampling by foot and damage from vehicles. Previous research has indicated that this is more likely to occur in peatlands in close proximity to areas of high urban population (Yeloff *et al.*, 2006).

1.3.2 Over-grazing

Peat erosion can be worsened by over-grazing by sheep. Studies have shown that on blanket mire, keeping more than one sheep per hectare increases the area of bare ground, carrying an increased risk of damage by erosion (Cooper *et al.*, 2001). Furthermore, a study by Worrall and Clay (2012) has shown that increases in grazing intensity also have an apparent linear response on the greenhouse gas flux rate. Their study suggests that the presently accepted grazing intensities would lead to peatland environments that are net sources of greenhouse gases.

1.3.3 Prescribed Burning

A contentious current issue in nature conservation in the UK is the prescribed burning of blanket bog, which has been used to manage vegetation growth in these ecosystems for centuries. However, its use has increased over approximately the last 200 years for both sheep and grouse management (Muller *et al.*, 2012). Burning management began in the medieval period at least, with patch burning starting in approximately AD 1900 (in Scotland) (Ramchunder *et al.*, 2009). Patch burning consists of burning in sections, creating a mosaic of heather of different ages within the landscape. Draining of peatlands by creating ditches during the middle of the twentieth century also assisted in drying out these landscapes for grouse management. As part of the management of grouse populations, landowners are advised to burn ageing dwarf shrubs in order to encourage the growth of younger shoots. Rotational burns are usually undertaken every 8 to 25 years; however, this can differ depending on various factors including grazing level and type of habitat (Ramchunder *et al.*, 2009).

There is an increasing recognition that upland blanket bogs play an important role providing a wide range of uses and therefore, the role of burning in management practices is increasingly being questioned. Burning leads to vegetation dominated by *Calluna vulgaris* at the expense of peat-forming species, such as *Sphagnum* species, which are thought to be particularly sensitive to fire (Muller *et al.*, 2012, Worrall *et al.*, 2007). Despite this, a recent study by Muller *et al.* (2012) found that, contrary to speculation, an absence of burning did not favour the growth of *Sphagnum* spp. or other peat-forming species. It was found that where a short-rotation burning programme was prescribed (3-6 years), the vegetation shifted towards one dominated by peat-forming *Eriophorum* spp. and *Sphagnum*. Muller *et al.* (2012) postulate that this may be because the fire regime used resembled 'cool burns' where the vegetation is always relatively damp owing to high rainfall. In the future, with predicted climate change, wildfire in such fire- adapted ecosystems is expected to increase, and prescribed burning may be one solution to minimise long-term, ecological damage. Norton and De Lange (2003) also found that disturbances such as fire are important for maintaining a diversity of plant communities, including the presence of nationally threatened and declining plant species in peat bogs and suggest that without such disturbances, some species are likely to become locally extinct.

Peatland communities containing *Calluna* spp. are understood to have been converted to grassland of low species diversity by grazing and burning practices during the 12^{th} – 14^{th} centuries (Ramchunder *et al.*, 2009). The intensification of burning has increased since the late 18^{th} century and is thought to have contributed to the replacement of species-rich peat-forming bog communities with somewhat species-poor grasses such as *Eriophorum* spp. (Ramchunder *et al.*, 2009, Yeloff *et al.*, 2006). Clay (2009) also suggests that the burning of peatland vegetation endorses the development of grass-dominated communities, particularly on shorter burning rotations. This vegetation response improves grazing for sheep and is reflected in higher sheep performance on burnt plots. Grouse production has also been correlated with the density of burnt areas.

The use of fire is complex and poorly understood. However, both researchers and conservationists are increasingly becoming aware of the role of fire in peatland ecosystems. They are also becoming aware of the need to comprehend the relationship between fire and management practices in order to conserve, restore and manage current biodiversity. The understanding of past fires disturbance dynamics is incomplete and there are other problems related to changing environmental conditions, such as the role of invasive species, air pollution and climate change. Such problems may make it difficult to apply the knowledge acquired from studies of past fires to future fire management (Conedera *et al.*, 2009).

Dispersal of particulate charcoal following the incomplete combustion of organic matter provides direct evidence of burning which can be preserved as a fossil charcoal assemblage in peat bogs. This can then be sampled and analysed in order to reconstruct fire history. Pollen records in sediments may also be used in conjunction with reconstructions from charcoal data in order to highlight changes in the surrounding vegetation as a possible result of fire. The ratio of charcoal influx to pollen influx can be used to detect peaks relating to fire events because when the charcoal influx increases, the pollen source is reduced (Conedera *et al.*, 2009). Fire reconstruction should not be based on pollen or vegetation reconstructions alone, as various other ecosystem disturbances (such as land clearance) can lead to a signal that could be mistaken as being caused by fire (Conedera *et al.*, 2009).

With the use of charcoal analysis, previous ecological responses to wildfires can be reconstructed and may provide insight into how current ecosystems could be managed to withstand predicted increases in wildfire (Bergeron *et al.*, 2011), and whether managed burning may assist in this. Charcoal analysis could also be used to ascertain at what point in time burning management began in Yorkshire and if the increases seen in other parts of the UK are also seen here.

1.3.4 Climate Change

Global warming and the subsequent increase in evapotranspiration may well lead to lowered water tables in peatlands and an increase in wildfire frequency (Hogg *et al.*, 1992). Furthermore, changes in precipitation patterns and warming are expected to affect peat bog vegetation composition and thereby its long-term carbon sequestration capacity. Heijmans *et al.* (2013) found that temperature increases from 1 °C onward shifted peat bogs in the eastern Netherlands into tree-dominated ecosystems. In their simulations, drought events facilitated tree establishment, but temperature determined how much tree biomass could develop. The results suggest that under current climatic conditions, peat bog vegetation is rather resilient to drought events, but very sensitive to temperature increases, indicating that future warming is likely to trigger persistent vegetation shifts (Heijmans *et al.*, 2013).

1.3.5 Other Problems

Peatlands are also at risk from acid rain, particularly those in close proximity to industrial areas. Recent studies have shown that the degree of acid rain deposition onto peat bogs may be particularly important in regulating the production and emission of CH_4 from peat (Nedwell and Watson, 1995, Watson and Nedwell, 1998, Gauci, 2002). Evans *et al.* (2014) found that acid deposition has had a detrimental effect on the chemical and biological status of both upland terrestrial and aquatic ecosystems across much of the UK, as well as parts of Europe and North America owing to industrial pollution. In all these areas, however; atmospheric sulphur pollution has declined substantially following peaks in the 1970s and 1980s. In the UK in particular, emissions have decreased by around 90% since the 1970s. However, there is a lack of evidence to assess the effects that the high levels of acidification during the 1970s and 1980s may have had on peatlands and linked water sources today. One of the principal effects of long-term acidification is the decreased production of *Sphagnum* under elevated N deposition (Granath *et al.*, 2012). Long-term enhanced nitrogen deposition can also increase ecosystem respiration and carbon loss from *Sphagnum* bogs (Kivimäki *et al.*, 2013).

Peat is often cut to be used as fuel. The amount of peat cut from peatlands was much less until the introduction of tractor powered peat-harvesters in the early 1980s. The effects of peat cutting using machinery include a reduction in canopy height, biomass and species diversity. Few peatlands recover following such disturbance with many remaining barren of vegetation 10 years after harvesting ends (Cooper *et al.*, 2001). Charman & Pollard (1995) assessed vegetation recovery on Dartmoor and discovered that moorland vegetation had a considerably slower recovery rate than grassland and heath. Grazing and trampling by domestic animals can also further restrict the establishment of vegetation on bare peat (Cooper *et al.*, 2001).

Peatlands may also be subject to drainage. One of the main aims of drainage is to benefit the growth of *Calluna vulgaris* to improve the habitat for grouse and sheep; however, any enhancements in the nutritional value of *C. vulgaris* are counterbalanced by the decline in cover and the spread of unpalatable grasses. Investigations have also shown that plant species dependent on high water tables such as *Sphagnum* spp. have a lower abundance when closer to drains (Ramchunder *et al.*, 2009).

Persistent environmental change such as drainage and forest clearing threatens the stability of peatlands and makes them susceptible to fire. This was demonstrated by the occurrence of widespread fires throughout the forested peatlands of Indonesia during the 1997 El Niño event (Page *et al.*, 2002). Peatlands are also subjected to loss of land by afforestation, as well as reclamation of land for agricultural purposes. Many of the problems peatlands face are notably interlinked, with drainage and over-grazing leading to erosion and wildfire. This then exacerbates the problem of erosion, in turn leading to increased carbon dioxide and methane entering the atmosphere and increased dissolved organic carbon (DOC) from peatlands entering water sources (Page *et al.*, 2002). It is generally understood that such areas at risk need to be restored by blocking any drains and re-vegetating. However, how these areas are re-vegetated and with which species is where palaeoecological studies can assist.

1.4 Conservation of Upland Peatlands

In order to conserve peatlands and restore those that have become degraded, an understanding of what has caused the change locally is required to establish appropriate responses at site level (Davies and Bunting, 2010). There has been recognition amongst palaeoecologists that the long-term datasets generated through palaeoecological techniques could be of use in nature conservation (Birks, 1996, Froyd and Willis, 2008, Davies and Bunting, 2010, Willis *et al.*, 2010, Birks, 2012, Hjelle *et al.*, 2012, Muller *et al.*, 2012, Wilmshurst *et al.*, 2014). In the case of upland mires, it has been argued that palaeoecology can be applied to conservation to provide the long-term ecological background to help answer questions covering the more recent time periods of principal interest to conservationists (Chambers and Daniell, 2011, Seddon *et al.*, 2014).

Few studies have used palaeoecological techniques to advise conservationists explicitly, with only 16% of studies published in the Journal of Applied Ecology in 1999 addressing timescales greater than a decade (Ormerod *et al.*, 1999). However, over recent decades, there have been studies in England and Wales involving collaboration between conservation agencies and palaeoecologists in which palaeoecological data have been generated from mires that might then inform conservation practice (Chambers *et al.*, 2013b, Chambers and Daniell, 2011, Chambers *et al.*, 2007b, Chambers *et al.*, 2007c, Chambers *et al.*, 1999).

Palaeoecology allows the study of natural ecological processes on a timescale much longer than is possible from monitoring studies (Charman and Pollard, 1995, Birks, 1996, Preston *et al.*, 2002, Chambers *et al.*, 2007b, Froyd and Willis, 2008, MacPherson, 2009, Davies and Bunting, 2010). Reliance on short-term monitoring for evidence in conservation is insufficient owing to the rapid rate of change in landscape influencing human activities, and projected climate changes. Though emphasis is placed on restoration, few local conservation practitioners will be fully aware of the range of past vegetation communities to which degraded habitats might be restored (Chambers and Daniell, 2011). This is of high importance as ecological processes develop over decades and even centuries. Palaeoecological records are often overlooked in conservation initiatives because they are perceived as too descriptive, imprecise and difficult to understand by non-specialists.

For example, in using pollen derived palaeoecological data for conservation purposes, one of the main difficulties is translating fossil pollen assemblages in terms of plant communities. This is partly owing to the ambiguity in defining pollen source areas and in the variability of pollen production by different plant species. Plant macrofossil analysis can be used in order to provide more local information; however, this is not always possible depending on preservation conditions of the sedimentary record (Muller *et al.*, 2012). Despite this, such information can provide valuable reasons to support management decisions (Davies and Bunting, 2010).

Palaeoecological studies to aid conservationists have been carried out in Wales and Northern England (Davies and Bunting, 2010, Chambers *et al.*, 2007b, Chambers and Daniell, 2011) with promising results but no detailed published study has yet been carried out in Yorkshire. Chambers and Daniell (2011) used palaeoecological data to propose that there has been a recent shift in vegetation communities at sites in Exmoor and Mid and South Wales. The data show the expansion of a grass species, *Molinia caerulea* after the start of the industrial revolution. There is concern over the degradation of blanket mire communities following observed changes in vegetation composition with evidence of limited ericaceous species and few *Sphagna*. Many areas are now dominated by graminaceous species such as *Molinia caerulea* and *Eriophorum vaginatum* (Chambers, 2001a, Grant *et al.*, 1996, Davies and Bunting, 2010).

Conservation preference is often given to Callunetum but this needs to be modified as it is now understood that it may not have always been present. In some parts of the UK over recent centuries, *Calluna*-dominated communities are part of a relatively recent shift (Davies and Bunting, 2010, Chambers *et al.*, 2007b, Chambers *et al.*, 2007c, Chambers *et al.*, 1999). It is also assumed that smaller and/or declining populations are at the greatest risk. However, there may be a naturally fluctuating population size. Also, the geographical and ecological tolerances of rare plants presently restricted to isolated areas may have been much wider before human influence.

Conservationists require knowledge such as whether an ecosystem is close to a threshold and what makes an ecosystem more resilient to a threshold event. Palaeoecology can potentially answer this through understanding the natural history of a species. Conservation management must not assume static species distribution in the absence of human disturbance. Within conservation, there is a widespread assumption that without human intervention, peatlands would be treeless and dominated by *Sphagnum* (Davis and Wilkinson, 2004, Chambers, 2001b). There may be future shifts in species distributions as a result of climate change (Brown, 2010). Palaeoecological analysis can examine the complex inter-relationships between impact of disturbance and migration rates of species in conjunction with climate change to predict future plant community composition (Froyd and Willis, 2008).

Few peatland habitats are completely natural as they have a long history of human influence. Therefore, there should be a focus on restoring a habitat of the most benefit to a range of flora and fauna (Brown, 2010). Palaeoecology can establish ecological reference points for habitat restoration and provide answers to the fundamental question of what was the previous abundance and relative composition of plant species in a particular ecosystem, especially those species currently considered rare or threatened. The current structure of peatlands is determined largely by past management practices (Brown, 2010). According to Brown (2010), understanding the role of past human impact should therefore be an important aspect of restoration strategies.

It is not only possible to restore a site to a state it has previously occupied. It may be conceivable to restore a site to a number of states within a succession. There is potential also to restore only a single part of a site without having restored other areas, making defining ‘restored’ sites problematical. Ecologically, the concept of restoration has been to return the site back to its ‘original’ state (before human intervention – assuming that all other variables such as climate have been stable since this point) (Davis and Wilkinson, 2004). However, if human action initiated peat growth, there is the question as to whether it should be restored to a state that existed before human intervention. Furthermore, the danger is that once these sites are ‘restored’ (and restored to which state?) they will again be at risk from human pressures that are difficult to control, such as acid rain and pollution.

Testate amoebae have been used to inform peatland restoration schemes. Davis and Wilkinson (2004) discuss two lowland raised-mire sites in northwest England. It was found that catastrophic shifts in ecosystem status can be caused by gradual changes in environmental factors. It is frequently assumed that gradual changes in potential causes must produce gradual effects. However, this is often incorrect. Bog bursts may have this kind of effect on raised mires, with a gradual increase in wetness leading to a radical system failure and drastically altered hydrological conditions (Davis and Wilkinson, 2004).

It was also found that it could be difficult for *Sphagnum* to become dominant once again following the change to a grass and Ericales-dominated state. In northwest Europe it is frequently assumed that, without air pollution and drainage, raised mires should be dominated by *Sphagnum*. Peatlands that are not *Sphagnum*-rich are assumed to be damaged and are therefore managed with the aim of restoring the *Sphagnum*-dominated conditions. However, research by Sundberg and Rysin (2002) suggests that *Sphagnum* spores are significant in long-distance dispersal and colonisation of disturbed habitats. It has been found that some heavily disturbed mire contained more *Sphagnum* species than undisturbed mire. Some of these species had spread extensive distances and had sporadic distributions, therefore demonstrating that priority of colonisation is important before other, non-random, processes gradually take over. They found that *S. russowii* and *S. capillifolium* were disproportionately frequent colonisers following fire on mires.

Davis and Wilkinson's (2004) study has implications for the stereotypical view of natural raised bog vegetation. The data suggest that a less rigid definition of natural states for raised-mire vegetation may be required. Most importantly, they suggest that strict adherence in restoration to a state 'before human intervention' need not necessarily correspond with 'traditional' ideas of mire vegetation. It may be a difficult task to 'restore' the peatlands, as from the palaeoecological record, there is no evidence that bogs can be restored after severe anthropogenic damage within the human timeframe (Clay, 2009).

According to Davis and Wilkinson (2004), 90% of blanket mires and 98% of raised mires in Britain have been exploited to some extent in the last 50 years. When plant life eventually returns to these degraded areas, the species that dominate are generally those of dry heath, especially *Molinia caerulea* (Davis and Wilkinson, 2004). Sites such as this can no longer be considered wetlands in any ecological sense. For the majority of sites, especially lowland raised-mires, conservation is no longer enough. There is little left to conserve except bare peat or dry *Molinia* grassland and therefore, what is necessary are site specific plans to create environments capable of peat forming and rich in biodiversity (whatever the intended 'use' of the site), which could involve management and restoration in order to create a functioning ecosystem, which may or may not resemble a state that previously existed at the site.

Recent restoration projects on fens and bogs in Finland have managed to raise the water tables of degraded sites by removing trees where afforestation has occurred and re-wetting by damming drainage ditches. Although the cover of shrub size and dwarf shrubs increased, including an expansion of species such as *Betula pubescens, B. nana, Empetrum nigrum, Ledum palustre, Vaccinium uliginosum, V. vitis-idaea*, as well an increase in *Sphagnum angusifolium* and *S. russowii*, cover of *Eriophorum vaginatum* also increased during the restoration period in both studies (Komulainen *et al.*, 1999, Jauhiainen *et al.*, 2002).

Such studies have not been long enough to know whether self-supporting mires will be achieved (Jauhiainen *et al.*, 2002). In using palaeoecological data, it can be ascertained what the previous vegetation composition may have been, perhaps with a much lower abundance of *Eriophorum vaginatum* than achieved in these short restoration projects. However, it is unknown how long it will take before the species composition resembles those of 'pristine' sites, or if this is possible given the time that would be necessary to create a functioning peatland ecosystem no longer in need of management.

It is demonstrated that there are multiple causes for recent changes in vegetation including changes in grazing regime, burning patterns and atmospheric nitrogen deposition, which is continuing to favour grass dominance. Efforts to restore degraded blanket bogs by reducing *Molinia* growth are justified as research has found that the shift to dominance is recent and human-induced (Chambers *et al.*, 1999). Preferred vegetation types used for restoring the uplands in the UK include

Sphagnum, which is now relatively rare in England, Wales and Northern Ireland owing to atmospheric pollution, drainage, burning, peat extraction, over-grazing, and afforestation. Palaeodata from Chambers and Daniell (2011) demonstrate in South Wales and Northern England that there was a former presence of plant species including *Sphagnum austinii* which was regionally extinct, possibly as a result of human activity. This type of *Sphagnum* was also a major peat former in raised bogs in England and Wales for thousands of years throughout the mid-late Holocene. Therefore, regional palaeodata show that inter-regional translocation of key bog species could be justified as part of future habitat restoration (Chambers *et al.*, 2007b).

1.5 Peatlands as Palaeoclimatic Archives

It has been claimed that proxy climatic data can be inferred from late-Holocene peat stratigraphy (Barber, 1981). Many studies have suggested an association between the visible stratigraphy of peatlands and past climatic change (Blackford and Chambers, 1991). Ombrotrophic (rain-fed) peatlands have a moisture balance that is solely dependent on precipitation and evapotranspiration. They also have a surface profile that is slightly convex or flat and so they receive no surface runoff (Blundell and Barber, 2005). Many peatlands have the ability to accumulate autochthonous material sequentially, to sequester carbon for thousands of years, and to contain within them a detailed archive of local and regional vegetation history. This makes peatlands ideal for researching Holocene environmental and climatic changes (Blackford, 1993). Following the work of pioneering palynologists such as von Post, Godwin and Jessen, for more than half a century in northwest Europe, peatlands have been used in the study of vegetation history (Chambers and Charman, 2004).

Peatlands also contain a record of surface wetness and a range of methods have been developed to reconstruct this over time in order to produce records of hydroclimate variability, including peat humification (Blackford and Chambers, 1993), plant macrofossils analysis (Barber, 1981), testate amoebae analysis (Charman *et al.*, 1999) geochemical analyses and various dating methods, which can be combined in multiproxy studies of climate and environmental history at high resolution (Blundell and Barber, 2005). For example, the increasing use of tephrochronology means that the precision and accuracy now achievable in Holocene peat-based chronologies is much higher than in the pioneer studies, meaning that temporal resolution of records can be subdecadal, especially in recent peats (Chambers and Charman, 2004).

These techniques have been applied to a large number of sites from a range of geographical locations in Europe, the Americas and New Zealand (Barber *et al.*, 2004, Charman *et al.*, 2006, Chambers *et al.*, 2007a, Sillasoo *et al.*, 2007, Swindles *et al.*, 2007) (Charman *et al.*, 2009) but have not been without complications and as a result, multi-proxy records have been used in an attempt to reduce the margin of error (Blundell and Barber, 2005).

Such studies have reconstructed palaeoclimatic events including climatic deteriorations at 6800 cal. BP (Feurdean *et al.*, 2008), 5000 cal. BP (Anderson, 1998, Barber and Langdon, 2007), 4400 cal. BP (Hughes *et al.*, 2000), 2800–2300 cal. BP (Barber *et al.*, 2003, Langdon *et al.*, 2003, Bond *et al.*, 1997, Barber *et al.*, 2013, van Geel *et al.*, 1996, van Geel and Renssen, 1998, Chambers *et al.*, 2007a, O'Brien, 1995), 1400 cal. BP (Blackford and Chambers, 1991), 700–500 cal. BP (LIA) (Barber and Langdon, 2007; Charman *et al.* 2006; Swindles *et al.*, 2012; Baker *et al.*, 1999; Charman *et al.*, 2006; Charman *et al.* 2012) and the MWP between 1050–650 cal. BP (Andersen, 1998; Barber, 1981; Tallis, 1985; Wells and Wheeler, 1999).

1.6 Aim, Research Questions and Objectives

This thesis will report the results of palaeoecological reconstructions of Mossdale Moor, Oxenhope Moor and West Arkengarthdale, Yorkshire, UK. This was conducted in collaboration with the Yorkshire Peat Partnership (YPP - an organisation restoring and conserving upland peat resources in order to ensure the long-term future of these ecosystems) with a view to supporting and informing the practical moorland conservation work by determining the former vegetation of these degraded peatlands.

1.6.1 Aim

The aim of the research is to reconstruct the past vegetation cover and to understand any factors causing changes in that cover through time. Particular focus will be placed on potential effects of land-use management.

1.6.2 Research Questions

Research questions were formulated in conjunction with the YPP with a view to support the conservation taking place at the selected sites. Palaeoecological data will provide evidence for the previous vegetation, its development, past changes, timing of the changes and the relationship with climate. Similar analyses have been carried out in comparable areas in northern England, with promising initial results (Chambers and Daniell, 2011). This research project aims to determine whether recent changes in mires have been caused by human actions and to determine which factor(s) led to recent degradation. This will support understanding of the causes of vegetation degradation in an area where knowledge is lacking and ultimately, will aid understanding of the previous habitat, whether and how it can be restored, and to what end.

1. What are the vegetation changes throughout the entire peat profile at each site?
2. How far can the cause(s) of detected changes be reliably inferred?
3. How can this information be used to help set feasible targets for restoration and conservation?

These research questions will be addressed by the following objectives:

1.4.3 Research Objectives

- to determine the former vegetation cover of three degraded peatland sites in Yorkshire throughout the entire peat profile.
- to understand the factors causing the changes through time.
- to apply this knowledge to inform conservation management.

Chapter 2: Methods

2.1 Site Selection

Mossdale Moor, Oxenhope Moor and West Arkengarthdale were selected for palaeoecological analysis by the Yorkshire Peat Partnership (YPP) based on the current judgement that Oxenhope Moor is the most degraded, West Arkengarthdale the least and Mossdale Moor being between the two. The sites were also assessed by Frank Chambers, Julia McCarroll and Julia Webb to make sure they were suitable for palaeoecological analysis. The YPP aim to understand what the vegetation changes are throughout each entire peat profile, what might have caused these changes and how this information can aid them in their conservation and restoration projects.

2.1.1 Mossdale Moor

Mossdale Moor is degraded blanket mire at 550m altitude located in Upper Wensleydale, North Yorkshire, UK (Figure 2.1). The coring site is located on a small plateau at the bottom of the north side of Widdale Fell. There are peat hags at the site, some of which are 3 m above bedrock in parts. The site is situated on mudstone above a thin sandstone which overlays limestone (Hall, 1979). The modern-day peat supports species characteristic of National Vegetation Classification (NVC) M19 (*Calluna vulgaris-Eriophorum vaginatum* blanket mire) (Rodwell, 1998) including *Calluna vulgaris, Eriophorum vaginatum, Trichophorum cespitosum, Erica tetralix* and *Vaccinium myrtillus*. In the last few hundred years, Mossdale Moor has supported sheep and grouse. Various management practices such as burning, drainage and grazing have been undertaken to develop the moor for livestock and grouse rearing. This has altered the vegetation characteristics of the moor from typical blanket mire towards heathland communities.

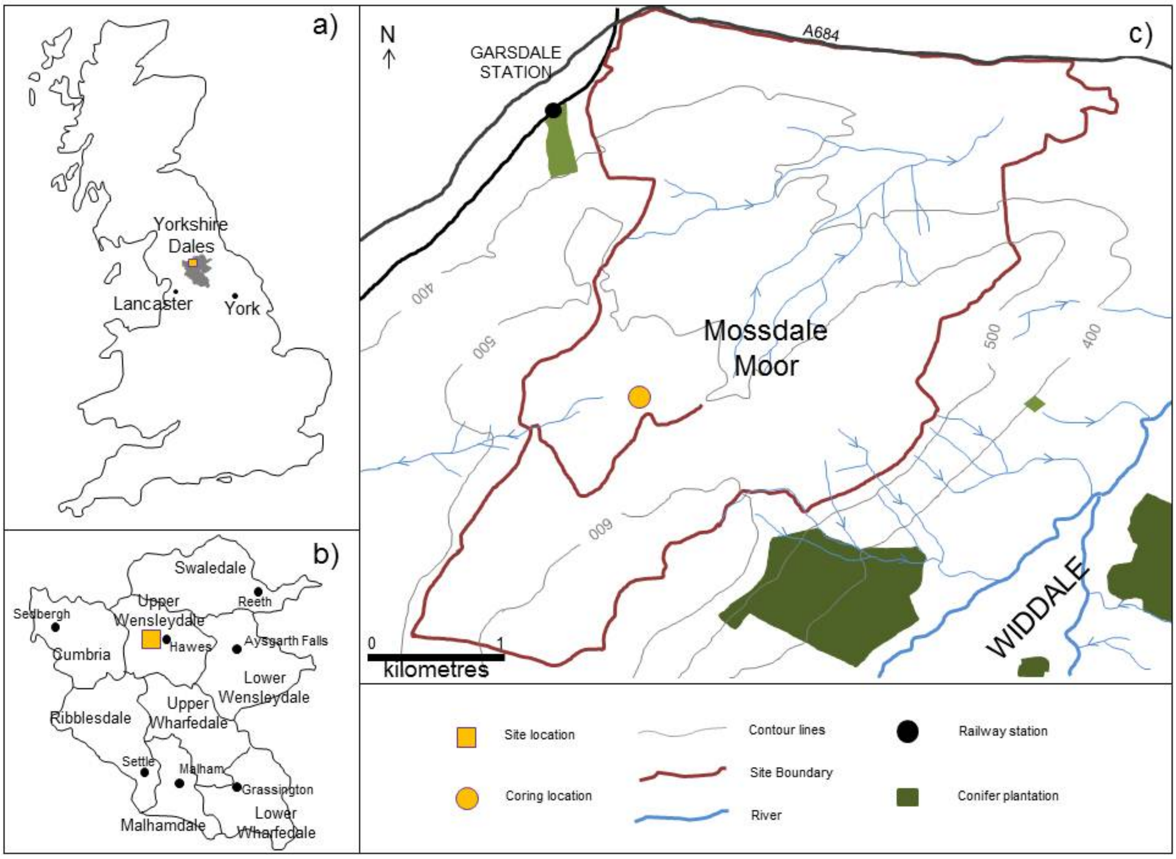


Figure 2.1: a) Map of United Kingdom showing location of the Yorkshire Dales in relation to the cities of Lancaster and York. **b)** Map of the Yorkshire Dales showing location of Upper Wensleydale, the village of Hawes and Mossdale Moor. **c)** Map of Mossdale Moor showing exact coring location at Latitude: 54.300292N, Longitude: -2.315507W.

2.1.2 Oxenhope Moor

Oxenhope Moor is degraded blanket mire at 430m altitude located north of Hebden Bridge in West Yorkshire (Figure 2.2). The modern-day peat supports species characteristic of NVC types M20 (*Eriophorum vaginatum* blanket and raised mire) and M25 (*Molinia caerulea-Potentilla erecta* mire as surveyed by Natural England in 2008) (Rodwell, 1998). Species identified at the site include *Andromeda polifolia, Arctostaphylos* spp., *Betula nana, Carex bigelowii, Calluna Vulgaris, Cornus suecica, Drosera* spp., *Erica tetralix*, *Empetrum nigrum, Eriophorum angustifolium, Eriophorum vaginatum, Menythanes trifoliata, Myrica gale, Narthecium ossifragum*, Non-crustose lichens, *Pleurocarpous* mosses, *Racomitrium lanuginosum, Rubus chamaemorus, Rhynchospora alba, Sphagnum* spp. (*S. cuspidatum* and *S. fallax*), *Trichophorum cespitosum*, and *Vaccinium myrtillus*. The higher ground is dominated by *Eriophorum* spp., but to the east, the ground slopes down towards a reservoir where *Molinia* becomes dominant.

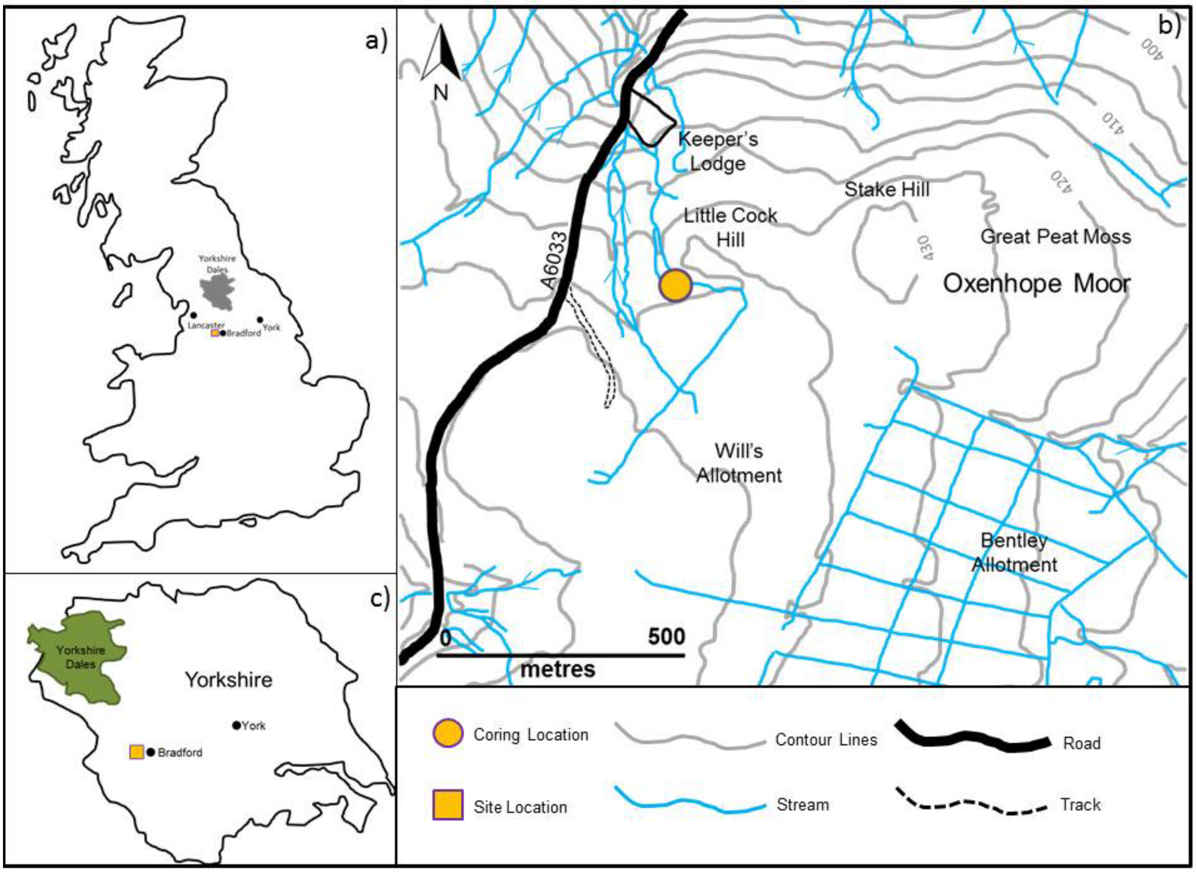


Figure 2.2: a) Map of United Kingdom showing location of the Yorkshire Dales in relation to the cities of Lancaster and York. **b)** Map of Yorkshire and the Yorkshire Dales showing location of Bradford and Oxenhope Moor. **c)** Map of Oxenhope Moor showing exact coring location at Latitude: 53.793759N, Longitude: -1.977952W.

2.1.3 West Arkengarthdale

West Arkengarthdale is blanket mire at 380m altitude located north-west of Reeth in North Yorkshire (Figure 2.3). A vegetation survey conducted during fieldwork identified that the modern day peat supports species characteristic of NVC type M20 (*Eriophorum vaginatum* blanket and raised mire) (Rodwell, 1998). Species identified include *Eriophorum vaginatum*, *Sphagnum* (including *S. cuspidatum* in pools), *Calluna vulgaris*, *Vaccinium oxycoccus*, *Vaccinium vitis-idaea*, *Polytrichum commune* and *Potentilla erecta*.

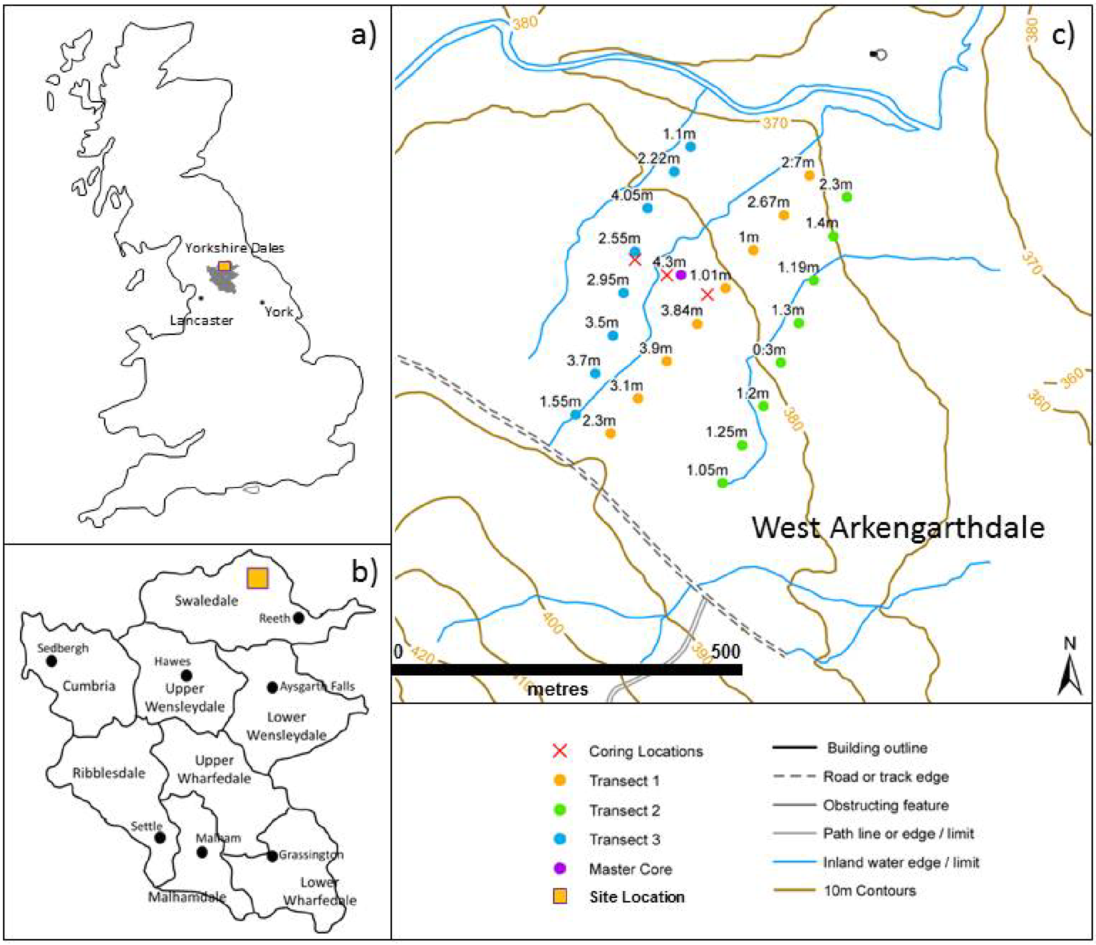


Figure 2.3: a) Map of United Kingdom showing location of the Yorkshire Dales in relation to the cities of Lancaster and York. **b)** Map of the Yorkshire Dales showing location of Swaledale, the village of Reeth and West Arkengarthdale. **c)** Map of West Arkengarthdale exact coring location at Latitude: 54.458815N, Longitude: -2.067067W.

2.2 Field Sampling Strategy

The field sampling strategy was based on the method used in the ACCROTELM Research Project (ACCROTELM, 2006, De Vleeschouwer *et al.*, 2010b). The deepest point was selected using a depth probe in transects across each site and then overlapping, adjacent cores were extracted using a 5 cm diameter Russian corer, photographed and described using the Troels-Smith (1955) method. The samples were then placed in labelled plastic guttering, wrapped in airtight carbon-stable bags and transported to the laboratory where they were stored at 4°C.

A monolith was also obtained from Mossdale Moor at an exposed section near the coring location. At Oxenhope Moor and West Arkengarthdale, two cores either side of the master cores were also described using the Troels-Smith (1955) method to aid stratigraphic understanding of the sites.

2.3 Laboratory Methods

2.3.1 Sampling in the Laboratory

Sampling in the laboratory followed the protocol used by the ACCROTELM project (ACCROTELM, 2006). The cores were sampled at contiguous 1 cm intervals for humification, plant macrofossils and pollen. Therefore each slice was divided into 3 sections and packed into sealed bags except the samples for pollen which were packed into labelled 15 ml centrifuge tubes. Each bag/tube was labelled with the site code, core number, depth and intended process and stored in the fridge until required.

2.3.2 Chronology

2.3.2.1 Radiocarbon Dating

Age-depth models for each site have been produced in OxCal version 4.2 (Ramsey, 2009) based on calibrated radiocarbon dates obtained from plant macrofossils where possible (Figures 3.1, 4.1, 5.1 and 5.2). Where this was not possible, bulk peat samples were sent to Beta Analytic Miami for analysis, where following pre-treatment, plant material was selected for dating. Calibration of the radiocarbon ages to calendar years BP was conducted using INTCAL13 (Reimer *et al.*, 2013) in OxCal version 4.2 (Ramsey, 2009). The depths selected for radiocarbon dating were chosen following pollen analysis and their positioning at particular points of interest or on boundaries selected by CONISS and by eye.

2.3.2.2 Spheroidal Carbonaceous Particles (SCPs)

When dating recent peats, dating techniques such as radiocarbon dating are not generally applicable due to the long half-life of carbon. As a result, many alternative dating techniques have been developed including the use of SCPs, which are small spheroidal particles of carbon produced from the incomplete combustion of fossil fuels (Parry *et al.*, 2013). They are emitted to the atmosphere and dispersed over wide geographical areas and as a consequence, they have been recorded in many areas of the world including those remote from sources. They are not produced by any natural processes and therefore are unambiguous indicators of atmospheric deposition from power generation and other industrial emissions (Rose and Appleby, 2005). SCPs are well preserved in sediments and have proved useful for reconstructing atmospheric pollution histories from lakes and peatlands and as age-equivalent markers for dating stratigraphic sequences spanning the last 150 years (Swindles 2010). They are also very cheap and easy to analyse and can provide several relative dating features: the start of the record in the mid-19th century; the post-Second World War rapid increase in concentration and the SCP concentration peak (Rose and Appleby, 2005, Parry *et al.*, 2013). However, dates from SCPs rely on calibration from ^{210}Pb in mineral sediments, where mobility is not an issue (Parry *et al.*, 2013). Furthermore, there is now an urgent need to calibrate an independent dating technique to that of ^{210}Pb so that the sediment record for the full industrial period continues to be reliably dated in the future after the decay of ^{210}Pb progressively prohibits it from dating the early part of this period (Rose and Appleby, 2005). The pollen preparation method does not degrade SCPs and therefore, SCPs were counted alongside pollen at all three sites. The results are displayed on each pollen diagram (Figures 3.5, 4.4 and 5.5).

2.3.2.3 ^{210}Pb Dating

Dating using the fallout radioisotope ^{210}Pb is considered one of the most valuable techniques for dating recent sediments. The natural constant fallout of ^{210}Pb allows continuous chronologies to be calculated and ^{210}Pb dating has been applied in a number of circumstances in peats and is now a well-established technique. Despite this, there is still a large degree of uncertainty about the mobility of ^{210}Pb in peats and thus the validity of age-depth models based solely on it. The mobility of ^{210}Pb is not an issue in most sediment types; however, there is evidence of Pb mobility in peats as a result of fluctuating water tables and it is suggested this would impact upon the reliability of ^{210}Pb dating. As a result, caution is now applied when dating peats using ^{210}Pb (Parry *et al.*, 2013).

Recent research by Parry *et al.* (2013) suggests that drier sites provide more reliable ^{210}Pb chronologies because mobility is reduced, whereas wetter sites show less predictable patterns of mobility. Further advances are required in understanding the processes behind the variable quality of fallout radionuclide and SCP dates in peats and therefore the use of two or more dating techniques together is preferable. Therefore, both SCPs and ^{210}Pb were used in the analysis at Mossdale Moor. However, owing to financial and time restrictions, the same could not be applied at Oxenhope Moor and West Arkengarthdale, where only analysis of SCPs and radiocarbon dating were employed.

^{210}Pb dating at Mossdale Moor followed the protocol outlined in He and Walling (1997). A peat monolith was cut into 1 cm sections down to 32 cm depth, which were oven-dried and weighed. Each core slice was then homogenised and subsamples sealed into 50 mm Petri dishes. The samples were then stored for 21 days to allow equilibration between ^{214}Pb and its parent radioisotope ^{226}Ra prior to measurement by gamma spectrometry. Measurements of unsupported ^{210}Pb activities in the soil samples were undertaken by gamma-ray spectrometry, using a high-resolution, low-background, low-energy, hyperpure n-type germanium coaxial y-ray detector (EG and G ORTEC LOAX HPGe) coupled to an ORTEC amplifier and multichannel analyser at the University of Exeter. Total ^{210}Pb was measured by its gamma emissions at 46.5 keV and its unsupported fallout component calculated by subtraction of ^{226}Ra activity, which in turn was measured by the gamma emissions of ^{214}Pb at 295 and 352 keV. The Constant Rate of Supply (CRS) model was used to derive an age depth model from ^{210}Pb data for each core and apparent accumulation rates following procedures described by Appleby (2001). The CRS model is considered the most suitable in ombrotrophic peats as

^{210}Pb inputs are dominated by atmospheric inputs. Uncertainty was calculated from analytical uncertainty and the error propagated from using the CRS model by colleagues at the Northeast Normal University in China. ^{210}Pb dates are displayed alongside radiocarbon dates from Mossdale Moor (Figure 3.1).

2.3.3 Magnetic Susceptibility

2.3.3.1 Review of Method

Magnetic minerals are near-ubiquitous in the natural environment and are highly sensitive to changes in environmental conditions. They are therefore extremely useful palaeoenvironmental indicators. Magnetic susceptibility is a measure of how ‘magnetisable’ a material is (Dearing, 1999, Gale and Hoare, 1991).

Magnetic susceptibility basically measures the total attraction of the first two groups of minerals to a magnet; or a rock’s magnetisability. Rocks with relatively high concentrations of magnetite, like basalt, have much higher magnetic susceptibility values than rocks, such as limestone which usually have no magnetite crystals at all (Dearing, 1999).

Oldfield *et al.* (1981) have shown that ombrotrophic peat bogs preserve a record of particulate output from fossil fuel combustion. Since these mires are not associated with flowing water, particulate matter deposited on the plant surfaces remains approximately in situ to be incorporated in the peat as successive layers of vegetation accumulate. Thus a peat profile will contain a record of particulate deposition from the atmosphere (Oldfield *et al.*, 1981, Petrovský *et al.*, 2000).

Magnetic susceptibility may detect possible tephra layers within the peat profile (Swindles *et al.*, 2010) and can also be used to investigate fire histories as susceptibility increases following burning of surface humus and litter layers (Gale and Hoare, 1991). MS can also be used to infer peat accumulation rates as well as being a cost-effective, quick and non-destructive method.

2.3.3.2 Laboratory Procedure

Magnetic susceptibility was measured in the laboratory using the Bartington MS2 System before the sub-sampling of the cores. Magnetic susceptibility is a mean of the core readings with a drift correction and is a record of broad trends rather than absolute values for specific levels. Precise mass specific measurements (with units) are only possible where the sample volume is accurately defined, which was not the case in this study. The cores were passed through the magnetic field and measured at 0.5 cm intervals using overlapping cores (a) and (b) at each site in an effort to avoid using the top and bottom end of each core which is at a higher risk of contamination as each time a sample is collected, the nose of the corer will disturb the layer of peat directly beneath, from which the upper part of the next sample should be taken. Therefore, if one-borehole sampling is conducted, the top several centimetres of each core are likely to be unsuitable for analysis. The preferred two-borehole technique comprises taking alternating and slightly overlapping samples from two different boreholes (De Vleeschouwer *et al.*, 2010a). The same overlap was used in sub sampling for remaining proxies. Magnetic susceptibility is displayed in SI units for each of the three sites (Figures 3.3, 4.2 and 5.3).

2.3.4 Humification Analysis

2.3.4.1 Review of Method

One of the most widely used techniques in peat-based palaeoclimate reconstruction is peat humification analysis. It is assumed that in a drier climate, water tables will be lower and therefore it will take longer for plant material to reach the anoxic catotelm, subsequently leading to more aerobic decomposition (Blackford and Chambers, 1993). Humification analysis allows changes between and within stratigraphic units to be quantified. The degree of humification is often determined by using an alkali extraction and colorimetric technique, whereby humic acids produced during decomposition are extracted (Blackford and Chambers, 1991). More highly decomposed peat will produce a darker coloured extract and therefore reduced light transmission (Blackford and Chambers, 1993). Yeloff and Mauquoy (2006) highlighted that different plant species may produce different amounts of humic acids. This was termed a ‘species signal’ by Chambers *et al* (1997); however, the species signal is generally unknown. Secondary decomposition may also present another problem, which involves affecting the humification record following subsequent lowering of the water table.

A method of correcting humification data has been developed by Hughes *et al.* (2012) based on the k-values of the species present, in an effort to remove the 'species signal'. The technique was found to be most effective over long (>8000 years) timescales where abrupt changes between *Sphagnum* and sedge-dominated peats occurred, rather than shorter sequences (Roland *et al.*, 2014) and therefore, the technique was not applied in this present study. To avoid the species signal, peat humification could be focussed on peat cores from mires with long records of single-taxon dominance and stable-isotope analyses could be conducted on these single species in those same peat cores (Chambers *et al.*, 2012). However, this was not possible in this study and as it forms part of a multi-proxy study, was not of high concern.

Despite the efficiency of humification analysis being called into question recently, it still remains a moderately fast and simple, operator independent way of producing high-resolution, contiguous datasets, which can aid palaeoclimatic reconstruction when incorporated as part of a comprehensive palaeoecological multi-proxy study (Roland *et al.*, 2014, Chambers *et al.*, 2012). Humification results from various studies covering many sites show general agreement between each other and with other proxy records, therefore suggesting that the technique is generally dependable despite the fundamental mechanisms remaining unclear (Payne and Blackford, 2008).

2.3.4.2 Laboratory Procedure

The preparation and quantification of humification samples follows a modified methodology based on that described by Chambers *et al.* (2011a). The protocol used differs where 0.1 g of sediment is used as opposed to 0.2 g and therefore one phase of filtration has been removed. Humification was analysed contiguously at every centimetre for each of the three sites. 1 cm^3 of peat was sampled, placed in a plastic weighing boat and dried in an oven for 48 hours at 60ºC. Each sample was then ground separately in an agate pestle and mortar and then returned to the weighing boat. 0.1 g of sample was accurately weighed on a top-loading balance (to 3 decimal places) and the sample weight was recorded. The sample was then transferred into a 150 ml beaker where 100 ml of 8% NaOH solution was added to each beaker before the samples were simmered on a hotplate for 1 hour. The beakers were occasionally topped up with deionised water to prevent drying out and to ensure the solution did not become too concentrated. The contents of each beaker were then poured into a 200 ml labelled volumetric flask using a funnel and all residue was washed into the flask with deionised water. The contents of each flask was then filtered into separate 50 ml labelled volumetric flasks through a filter funnel using Whatman No. 1 grade papers (size 15 cm). Only 50 ml of filtrate was transferred. The samples were then measured in a spectrophotometer (set at a wavelength of 540 nm) by pipetting a small volume of filtrate into the first one of three cuvettes and measuring absorbance and % transmission. This was repeated for a second and third time using separate cuvettes and an average was taken of the three readings. The data were then smoothed and de-trended in MS Excel in order to display a horizontal trend line indicating the difference between wet and dry shifts (Figures 3.4, 4.3 and 5.4).

2.3.5 Pollen Analysis

2.3.5.1 Review of Method

Pollen analysis or palynology has been referred to as an excellent quantifiable method for reconstructing vegetation histories. Pollen analysis has a long history and multiple purposes, including reconstructing vegetation history, assessing climate response, human impact, informing biodiversity conservation (Chambers *et al.*, 2011b), honey analysis and in forensic science (Moore *et al.*, 1991).

It is important to consider that other factors such as local soil influences, human impact and the slow response of vegetation to climate also contribute as well as what exactly is being recorded in the pollen record. For instance, local taxa are likely to dominate and this raises the question as to which pollen taxa represent plants that grew on the mire surface. Another point for consideration is that different mire taxa produce varying amounts of pollen. This can cause rises and falls in pollen where this is a periodic dominance of particular mire taxa (e.g. *Calluna* and Cyperaceae) (Chambers *et al.*, 2012). Furthermore, towards the surface of heavily grazed mires in the UK, an ‘increase’ in native arboreal pollen taxa might arise, probably owing to overgrazing of the flowering of local graminaceous species, which may suggest to the pollen analyst that afforestation has occurred but that may well not be the case (Chambers *et al.*, 2011b). However, pollen analysis remains, particularly for Holocene mire sites, often the single or the most important proxy technique for palaeoenvironmental reconstruction used by scientists (Chambers *et al.*, 2012).

2.3.5.2 Laboratory Procedure

The preparation and quantification of pollen samples follows a modified methodology based on that of Bas van Geel (1978) and the pollen protocol used by Chambers *et al.* (2011b). 1 cm^3 of peat was boiled in 5 ml of 10 % NaOH for 10 minutes to remove humic compounds. The sample was then sieved through a 180 µm mesh and poured into a 50 ml centrifuge tube. In between each sample, the metal sieves were oxidised so that any microfossils from earlier samples were destroyed. The sample was then centrifuged up to a speed of at least 2700 rpm for 3 minutes. The tubes were then decanted and the samples washed and centrifuged at least twice until the supernatant was clear (the samples were transferred back to 15 ml tubes at this point). The following steps were undertaken in the fume cupboard. *Lycopodium* tablets which had already been dissolved in 10 ml 10% HCl were added to the samples, then centrifuged and washed twice with deionised water. The samples were then dehydrated with 5 ml glacial acetic acid, mixed and centrifuged. The samples were then acetolysised in a mixture of 1 part sulphuric acid to 9 parts acetic anhydride to dissolve cellulose. The samples were then heated at 100 °C for 10 minutes in a water bath. They were then topped up with glacial acetic acid to stop the acetolysis reaction and then centrifuged and washed with glacial acetic acid (to remove residual dissolved cellulose), then deionised water and centrifuged until the supernatant was clear. A 5 ml water wash with a few drops of sodium hydroxide (alkali to enable absorption by pollen grains) and Gram's saffranine was added and then the samples were centrifuged and decanted again. A few drops of glycerine were then added to the residue dependent upon the residue size (equal glycerine to residue size). The microscope slides were then prepared by pipetting a few droplets on a microscope slide and covering with a glass cover slip.

Pollen grains were identified using Moore *et al.* (1991) and a reference collection of type slides at the University of Gloucestershire. The pollen sum (500 grains) included pollen of trees, shrubs, cultivated plants and ruderals. The abundance data are represented on pollen diagrams prepared using TILIA v.1.7.16 and TILIA*GRAPH (Grimm, 1991) (Figures 3.5, 4.4 and 5.5). The species were grouped by trees, shrubs, mire and heath, woodland and grassland. The diagrams were zoned using both CONISS within TILIA and by noting any changes in pollen abundance by eye. CONISS is an agglomerative cluster analysis technique which compares the total pollen assemblage of each sample with that of its stratigraphic neighbours. Samples that display the lowest dissimilarity are grouped into clusters.

2.3.6 Plant Macrofossil Analysis

2.3.6.1 Review of Method

Changes in peat stratigraphy from plant macrofossil analysis in ombrotrophic mires are regarded as reflecting changes in the hydrological condition at the time of peat accumulation. Such changes have been interpreted as indicating fluctuations in climate, to trace mire development pathways, in studies of long-term vegetation development and to inform conservation management (Mauquoy *et al.*, 2010). Macrofossil remains can regularly be identified to a higher taxonomic resolution than pollen and their deposition near their source enables identification of the local occurrence of taxa (Mauquoy *et al.*, 2010).

Furthermore, plant macrofossils may remain of taxa that produce very little, poorly preserved pollen, or do not produce pollen. However, macrofossils are not usually produced in such abundance as pollen, and larger volumes of sediment are required for their study. Because of their variable local production and dispersal, their representation is very difficult to quantify beyond general terms (Birks and Birks, 2000). There is also the risk that certain taxa such as *Vaccinium oxycoccus* which weaves and spreads across other plants, may be underrepresented in a relatively small sample area in comparison to the size of the site. Therefore, it might be considered that the standard size Russian corer (diameter 5 cm) is too small. This then raises the issue of obtaining a larger sample size, which then means that more sample would have to be analysed, therefore becoming more time intensive. Plant macrofossil analysis relies on the analyst estimating percentages which will vary somewhat between analysts and therefore can make it difficult to compare results from differing sites/studies where there has been more than one analyst.

Despite this, they are a direct representation of the vegetation that produced them, leading to reconstructions at an ecological or site scale and the possibility of interpretations of vegetation change and dynamics. In addition, terrestrial plant material is ideal for AMS ^{14}C dating, overcoming problems with bulk sediment dating such as imprecision because of the amount of sediment needed from a core, old carbon effects and contamination by roots (Birks and Birks, 2000).

The conditions in a blanket mire, including high decay resistance, low pH and waterlogged conditions, usually warrant excellent preservation of mosses such as *Sphagnum* species. Roots and epidermal tissues of monocots are also often well preserved, as well as leaves, stems and seeds of dwarf shrubs. Preservation of macrofossils in blanket mires, however, is variable, and sometimes poor, owing to increased fluctuation of the water-table, a higher degree of humification and slower growth rate (Chambers *et al.*, 2012).

Bog surface wetness can be reconstructed based on the identification of plants representative of both relatively low local water tables (represented by an increase in hummock species of *Sphagna* and *Calluna vulgaris/Empetrum nigrum*) and phases of higher local water-table depths (with aquatic, pool *Sphagna* and *Rhynchospora alba/Eriophorum angustifolium*). Ordination techniques including De-trended Correspondence Analysis (DCA) have been used to generate an index of bog surface wetness based on the total sub-fossil dataset for a peat profile, where it is assumed that the principal axis of variability is linked to hydrology (Chambers *et al.*, 2012).

However, there are difficulties in using DCA; for example, Barber *et al.* (1994) were required to combine the records of *Sphagnum magellanicum* and *S. imbricatum* because *S. magellanicum* seemed to be a direct replacement of *S. imbricatum* at a certain point in the stratigraphic record. Scientists should be fully aware of the patterns in the dataset, and not assume that the first component will automatically be hydrological (Chambers *et al.*, 2012).

2.3.6.2 Laboratory Procedure

Each peat section (from each core and site) was cleaned using a sharp scalpel and palette knife to remove surface contamination, before contiguous sub-sampling at 1 cm intervals through the total depth of each core. Sub-samples measuring approximately 4 cm^3 were taken using a scalpel and sieved through a 125 µm mesh with a standard 5 litre volume of tap water. The samples were transferred to 3 glass petri dishes and spread out to form a monolayer, before quantification using the quadrat and leaf count (QLC) method of macrofossil analysis described by Barber *et al.* (1994). The percentage cover of each vegetative macrofossil component was logged using a 10x10 grid graticule mounted in a stereo dissecting microscope at x10 magnification. Fifteen replicate scans were completed at every sample level to provide a representative estimate of vegetative macrofossil abundance. Seeds were counted as numbers rather than percentages.

Samples were first analysed every 16 cm, then every 8 cm and then every 4 cm where possible depending on total depth of the core. Plant macrofossils were identified following training given at the University of Reading and University of Southampton using type collections and with reference to modern plant material sampled from the study sites. In addition to notes and photos provided on identification from the University of Southampton, Daniels and Eddy (1985) was used to identify *Sphagna* and Smith (2004) was used for non-*Sphagnum* bryophytes. The abundance data are represented on the plant macrofossil diagrams prepared using TILIA v.1.7.16 and TILIA*GRAPH (Grimm, 1991) (Figures 3.6, 4.5 and 5.6). Zonation was based on ecological changes noted by eye.

2.3.7 De-trended Correspondence Analysis (DCA)

DCA was performed using R (R Core, 2012) and “Vegan” (Oksanen, 2013) in order to explore relationships between the plant macrofossil components and for the reconstruction of ecological patterns of the site. A point to consider when using DCA is that it is objective as it relies on natural patterning within the data. The strength of the interpretation of the final curve relies on an analysis of the axis 1-

axis 2 ordination bi-plot where it is determined whether axis 1 reflects a known ecological gradient. Fundamentally, the interpretive relevance of the DCA relies on whether the axes represent realistic environmental variables (Daley and Barber, 2012). Bi-plots using de-trending by segments and down-weighting of rare species are presented in Figures 4.6, 5.7 and 5.8.

2.3.8 Dupont Hydroclimatic Index (DHI)

Another statistical technique that can be applied to plant macrofossil data is the Dupont Hydroclimatic Index (DHI) (Dupont, 1986). DHI is a weighted averaging function where 'weights' are given to individual species based on qualitative ecological knowledge of their modern relationship to water table depth (Daley and Barber, 2012). More recent modification has included the allocation of monocotyledonous remains to specific classes, including class 7 for *Eriophorum vaginatum* remains (Mauquoy *et al.*, 2008, Daley and Barber, 2012). In a test of DCA against the DHI, Daley and Barber (2012) found that the latter provided a curve that correlated more closely with variations in independent proxy data from the same core, where the record incorporated data from both the upper and lower peat types, thus indicating that DHI may yield a meaningful result. Weights were assigned to species based on those used in Daley and Barber (2012) and Mauquoy *et al.* (2008) and the DHI scores were calculated in Excel using plant macrofossil percentages. The results were then smoothed and de-trended and are presented in Figures 3.7, 4.7 and 5.9.

Chapter 3: Mossdale Moor Results and Interpretation

This chapter covers the results and interpretation of laboratory analysis from the peat core obtained from Mossdale Moor. The results have been consolidated and presented in tables where appropriate to aid comparison and interpretations using all the methods as evidence.

The ecological condition of Mossdale Moor is described as degraded blanket mire with peat hags at the site with modern-day peat supporting species characteristic of National Vegetation Classification (NVC) M19 (Rodwell, 1998). Various management practices such as burning, drainage and grazing have been undertaken to develop the moor for livestock and grouse rearing, which has altered the vegetation characteristics of the moor from typical blanket mire towards heathland communities.

3.1 Lithology

The lithology of Mossdale Moor is shown in Figures 3.5 and 3.6 alongside the pollen and charcoal and plant macrofossil results, following the Troels-Smith (1955) method and is described in Table 3.1.

3.1.1 Description

Mossdale Moor is underlain by an irregular surface of pale grey clay sediments overlain by highly humified Sh (very humified organic matter). The overlying material is decomposed such that it is difficult to ascertain whether the sediment is limus, turfa or detritus. Above this are thick layers of Turfa herbacea (Th) peat, composed largely of the roots of herbaceous plants, mainly *Eriophorum vaginatum*.

Table 3.1: Description of lithology at Mossdale Moor and depths (cm).

Depth (cm)	Description
0–27	Herbaceous (notably *Eriophorum vaginatum*) and highly humified peat.
27–50	Mainly herbaceous peat with some highly humified peat.
50–67	Mainly highly humified peat with some herbaceous peat.
67–100	Mainly highly humified peat.
100–150	Mainly highly humified peat.
150–158	Mainly highly humified peat with some Limus detritus.
158–170	Mainly Limus detritus with some highly humified peat.

3.2 Chronology

3.2.1 Description and Interpretation of SCPs

The first occurrence of SCPs can be seen at 20 cm depth (Figure 3.5), dated to approximately cal. AD 1740 according to radiocarbon dates (Figure 3.1). The industrial revolution started as early as AD 1760; however, small-scale local manufacturing may have contributed to the SCP record in the area before this. The first peak in SCPs can be seen at 13.5 cm depth, dated to cal. AD 1900, which may be indicative of the industrial revolution. The biggest peak, however, is seen at 1.5 cm depth, dated to cal. AD 2000. The most recent peak would usually relate to the 1970s or 1980s, which may suggest that peat has not been actively forming at Mossdale Moor in recent years or that erosion has been taking place, which is not unexpected given its degraded state.

3.2.2 Description and Interpretation of Radiocarbon Dates

The date from the base of the peat was obtained using charred material extracted at Beta Analytic from a bulk peat sample (151–149 cm) as no suitable plant macrofossils could be extracted at this depth (Table 3.2). The age of this date implies a much slower accumulation rate between 150 cm and 118 cm depth. The sample at 34.5 cm depth was dated using *Polytrichum commune*. Samples at 58.5 cm, 74.5 cm, 94.5 cm and 118.5 cm were dated using *Eriophorum vaginatum* leaf remains, implying a possible decrease in age owing to the possibility of misidentification between leaf and root remains therefore explaining why the ages at 58.5 cm and 74.5 cm depths are too young. Samples at 134.5 cm and 65.5 cm depths were dated using the plant fraction of peat samples extracted at Beta Analytic. All dates have been modelled (see Figure 3.1) and those that show increasing age with depth have been accepted.

Table 3.2: Radiocarbon Dates from Mossdale Moor: Depth (cm), Radiocarbon date (yr BP), Beta Analytic Lab Number, Calibrated Ages (yr BP) and Material used. *Rejected radiocarbon dates – both dates were rejected based on the fact that they appear too young. **Radiocarbon dates were calibrated using OxCal version 4.2 (Ramsey 2009). (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Depth (cm)	Radiocarbon date (yr BP)	Lab No.	Calibrated Age (yr BP)**	Material
150	5310 ± 30	364579	6267 (6105.5) 5944	Charred material
134.5	2610 ± 30 BP	385276	2844 (2692) 2539	Plant material
118.5	1520 ± 30	327200	1528 (1421) 1314	Monocot leaves
94.5	1340 ± 30	327199	1334 (1257) 1180	Monocot leaves
74.5	350 ± 30*	327198	503 (404.5) 306	Monocot leaves
65.5	1070 ± 30 BP	385275	1067 (994) 921	Plant material
58.5	480 ± 30*	327197	625 (547) 469	Monocot leaves
34.5	530 ± 30	327196	645 (573.5) 502	*Polytrichum commune*

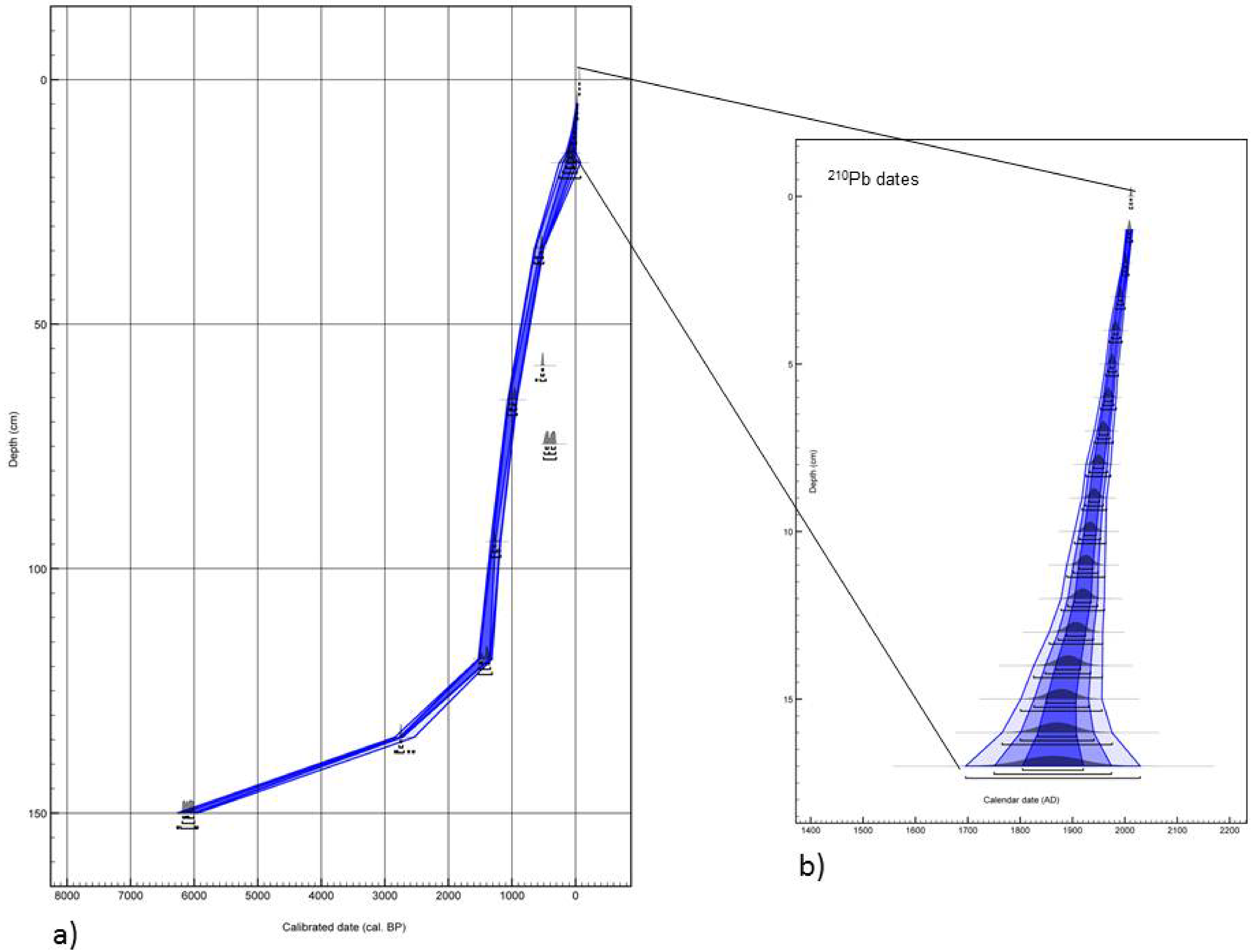


Figure 3.1: a) Bayesian (P_Sequence) age-depth model for Mossdale Moor from a combination of 6 accepted and 2 rejected (excluded from blue line) AMS radiocarbon dates and **b)** 17 ^{210}Pb dates both constructed using OxCal version 4.2 software (Ramsey, 2009) and calibrated using INTCAL13 (Reimer *et al.*, 2013).

3.2.3 Description and Interpretation of ^{210}Pb dates

Depth profiles for ^{210}Pb typically show exponential decline with depth throughout the core (see Figure 3.2). The Constant Rate of Supply (CRS) model was used to develop an age-depth model from ^{210}Pb data using the method described by Appleby (2001). The CRS model is thought to be the most appropriate in ombrotrophic peats as ^{210}Pb inputs are dominated by atmospheric inputs (Appleby, 2008). Uncertainty was calculated by colleagues at Northeast Normal University, China using analytical uncertainty and the error propagated using the CRS model. The level of activity decreases below 17 cm depth and at this point, the error margin becomes unreliably larger and the dates calculated exceed beyond the 130 year range of ^{210}Pb dating (Appleby, 2008) and so were excluded from the age-depth model (see Figure 3.1).

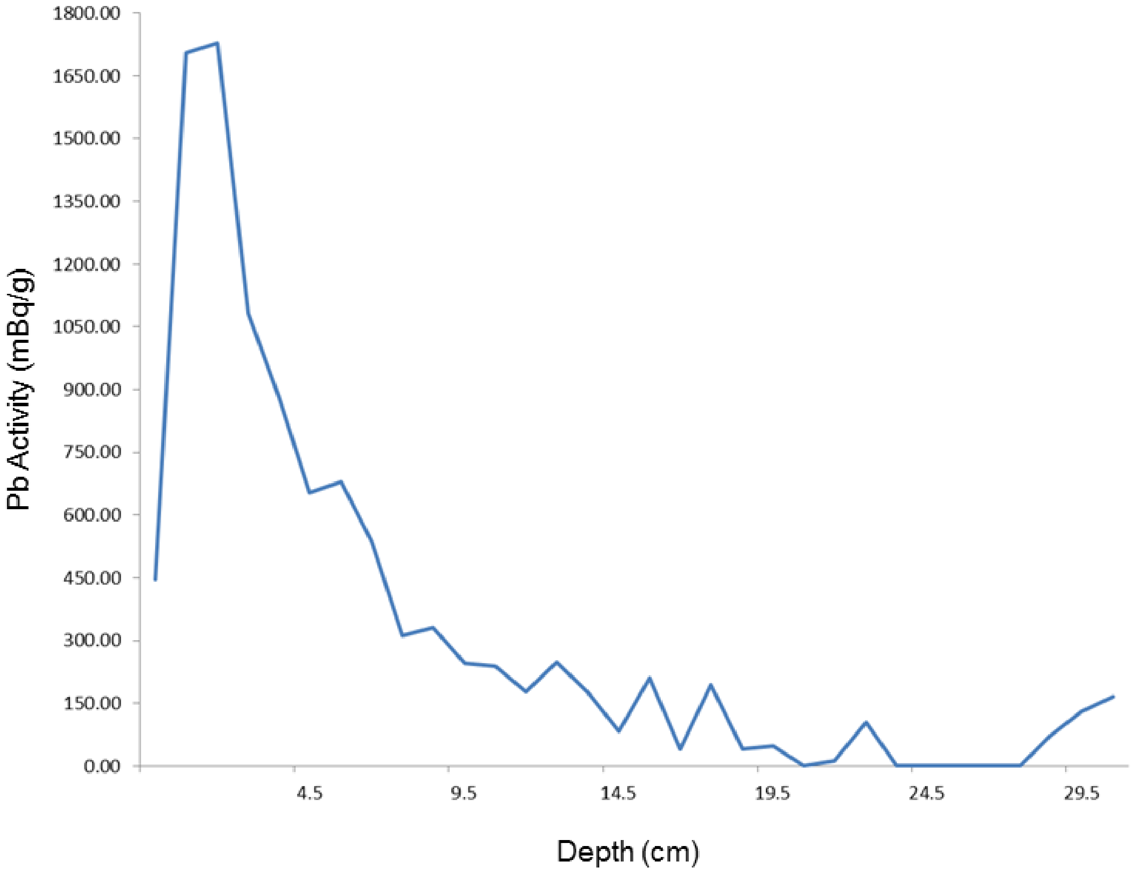


Figure 3.2: ^{210}Pb activity (mBq/g) and depth (cm) at Mossdale Moor.

3.3 Magnetic Susceptibility

3.3.1 Description

The Magnetic Susceptibility (MS) curve can be sectioned into five zones based on changes in values. These are: 170–115 cm, 115–75 cm, 75–40 cm, 40–21 cm and 21–0 cm (Figure 3.3). In the first zone, values are relatively low at -5 at 150 cm depth and then increase to -2 at 130 cm depth. At approximately 117 cm depth, values reach the lowest in the profile at -12. In the second zone, at 115 cm depth, values increase to -2.5 and fluctuate between -2.5 and -2 until 75 cm depth, where values increase to approximately -2. In zone 3, values increase to -5.5 before 75 cm depth and then increase again to -4.0 at 60 cm depth. They then decrease to -6.5 at 50 cm and then increase at 40 cm to approximately -4.0. In the fourth zone, values increase and fluctuate slightly around -2.0. In the final zone, MS values decrease to approximately -5, before beginning to increase from 15 cm up to a maximum of 3.5, the highest value in the profile, before decreasing to 2.0 towards the surface.

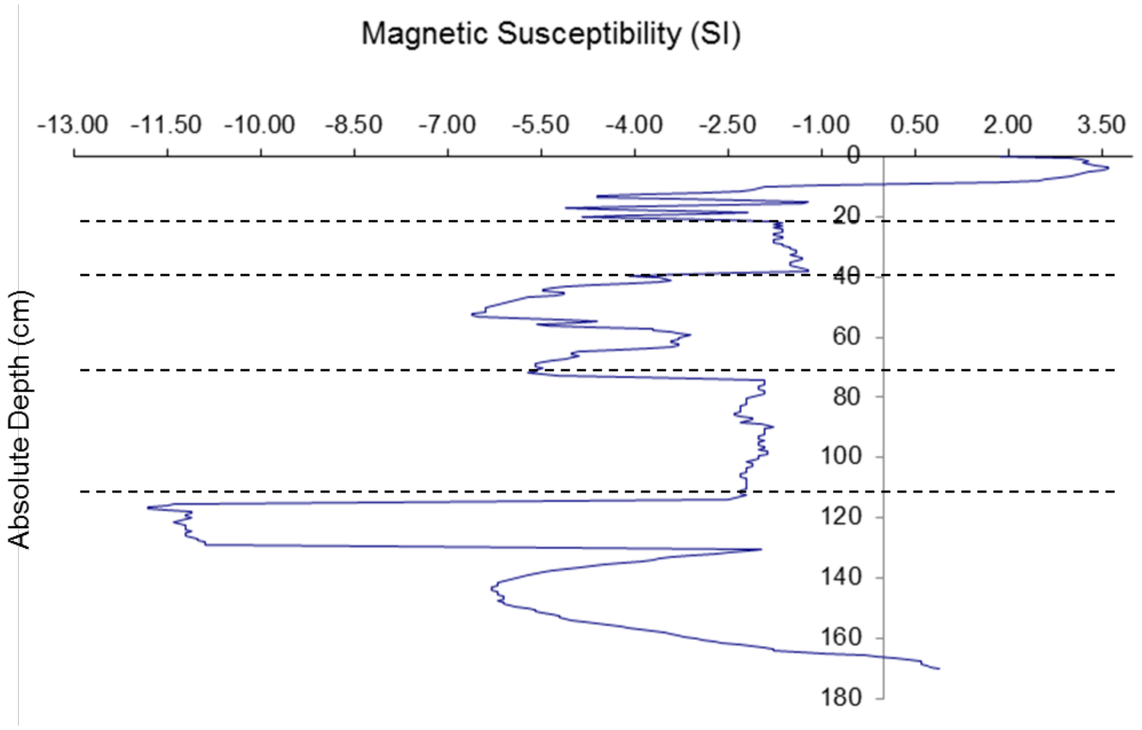


Figure 3.3: Magnetic Susceptibility (SI) and depth (cm) at Mossdale Moor.

3.3.2 Interpretation

The high MS values towards the base of the profile (150–140 cm) could be attributed to an increase in mineral content. At this depth, the peat was beginning to establish above clay sediments which have a higher magnetisability. During these depths, the number of *Lycopodium clavatum* spores from pollen analysis is low (Figure 3.5), suggesting high accumulation rates (a high number of *L. clavatum* spores means that it took longer to reach the count of 500 terrestrial pollen grains – less pollen suggests that peat may have been accumulating quickly and thus pollen grains are more diluted within the peat).

Between 115 cm and 75 cm depth, high MS values can be seen, as can a high accumulation rate as indicated by the presence of very few *L. clavatum* spores (Figure 3.5). At 75 cm, a peak in MS values is consistent with a peak in *L. clavatum* counts suggesting a brief period of slower accumulation. Another peak in *L. clavatum* spores can be seen between 50–40 cm depth, coincident with a peak in MS values at 50 cm depth, again, suggesting another brief period of slower accumulation. The increase in MS values seen between 40–20 cm could be attributed to a low accumulation rate, evidenced by high *L. clavatum* counts, the highest in the profile. A link to fire has been dismissed as charcoal is low at this point (Figure 3.5).

The rise in values towards the surface (c. 15–0.5 cm) could be attributed to increasing atmospheric pollution from the combustion of fossil fuels (Oldfield *et al.*, 1981, Petrovský *et al.*, 2000). The decrease from 0.5 cm to the surface may be attributed to the introduction of clean air policies in recent decades, thus reducing atmospheric pollutants and therefore reducing the MS values. Peat accumulation rate is also low at this point, as indicated by a high number of *L. clavatum* spores. The number of charcoal fragments is high, indicating the occurrence of fire on the mire, which may have an effect on MS (Gale and Hoare, 1991).

3.4 Humification

The transmission percentage (%T) and absorption were both measured when analysing humification. %T decreases in proportion to the fraction of mineral matter in the peat; however, the mineral content was negligible (except in the basal lacustrine samples where humification analyses results were not included) and so the results were not corrected. The raw percentage transmission results were exponentially smoothed in MS Excel and then de-trended using a linear regression model to remove any long-term trends; hence, transmission is no longer expressed as a percentage, but as a number.

3.4.1 Description

T values are higher between 140–110 cm depth, where they range between 0.9 and 1.6, the highest T value in the profile (Figure 3.4). Between 110–60 cm depth, T values are generally low, ranging between 0.6 and 1.1. Between 60–35 cm depth, values are low and fluctuate varying from a low of c. 0.6 to a high of c. 1.2. Values are particularly low at c. 37 cm depth where they reach 0.6. T values are relatively high between 35–0 cm depths, ranging between 0.9–1.3. T values are at their highest in this section when they reach 0.3 at c. 25 cm depth.

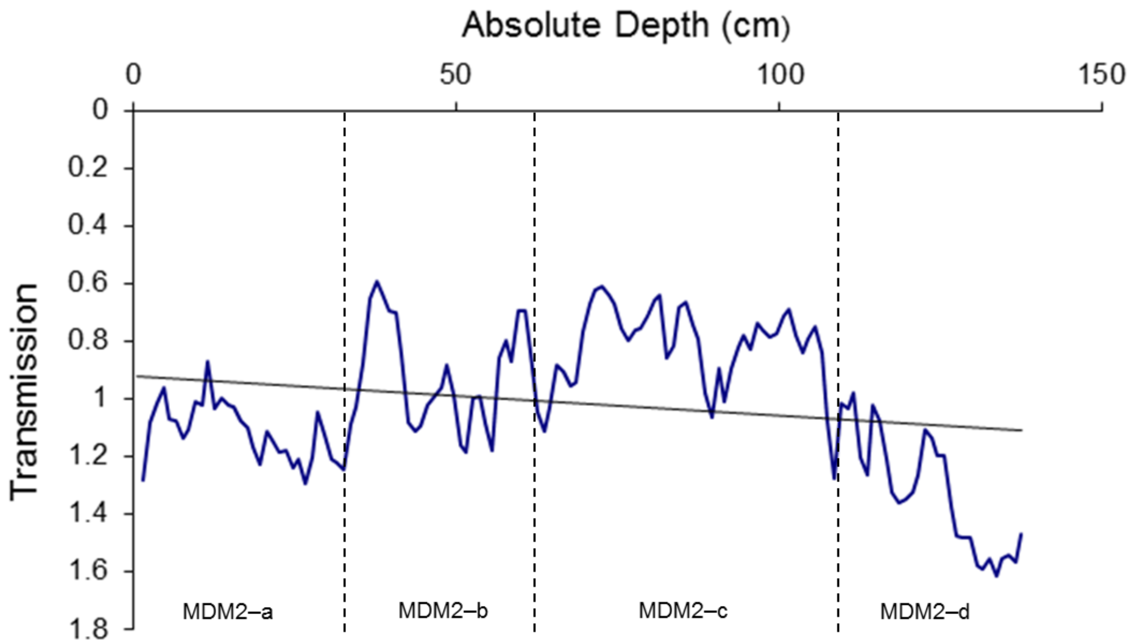


Figure 3.4: Humification (Transmission) and depth (cm) at Mossdale Moor.

3.4.2 Interpretation

At the base of the profile, between 140 cm and 110 cm depth (3900 cal. BP), high T values suggest that conditions were wet on the mire surface. Following this, conditions are generally interpreted as being dry between 110 cm (1350 cal. BP) and 65 cm depth (1000. cal BP), as indicated by low T values.

Between 60–35 cm depth, T values fluctuate over the trend-line suggesting a movement between wet and dry conditions on the mire surface before becoming dry at c. 60 cm depth, dated to 900 cal. BP (cal. AD 1050). T values reach a further low of 0.6 at 37 cm depth, dated to 600 cal. BP (cal. AD 1350) which could be interpreted as the warming associated with the Medieval Warm Period (MWP).

Between 35–0 cm depths, generally high T values suggest that conditions on the mire have been relatively wet between 570 cal. BP (cal. AD 1380) and the present day. However, this may also reflect the low decomposition rates of the acrotelm and the fact that this plant material has not had as long to decompose as the lower layers of peat in the catotelm. A particularly high T value of 1.2 at 26 cm depth is dated to 240 cal. BP (cal. AD 1700) which could be interpreted as the cooling associated with the Little Ice Age (LIA).

3.5 Pollen Analysis

3.5.1 Description

Table 3.3: Pollen zone descriptions at Mossdale Moor using: depth (cm), radiocarbon ages (cal. BP) and humification (Wet/Dry). (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Pollen Zone	Depth (cm)	Age (cal. BP)	Humification (Wet/Dry)	Description
MDM2 – A	160–145	c. >6100–5400	Wet	High percentages of *Corylus* (40%), *Myrica* (10%), Poaceae (20%) and *Filicales* (>40%). Low levels of *Calluna* (<10%).
MDM2 – B	145–120	c. 5400–1400	Dry	High percentages of *Calluna* (50%) and *Sphagnum* (400 spores counted). *Corylus* and Poaceae less abundant that in Zone MDM2 – A.
MDM2 – C	120–95	c. 1400–1300	Dry	*Corylus* and *Sphagnum* less abundant than in Zone MDM2 – B, high percentages of *Vaccinium* (20%) and *Alnus* (20%) and increasing percentages of *Calluna* (60%).
MDM2 – D	95–35	c. 1300–600	Wet	*Quercus*, *Alnus* and *Corylus* less abundant than in Zone MDM2 – C. High percentages of *Calluna* (80%), *Sphagnum* (>500 spores counted) and *Tilletia sphagni* (200 spores counted).
MDM2 – E	35–0	c. 600–-60	Wet	*Calluna*, *Corylus* and *Betula* are less abundant than in Zone MDM2 –B. Numbers of *Sphagnum* and T*illetia sphagni* spores are minimal (<20). High percentages of Poaceae (20%) and an increase in abundance of *Plantago* compared to previous zones.

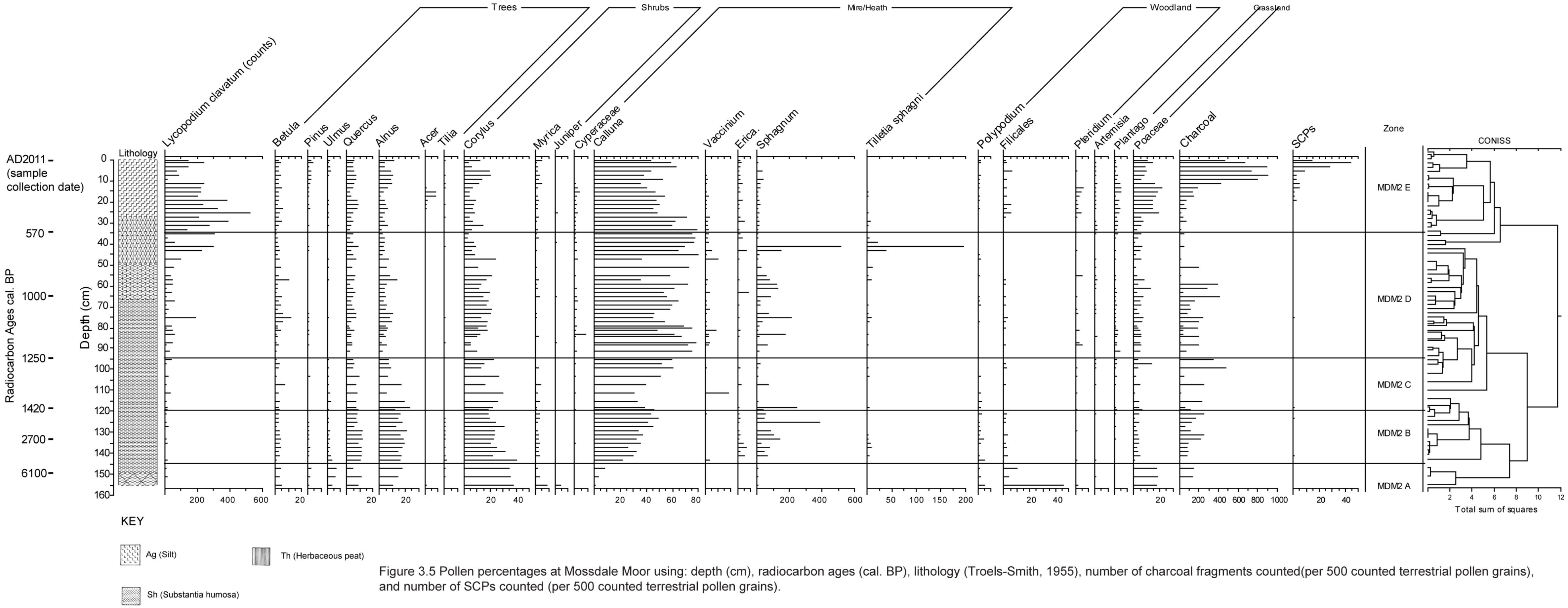


Figure 3.5 Pollen percentages at Mossdale Moor using: depth (cm), radiocarbon ages (cal. BP), lithology (Troels-Smith, 1955), number of charcoal fragments counted(per 500 counted terrestrial pollen grains), and number of SCPs counted (per 500 counted terrestrial pollen grains).

3.5.2 Interpretation

3.5.2.1 MDM2 – A (160–145 cm depth) *Filicales-Corylus-Poaceae*

Low levels of *Calluna*, a dryness indicator preferring well drained acid soils, coupled with high levels of *Corylus* (possibly growing in close vicinity to the bog) preferring damp neutral or moderately acid soils, reaching 40% in this zone suggests moist conditions (Clapham *et al.*, 1962, Preston *et al.*, 2002) (Table 3.3, Figure 3.5). This zone also sees the highest levels of Poaceae in the profile at 18%, suggesting relatively open ground. *Myrica gale* is at its highest numbers in this zone, which is associated with bogs, fens and wet heaths. Low levels of charcoal also suggest wet conditions on the mire. Most of the evidence indicates wet conditions; however, the combination of low levels of *Calluna* and the high numbers of Poaceae would suggest gradual establishment of grass heath and the initial colonisation of the basin.

3.5.2.2 MDM2 – B (145–120 cm depth) *Calluna-Corylus-Sphagnum*

Calluna is associated with drier conditions and is seen to rise in this zone, coincident with the presence of charcoal, particularly at 134 cm and 124 cm depths. Such conditions are suitable for *Quercus*, likely to be growing in close proximity to the bog, to remain steady. Contradictory to this, a peak in *Sphagnum* can be seen at 127 cm, which is associated with wetter conditions. Steady levels of *Alnus* perhaps growing close by the bog suggest a brief movement towards wetter conditions but not wet enough to significantly deter drier loving species such as *Calluna vulgaris* (Stace, 1997). However, *Calluna vulgaris* can inhabit a range of sites from dry exposed habitats to wet peat bogs and can colonise newly available habitats (Preston *et al.*, 2002). The evidence would suggest dry conditions at the beginning of this zone with a brief movement to slightly wetter conditions, followed by a return to drier conditions towards the top of the zone.

3.5.2.3 MDM2 – C (120–95 cm depth) *Calluna-Corylus-Pteridium*

Corylus decreases in this zone, as do *Alnus* and *Quercus*. Growing on the bog, levels of *Calluna* rise steadily throughout the zone before starting to descend at approximately 82 cm depth. *Vaccinium*, most likely the wetness indicator *V. oxycoccus*, normally coincident with *Sphagnum* and indicative of wet conditions reaches higher levels at c. 115 cm depth consistent with an absence of charcoal.

There are two peaks in the number of charcoal fragments counted before and after the absence at 101 cm and 94 cm depth, suggestive of how rapidly conditions can change in an environment.

3.5.2.4 MDM2 – D (95–35 cm depth) *Calluna-Corylus-Sphagnum*

Calluna rises again following a slight decrease at 80–70 cm depth. Cyperaceae is seen to increase in this zone, with a small peak at 85 cm depth. Cyperaceae is known to grow in environments with abundant water (Ueno and Takeda, 1992); *Sphagnum* and *Vaccinium* also increase at this depth. At 42 cm depth, *Sphagnum* numbers reach their highest throughout the profile at more than 500 spores counted. Numbers of *Tilletia sphagni* spores are consistent with this peak reaching 200 spores counted. van Geel (1978) stated that *Tilletia sphagni* infects *Sphagnum cuspidatum* more often than other *Sphagnum* species as it is more prone to infection caused by this fungus (Kupryjanowics, 2004). The high values of *Tilletia sphagni* combined with an increase of *Sphagnum* spores may indicate a more abundant presence of *Sphagnum cuspidatum* on the peat bog. *Sphagnum cuspidatum* is the most aquatic of the British species of *Sphagnum*, generally being found in pools and depressions in bogs (Atherton, 2010), therefore indicating wet conditions at the time. No charcoal fragments were counted at this depth (42 cm).

Alnus percentages decrease at this depth, indicating that at this point in the succession conditions are perhaps too wet to sustain the growth of shrubs and trees. The decrease in tree pollen at the beginning of this zone may have been caused by woodland clearance by man as it is synchronous with peak in charcoal at 95 cm depth. There is also no *Sphagnum*, a drop in *Corylus* and an increase in numbers of *Calluna*.

3.5.2.5 MDM2 – E: (35–0 cm depth) *Calluna-Poaceae-Plantago*

This zone is characterised by fluctuations in pollen percentages. Numbers of charcoal fragments and percentages of Poaceae and *Plantago* pollen reach much higher levels than throughout the entirety of the pollen diagram, which is indicative of burning management. *Plantago lanceolata* is indicative of human activity and can be found in cultivated ground and open habitats (Clapham *et al.*, 1962, Preston *et al.*, 2002). SCPs are also present in high numbers in this zone, another indicator of recent anthropogenic activity. *Sphagnum* decreases rapidly in this zone when compared to the previous (MDM2 – D). At 16 cm depth, dated at cal. AD 1740, *Calluna* slightly decreases whilst *Quercus, Alnus* and *Corylus* decrease to very low percentages. Poaceae and charcoal begin to increase in numbers throughout the zone, suggesting that the resulting vegetation changes may be a consequence of fire. *Quercus, Alnus* and *Corylus* then rise slightly at 10 cm depth dated cal. AD 1840 before decreasing again at 3–2 cm depth and then finally rising again at 1 cm depth. Numbers of charcoal reduce with the increase in tree and shrub pollen at the surface level; this may indicate recent efforts of restoration.

3.6 Plant Macrofossil Analysis

3.6.1 Description

Table 3.4: Plant macrofossil zone descriptions at Mossdale Moor using: depth (cm), radiocarbon ages (cal. BP) and humification (wet/dry). (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Plant Macrofossil Zone	Depth (cm)	Age (cal. BP)	Humification (Wet/Dry)	Description
MDM2 – 1	170–130	c. >6100–3100	Wet	Highest numbers of *Cennococcum* fungi (2), and high percentages of UOM (>90%) and Quartz grains (55%).
MDM2 – 2	130–100	c. 3100–1300	Dry	High percentages of UOM (80%), *Eriophorum vaginatum* (40%), *Equisetum fluviatile* (10%) and *Scheuchzeria palustris* (<5%). Cennococcum fungi are less abundant. Presence of charred remains.
MDM2 – 3	100–67.5	c. 1300–900	Dry	Presence of *S. palustris* throughout zone (10%), high percentages of *E. vaginatum* (40%) and Monocot roots (20%).
MDM2 – 4	67.5–15	c. 900–70	Wet	High percentages of identified Sphagnum (60%), notably *S. molle* (>80%), *E.vaginatum* leaves (30%) and Monocot leaves (20%). Presence of *Polytrichum commune* (<5%).
MDM2 – 5	15–0	c. 70–-60	Wet	Lower percentage of UOM (<30%), highest percentages of *Vaccinium oxycoccus* stems (10%), Monocot roots (>50%) and *P. commune* (5%).

3.6.2 Interpretation

3.6.2.1 MDM2-1 (170–130 cm depth) *UOM-Quartz-Monocots*

Numbers of *Cennococcum* fungi are higher in this zone than any other representing drier conditions, as do high levels of UOM (Chambers *et al.*, 2013b) (Table 3.4, Figure 3.6). The quartz grains come from the pale grey clay sediments underlying the peat.

3.6.2.2 MDM2-2 (130–100 cm depth) *Monocots-Eriophorum vaginatum-Scheuchzeria palustris-Equisetum fluviatile*

High percentages of UOM in this zone may suggest a higher rate of decomposition and thus drier conditions. *Eriophorum vaginatum* has a notable presence and is

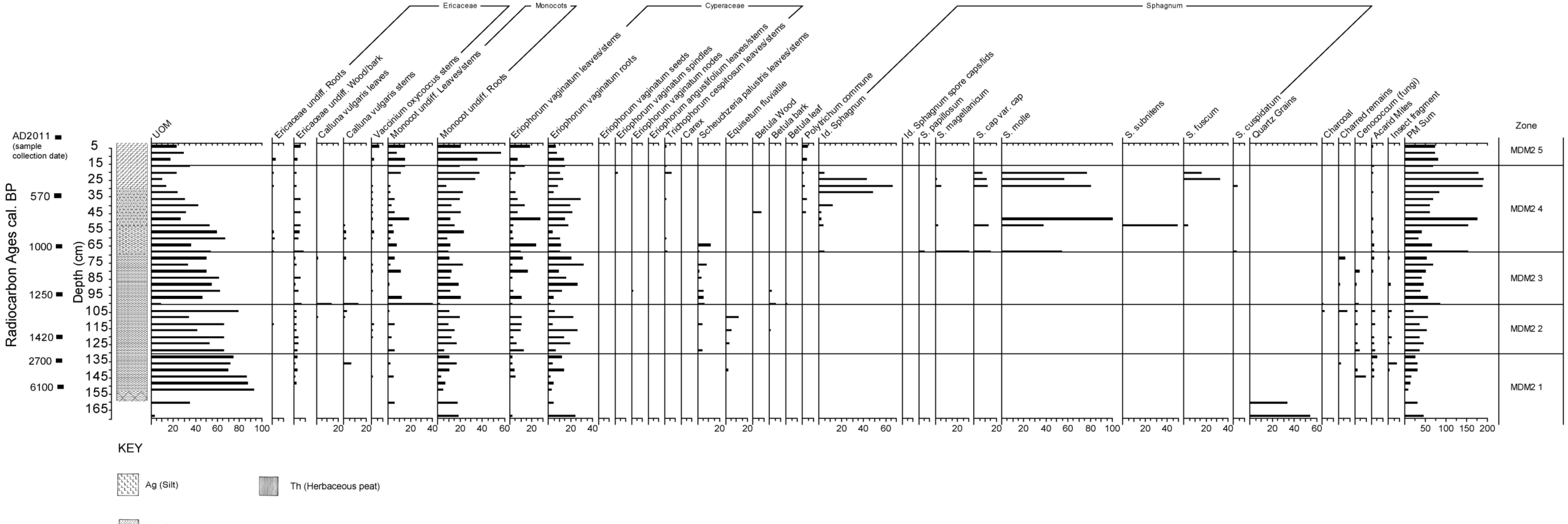


Figure 3.6 Plant macrofossil percentages at Mossdale Moor using: depth (cm), radiocarbon ages (cal. BP), and lithology (Troels-Smith, 1955).

usually found on wet heaths and mires, including blanket and raised bogs. It is characteristic of wet peaty moorlands, often dominant or co-dominant with *Calluna vulgaris*, where it survives, or even increases, after burning (Preston *et al.*, 2002). *Scheuchzeria palustris* is also present throughout the zone, maintaining a steady 5%. *Scheuchzeria palustris* is indicative of wet habitats, typically found in acid runnels, pools or semi-submerged in *Sphagnum* lawns at pool edges. It is now only found in Scotland as all English and Welsh sites were lost before 1900 owing to drainage and eutrophication (Preston *et al.*, 2002). *Eriophorum vaginatum* and *Scheuchzeria palustris* are both typical of a fen peat environment.

3.6.2.3 MDM2-3 (100–67.5 cm depth) *Calluna-Eriophorum vaginatum-Monocots-Scheuchzeria palustris*

Eriophorum vaginatum is known to survive and even increase after burning. The presence of charred remains would also support that fire was present at this time as would the presence of *Cennococcum* fungi, which is usually found in dry conditions. *Scheuchzeria palustris* reaches maximum percentage throughout the profile in this zone indicating a high water table. It is also associated with minerotrophic peatland areas, as is the case here as it occurs above the minerotrophic clay basal sediments. Thick layers of this grass usually precede *Sphagnum* growth (Mauquoy, 2007). This is concurrent with *Sphagnum* which begins to establish itself in the next zone, MDM2 – 4.

3.6.2.4 MDM2-4 (67.5–15 cm depth) *Scheuchzeria palustris-Sphagnum molle-Eriophorum vaginatum-Monocots*

This zone sees the introduction of *Sphagnum*, notably *Sphagnum*. section. *Acutifolia* which are hummock forming species. The majority of the identified *Sphagnum* consists of *S. molle*, *S. subnitens* and *S. fuscum*, all found on blanket bogs and usually forming hummocks (Rydin *et al.*, 2006), representative of relatively dry conditions. A very small amount of *S. cuspidatum* is identified at 30 cm depth, consistent with the lowest percentages of UOM throughout the profile, indicating a lower rate of decomposition owing to wetter conditions. *S. cuspidatum* is representative of wet conditions as it is usually found in pools. Below 30 cm depth, the percentage of UOM increases as the percentage of *Sphagnum* decreases, representative of dry conditions on the mire throughout the profile, with the exception of 30 cm depth, dated to 390 cal. BP (cal. AD 1550).

3.6.2.5 MDM2-5 (15–0 cm depth) *Monocots-Vaccinium oxycoccus-Polytrichum commune*

Low levels of UOM and the highest presence of *Vaccinium oxycoccus* and *Polytrichum commune* throughout the profile in this zone suggest that Mossdale Moor is becoming wetter and more biodiverse. However, low UOM may be representative of the low decomposition rate in the acrotelm compared to the lower layers of peat in the catotelm. The presence of a high level of monocots (60%) shows an expansion of grass species, possibly after the start of the industrial revolution. Such grasses are known to endure fire and burning at the expense of heather (Chambers, 2001a) and species such as *Sphagnum*, of which none was found in this zone.

3.6.3 De-trended Correspondence Analysis (DCA)

DCA was conducted on plant macrofossils using R (R Core, 2012). DCA was performed using “Vegan” version 2.0-9 (Oksanen, 2013) and the first and second axes of the ordination were plotted against each other but did not show that the plant macrofossil taxa are arranged along a hydrological gradient. The model did not perform well with an eigenvalue of 0.164 along axis 2 and 0.445 along axis 1 with only stratigraphic and abundance relationships indicated and therefore the data are not included in the results section.

3.6.4 Dupont Hydroclimatic Index (DHI)

As the DCA ordination failed to detect the presence of a mire surface wetness gradient in the plant macrofossil data, DHI (Dupont, 1986) has been applied to the plant macrofossil data to provide a qualitative indication of changes in water table (Figure 3.7). The indices used were: UOM 8, *Vaccinium oxycoccus* 5, *Calluna vulgaris* 8, Ericaceae undifferentiated 8, monocots undifferentiated 6, *Eriophorum vaginatum* 6, *Eriophorum angustifolium* 2, *Rhynchospora alba* 3, *Trichophorum cespitosum* 6, *Scheuchzeria palustris* 2, *Carex* 3, *Equisetum fluviatile* 2, *Betula* 7, *Polytrichum commune* 7, *Sphagnum papillosum* 4, *Sphagnum magellanicum* 3, *Sphagnum* section *Acutifolia* 4, *Sphagnum cuspidatum* 1, based upon the weights used in Daley and Barber (2012) and Mauquoy *et al.* (2008) and knowledge of ecological tolerances and habitat preferences of each species.

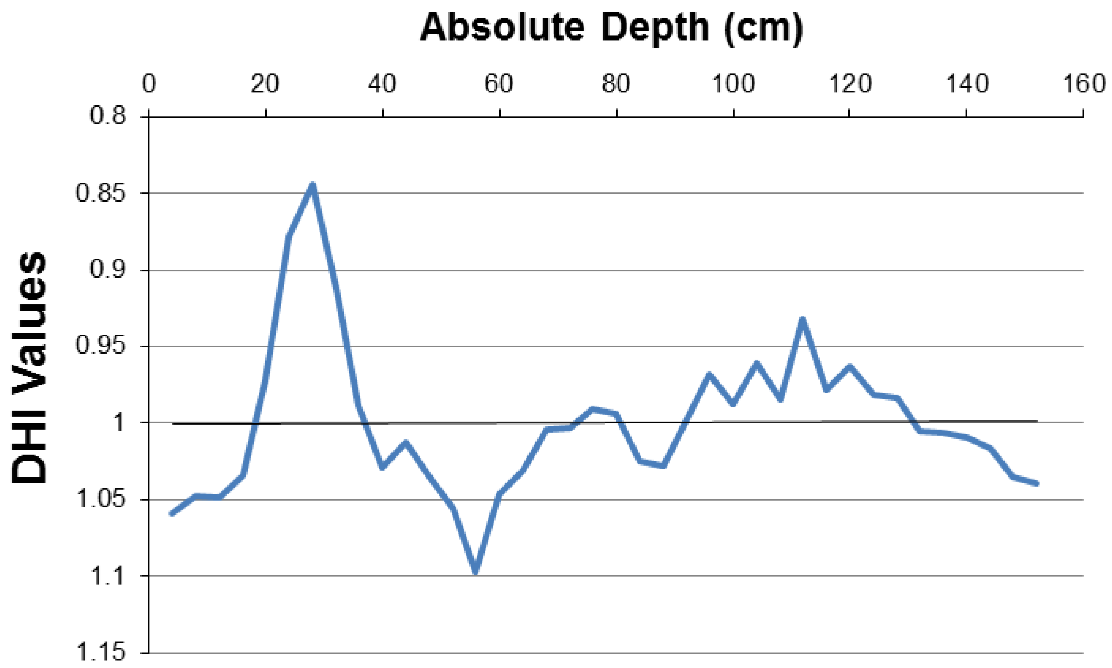


Figure 3.7: Smoothed and De-trended DHI curve for plant macrofossils from Mossdale Moor.

The data have been de-trended, therefore meaning they are now displayed as lower values than the scores attributed to the species. Low values indicate wet conditions, therefore suggesting that the mire was wet at 140–130 cm (3950–2300 cal. BP), 90–80 cm (1200–1100 cal. BP), 65–45 cm (1000–750 cal. BP) and 35–20 cm (cal. AD 1390–1760) depths (Figure 3.7). The DHI curve is in agreement with the humification curve at 140–130 cm depth, 65–45 cm depth and 35–20 cm depth (LIA). However, the reliability of the DHI curve is questionable, given that there seems to be a disappearance of *Sphagnum* in the plant macrofossils below 65 cm depth, as indicated by the presence of *Sphagnum* spores counted in pollen analysis. Furthermore, the humification curve suggests dry conditions between 90–80 cm depths, whereas the DHI curve suggests that the mire was wet. To overcome the difficulties created by the loss of *Sphagnum* from the plant macrofossil record (which may suggest high decomposition rates supported by high levels of UOM (Loisel and Yu 2013), it is possible to use lipid analysis to see whether any traces of *Sphagnum* are present at these depths despite the absence in the plant macrofossils. This will be further discussed in Chapter 6.

3.7 Summary of Magnetic Susceptibility, Humification, Pollen, Plant Macrofossil Data and SCP and Radiocarbon Dates

Higher numbers of *Sphagnum* spores occur from 135 cm depth (c. 3800 cal. BP) upwards accompanied by low humification (Table 3.5). At 125 cm (c. 2200 cal. BP), there is a rise in *Sphagnum* spores (400 spores counted) and the humification curve falls below the trend line; these are all indications of wetter conditions. The presence of *Vaccinium oxycoccus*, *Scheuchzeria palustris* and *Equisetum fluviatile* in the plant macrofossils and relatively low DHI values also support wetter conditions at this time.

A substantial dry shift is apparent between 107 and 95 cm depth (1400–1300 cal. BP). Evidence for this includes high humification, an absence of *Sphagnum* and high levels of UOM in the plant macrofossils. However, the DHI curve has low values at this stage, suggesting wet conditions, which seems to be an anomaly given that lower *Sphagnum* spores and increasing *Calluna* are identified from pollen analysis. Decreasing tree pollen and a slight decrease in *Corylus* can be seen from the pollen record as well as increasing charcoal. The decreasing tree and shrub pollen may be attributed to anthropogenic activity. This however, would not explain the high humification and absence of wetness indicators in the plant macrofossil record. It is possible that this observed signal is a combination of a drier climate and land clearance by man.

Human-induced changes are identified at 95 cm depth (c. 1300 cal. BP), where human clearance by fire is indicated by a charcoal fragment spike, an increase in *Calluna* pollen and increasing DHI values. From 95 cm depth upwards, humification is high, although it decreases again after 350 cal. BP. *Sphagnum* spore numbers are very low at this point as it cannot survive in dry, burnt areas whereas *Calluna* is known to thrive following burning (Atherton, 2010).

At 45 cm depth (660 cal. BP) [AD 1280], there is evidence for wetter conditions regionally, indicated by low humification and large numbers of *Sphagnum* and *Tilletia sphagni* spores, suggestive of the presence of *Sphagnum cuspidatum*, a wet-loving species (Atherton, 2010). However, *Sphagnum* remains comprise less than 20% of the total plant macrofossils at this depth and *S. cuspidatum* is not present. There are also low levels of charcoal and *Calluna* spores at this point, both indicative of dry conditions (Preston *et al.*, 2002). Furthermore, DHI values are high, suggesting dry conditions on the mire surface.

At 40 cm depth (600 cal. BP), *Sphagnum* spore numbers rapidly drop, before an increase in Poaceae pollen and charcoal at 35 cm depth (535 cal. BP). There is also an increase in *Calluna* pollen, a decrease in tree pollen and high DHI values at this depth. However, remains of *Sphagnum* in the plant macrofossil record reach a maximum, suggesting wet conditions locally. At 40 cm depth, humification is beginning to increase following a peak in wetness at 42 cm depth, suggesting that conditions are becoming drier but are still classed as wet at this point in time. This is consistent with deteriorating conditions associated with the onset of the Little Ice Age (Swindles *et al.*, 2012). The pollen record suggests drier conditions compared to the locally wetter conditions indicated by the humification and plant macrofossil records.

The start of the SCP increase at 20 cm is dated to c. cal. AD 1800. The SCPs remain relatively level despite a small peak at 13 cm depth (c. cal. AD 1906) until a more substantial peak at 6 cm depth (c. cal. AD 1960) and a final peak at 3 cm depth (c. cal. AD 1990). The decline in SCPs in the top 1 cm is most likely a result of clean air policies introduced in recent decades and according to the deposition-rate curve dates to approximately AD 1990.

A substantial increase in charcoal particles can be seen towards the top of the profile between 20–0 cm depth. This can be interpreted as recent (<200 years) management practices by man using burning to control the growth of certain species on the moor. Numbers of charcoal particles throughout the rest of the profile are much lower, thus indicating the greater influence of humans today compared with previous human impacts recorded by charcoal peaks lower in the profile.

At 16 cm depth, dated at c. cal. AD 1870, *Calluna* pollen slightly decreases whilst *Quercus, Alnus* and *Corylus* pollen decrease to very low percentages. Poaceae pollen and charcoal begin to increase throughout the zone, suggesting that the resulting vegetation changes may be due to the occurrence of fire. The charcoal peak at 9 cm depth is dated to c. cal. AD 1940 and the charcoal peak at 5 cm depth is dated to c. cal. AD 1975. The presence of *Plantago* pollen and grasses also point to a period of intense human influence which may include much higher levels of grazing.

The vegetation changes towards the surface of the profile at Mossdale Moor include a rise in Poaceae pollen in zone MDM2-E from 35 cm depth, consistent with a drop in tree and shrub species and *Sphagnum* spores, which may be linked to higher grazing activity relating to the wool industry. However, charcoal increases as this happens, which implicates fire as a causal factor. This is not a very recent change as it happened at approximately 535 cal. BP (AD 1420); indicating man's marked impact on the landscape even before the industrial revolution.

The peat is less humified towards the top of the profile, suggesting wetter conditions. However, this may not be the case as this reflects the difference between the catotelm and acrotelm in the peat. The changes in humification levels, therefore, are probably not accountable for the vegetation changes seen in pollen zone MDM2-E. Therefore, other factors need to be considered as causal factors, such as human activity. The high levels of charcoal from 15 cm upwards would suggest that fire had a relatively strong impact on the vegetation composition.

Pollution from surrounding industrial areas may have had an influence on Mossdale Moor; the peat in the upper levels of the core was almost black in colour, indicative of the pollution. *Sphagnum* spores decrease rapidly in this zone and *Sphagnum* plant macrofossils are absent. Atmospheric input of pollutants could have benefited certain grass species at the expense of other species sensitive to pollution including *Sphagnum* (Tallis, 1964) and high grazing numbers of sheep on the moor are also likely to have influenced this. An increase in both *Trichophorum cespitosum* and *Polytrichum commune* remains in recent times, both of which are more typical of wet heath, supports the view that the vegetation is changing from mire to heath.

Table 3.5: Overall interpretation of mire surface conditions at Mossdale Moor using: depth (cm) ages (cal. BP), humification (high/low), MS (SI), plant macrofossil description and pollen description. (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Depth (cm) and Age (cal. BP)	Humification	Magnetic Susceptibility	SCPs	Plant Macrofossils	Pollen	Interpretation
170–145 cm >6100–5000 cal. BP		High (average - 2.5) This may be attributed to increasing mineral content towards the base of the profile.		High UOM, Monocots, *Eriophorum vaginatum* and Quartz grains.	High *Corylus* , *Myrica* , Poaceae and *Filicales* . Low *Calluna* and charcoal. *Sphagnum* present.	Mire in wet state as indicated by low charcoal, low *Calluna* and the presence of *Sphagnum* . UOM is high, but this may be attributed to higher decomposition towards the base of the profile. MS is higher, perhaps owing to the inclusion of minerals towards the base hence why humification values were excluded.
145–120 cm 5000–1420 cal. BP	Wet (1.4) Some of the wettest conditions on the mire.	Low (average - 7) with a brief movement to higher values at 130 cm depth.		High UOM, Monocots, *Eriophorum vaginatum* and *Cenococcum* fungi. Presence of *Calluna vulgaris* and *Ericaceae* .	High *Alnus, Corylus, Quercus, Calluna* and *Sphagnum* . Low charcoal and Poaceae.	Perhaps wet conditions on the mire as evidenced by high *Sphagnum* spores and low charcoal and some of the least humified conditions throughout the profile. However, high UOM and lack of any wetness indicators in the plant macrofossils suggests otherwise.
120–95 cm 1420–1250 cal. BP	Low to high (0.7–1.3) Suggests a movement from dry to wet conditions.	Low (average - 7) with a movement from -2 to - 11.5 at 110 cm depth.		High UOM, decrease in Monocots, high *Eriophorum vaginatum* , presence of *Equisetum fluviatile* towards base of zone.	High percentages of *Corylus* , *Vaccinium* and *Alnus* and increasing percentages of *Calluna* , low *Sphagnum* , lower charcoal.	Relatively dry conditions on the mire as indicated by high UOM, an increase in *Calluna* spores and some relatively humified peat. However, a high percentage of *Vaccinium* , lower charcoal and decreasing humification towards the base of the zone suggests conditions were wetter towards 120 cm depth.
95–35 cm 1250–570 cal. BP	Low (0.9) Some of the driest conditions in the profile despite bried fluctuations to wetter.	Low (average - 4) with an increase between 75 and 95 cm depth to -2.		High UOM, decrease in and disappearance of *Sphagnum* , high *Eriophorum vaginatum* , high Monocots, presence of *Scheuchzeria palustris, Calluna vulgaris* and charred remains.	High charcoal, high *Calluna* , *Sphagnum* and *Tilletia sphagni* , lower Poaceae.	Mire in a dry state as indicated by high UOM, presence of *Calluna vulgaris* remains and charred material, high charcoal and high *Calluna* spores and some of the most highly humified peat. Cause may be fire as indicated by the high charcoal; possibly anthropogenic as indicated by the presence of *Plantago* pollen.
35–0 cm 570—60 cal. BP	High (1.1) Some of the wettest conditions in the profile with possible identification of LIA.	High (average of -1) with an increase towards the surface, possibly caused by increasing atmospheric pollution.	Introduction of SCPs from 20cm depth (AD 1740), with maximum at 1.5 cm depth (AD 2000), possibly indicating that peat accumulation has ceased or slowed or that erosion has taken place at Mossdale Moor in recent decades.	Low UOM, highest percentages of *Vaccinium oxycoccus* stems, presence of Monocot roots, *Polytrichum commune* and *Eriophorum vaginatum* and high percentages of identified *Sphagnum* , notably *S. molle* and a small amount of *S. cuspidatum* .	*Sphagnum* and *Tilletia sphagni* are low. High charcoal, high Poaceae and *Calluna* and an increase in *Plantago* .	Wet conditions on the mire as indicated by high T values, and remains of *Vaccinium oxycoccus, Polytrichum commune* and *Sphagnum cuspidatum* . This zone sees some of the least humified conditions (although this may be attributed to the increased preservation in the acrotelm). Introduction of burning of fossil fuels as evidenced by SCPs and possibly related high MS values. Possible evidence of degradation/erosion demonstrated by unusual SCP record.

Chapter 4: Oxenhope Moor Results and Interpretation

This chapter covers the results and interpretation of laboratory analysis from the peat core obtained from Oxenhope Moor. The results have been consolidated and presented in tables where appropriate to aid comparison and interpretations using all the methods as evidence.

The ecological condition of Oxenhope Moor is described as degraded blanket mire with modern-day peat supporting species characteristic of NVC types M20 and M25 (Rodwell, 1998). The higher ground is dominated by *Eriophorum* spp., but to the east, the ground slopes down towards a reservoir where *Molinia* becomes dominant.

4.1 Lithology

The lithology of Oxenhope Moor is shown in Figures 4.4 and 4.5 alongside the pollen and charcoal and plant macrofossil results, following the Troels-Smith (1955) method and is described in Table 4.1.

4.1.1 Description

Although some vegetative remains could be identified in the field, mainly *Sphagna* and sedges, the majority of the peat horizons are moderately-well humified (Table 4.1). Layers of *Sphagnum* peat (Tb) are observed between 100–133, 140–150 and 243–250 cm depths; *Sphagnum* was also identified from plant macrofossil analysis at these depths. The rest of the peat consists of mainly Th (herbaceous sedge peat) and Sh (highly decomposed peat), with Ag (silt) at the base of the profile, dated to >7000 cal. BP. *Eriophorum vaginatum* remains were notable throughout.

Table 4.1: Description of lithology at Oxenhope Moor and depths (cm).

Depth (cm)	Description
0–15	Mainly herbaceous (notably *Eriophorum vaginatum*) and highly humified peat
15–36	Mainly herbaceous (notably *Eriophorum vaginatum*) and highly humified peat with some *Sphagnum* peat.
36–50	Mainly herbaceous peat with some *Sphagnum* peat.
50–90	Mainly herbaceous (notably *Eriophorum vaginatum*) and highly humified peat with some *Sphagnum* peat.
90–100	Mainly highly humified peat with some herbaceous and *Sphagnum* remains.
100–133	Mainly *Sphagnum* peat with some herbaceous peat (notably *Eriophorum vaginatum*).
133–140	Mainly highly humified peat with some herbaceous and *Sphagnum* remains.
140–150	Mainly *Sphagnum* peat with some herbaceous peat (notably *Eriophorum vaginatum*).
150–180	*Sphagnum* and herbaceous peat (notably *Eriophorum vaginatum*).
180–243	Mainly herbaceous (notably *Eriophorum vaginatum*) and highly humified peat with some *Sphagnum* peat.
243–250	Mainly *Sphagnum* peat with some highly humified peat.
250–300	Mainly highly humified peat with some herbaceous and *Sphagnum* remains.
300–350	Highly humified and herbaceous peat (notably *Eriophorum vaginatum*).
350–370	Mainly highly humified peat with some herbaceous and *Sphagnum* remains.
370–440	Mainly highly humified peat.

4.2 Chronology

4.2.1 Description and Interpretation of SCPs

The first introduction of SCPs is at 24 cm depth (Figure 4.4), c. cal. AD 1700 according to the radiocarbon age-depth model (Figure 4.1), where the number counted per 500 terrestrial pollen grains counted reaches 18. The industrial revolution started in the mid-19th century (Swindles, 2010) and perhaps earlier if local industry contributed to SCP deposition; however, AD 1700 is too early. This discrepancy between the radiocarbon and SCP profiles could be attributed to possible vertical movement of SCPs (Garnett *et al.*, 2000) or the error margin associated with the date obtained from 28.5 cm depth, although this is only ±30 years. The sediment accumulation rate calculated in Table 4.3 is based on a uniform accumulation of peat between 28.5 cm depth and the mire surface from the collection date (AD 2012). It is possible that this varied and so the relative dates inferred from the varying counts of SCPs are perhaps more reliable. A second peak in SCPs (14 counted) can be seen at 8 cm depth, usually signifying an increase in the combustion of fossil fuels following the end of the second world war (Swindles, 2010). A possible post-1990s decline can be seen towards the surface, suggesting that the mire is still actively peat forming, even though the rate of accumulation seems to have slowed towards the surface.

4.2.2 Description and Interpretation of Radiocarbon Dates

The radiocarbon dates show an increasing sediment accumulation rate throughout the profile (Table 4.3), with the exception of a slower accumulation rate towards the base of the profile between 436.5 cm and 479.5 cm depth (34.5 years per cm of peat accumulated) and a decreasing rate towards the surface (14.2 years per cm between 0 cm and 28.5 cm depth). This might be expected as the peat was still establishing between 435 cm and 480 cm depth, therefore illustrative of a slower rate of accumulation in comparison to well established ombrotrophic peat. The rate may have slowed towards the surface owing to possible erosion and pressures from grazing and burning, therefore decreasing the amount of, or removing, peat forming species. All radiocarbon dates are in agreement and have therefore been accepted (Table 4.2).

Table 4.2: Radiocarbon dates from Oxenhope Moor: Depth (cm), Radiocarbon date (yr BP), Beta Analytic Lab Number, Calibrated Ages (yr BP) and Material used . *Radiocarbon dates were calibrated using OxCal version 4.2 (Ramsey 2009). All samples were dated using the fraction of plant material extracted from samples of peat by Beta Analytic. (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Depth (cm)	Radiocarbon Date (yr BP)	Lab Number	Calibrated Age (yr BP)*	Material
479.5	6090 ± 30 BP	382656	7159 (6979) 6799	plant material
436.5	4730 ± 30 BP	382655	5588 (5455) 5322	peat
380.5	3910 ± 30 BP	382654	4512 (4336) 4160	plant material
310.5	3170 ± 30 BP	382653	3480 (3366) 3253	peat
212.5	2270 ± 30 BP	382652	2354 (2253) 2152	peat
108.5	1300 ± 30 BP	382651	1304 (1196) 1088	peat
28.5	350 ± 30 BP	382650	503 (404.5) 306	peat

Table 4.3: Sediment accumulation rates calculated using calibrated radiocarbon ages and depth (cm) at Oxenhope Moor. (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Sediment accumulation rates	
Depth (cm)	Years per cm
479.5–436.5	34.5
436.5–380.5	20
380.5–310.5	13.8
310.5–212.5	11.3
212.5–108.5	10.1
108.5–28.5	9.8
28.5–0	14.2

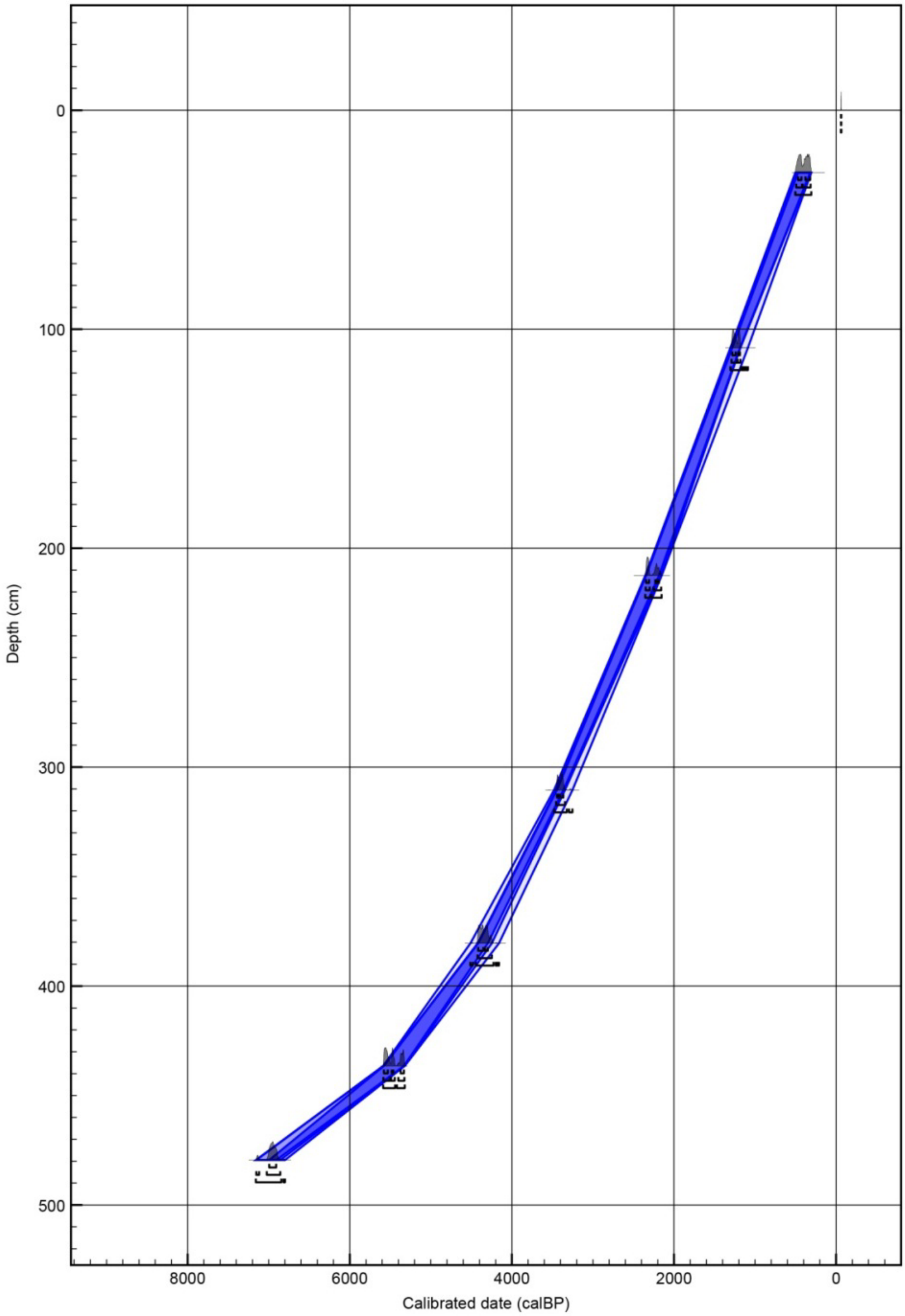


Figure 4.1: Bayesian (P_Sequence) age-depth model for Oxenhope Moor from 7 accepted AMS radiocarbon dates constructed using OxCal version 4.2 software (Ramsey, 2009) and calibrated using INTCAL13 (Reimer *et al.*, 2013).

4.3 Magnetic Susceptibility

4.3.1 Description

The magnetic susceptibility (MS) results can be sectioned into 3 zones based on changes in values. These are: 475–325 cm, 325–120 cm, 120–0 cm depths. In the first zone, values increase, fluctuating around 0, with the highest value of almost 0.5 at 390 cm (Figure 4.2). The lowest value in this zone of -1 is at 480 cm depth. In the second zone, values are much lower, decreasing to a minimum of -5.5 at 260 cm and fluctuate to as high as -1.5 at 240 cm depth. In the final zone, MS can be seen to decrease to -3.5 at 50 cm depth and increases to -0.5 towards the surface.

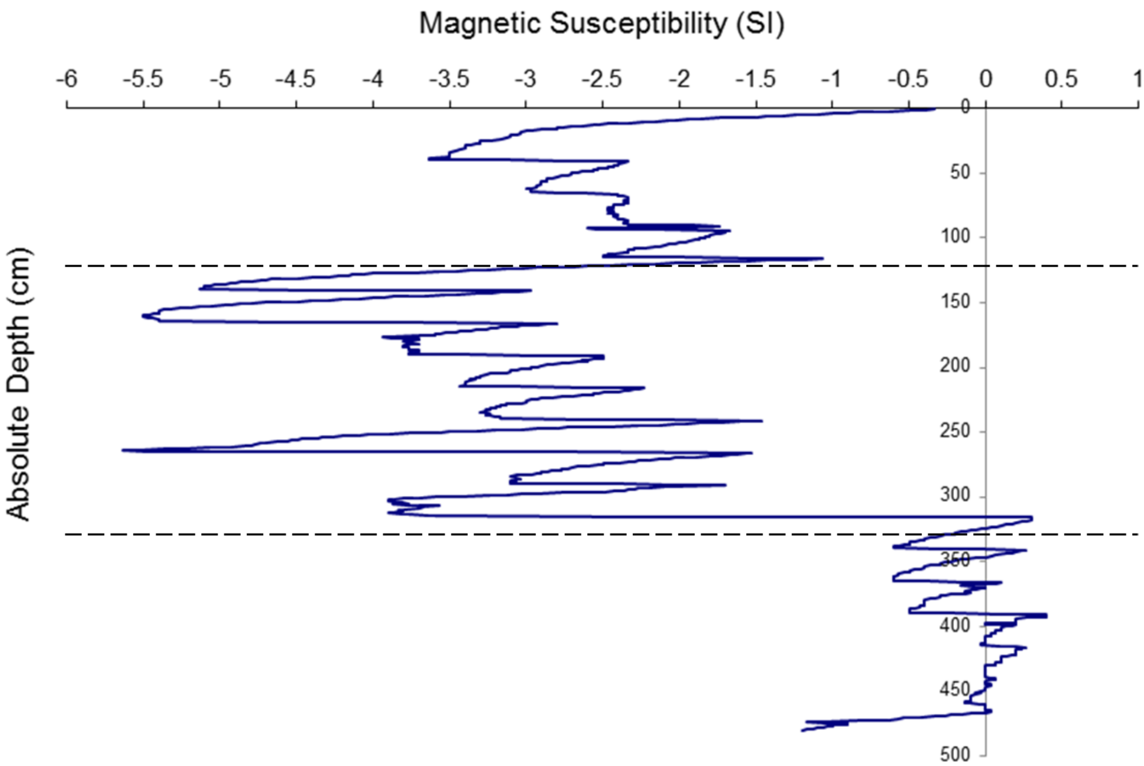


Figure 4.2: Magnetic Susceptibility (SI) and depth (cm) at Oxenhope Moor.

4.3.2 Interpretation

The first zone (475–325 cm) sees much higher MS values than the rest of the profile, ranging between -1–0.4 (Figure 4.2). This may be attributed to slower accumulation rates, also reflected in the age-depth model (Figure 4.1) or may be because there is a higher minerogenic content towards the base of the profile, although this is not significant enough to be noted by eye when sub-sampling. *Lycopodium clavatum* counts significantly drop synchronously with the higher MS values, perhaps suggesting faster accumulation rates. The peaks and troughs in MS throughout the core are not interpreted as being indicative of any major tephra layers as none were evident during pollen analysis. However, it is possible that micro-tephra are present within the core and may have an effect on MS values.

L. clavatum counts increase between 325 cm and 120 cm, suggesting slower accumulation rates at these depths in the profile. However, lower MS values (ranging between -1 and -5.5) at these depths might be indicative of faster accumulation rates, as reflected in the radiocarbon age-depth model (Figure 4.1).

Between 120 cm and 0 cm, MS ranges between -0.4 and -3.5 (SI). The rise seen from 25 cm upward could be attributed to atmospheric pollutants, causing the MS to increase owing to the higher content of magnetite in fly-ash particles from atmospheric pollution (Petrovský *et al.*, 2000, Oldfield *et al.*, 1981). This rise in MS could also be attributed to a change in accumulation rates as this seems to slow as indicated by the radiocarbon age-depth model (Figure 4.1) and relative ages given by SCPs (Figure 4.4). Conversely, the *L. clavatum* count is relatively high, suggesting a slow sediment accumulation rate. The MS rise seen throughout the zone could be also be related to an increase in burning at the site, which is thought to increase MS (Gale and Hoare, 1991). A rise in charcoal can be seen from the pollen diagram (Figure 4.4) at 120 cm depth and so the rise in MS could be attributed to increased burning; however, charcoal is higher prior to this at 160 cm depth, yet MS values are lower.

4.4 Humification

The raw percentage transmission results were exponentially smoothed in MS Excel and then de-trended using a linear regression model to remove any long-term trends; hence, transmission is no longer expressed as a percentage, but as a number (Figure 4.3). As discussed in the methods chapter (Chapter 2), more highly decomposed peat will produce a darker coloured extract and therefore reduced light transmission (Blackford and Chambers, 1993). The lower the number, the more humified the peat, therefore indicating drier and/or warmer conditions, causing an increased rate of decomposition.

4.4.1 Description

De-trended transmission (T) at Oxenhope Moor is highly fluctuating (Figure 4.3). However, the curve can be sectioned into six zones, with zone OXM–f (480–366 cm) having high values (c. 1.3), OXM–e (366–277 cm) having low values (c. 0.7), OXM–d (277–218 cm) having high values (c. 1.2), OXM–c (218–158 cm) having low values (c. 0.7), OXM–b (158–55 cm) having mid-range values (c. 1) and OXM–a (55–0 cm) having high values (c. 1.3). In OXM–f, the T curve fluctuates and reaches some of the highest values, reaching 1.39 at 383.5 cm depth, 1.5 at 410.5 cm depth and 1.56 at 470 cm depth. OXM–e sees a return to lower values, again for a sustained period, with T rarely increasing above 1. In OXM–d, T increases for a sustained period, despite a brief dip in T at 235.5 cm where it falls to 0.7. In OXM–c, T rarely exceeds 1 and the T curve is more stable, generally remaining around the 0.9 mark. In OXM–b, at 116.5 cm depth, another high value can be seen with T at 1.3. At 139.5 cm depth, in the same zone, the lowest value within the profile can be seen with T falling to 0.51. In OXM–a, at 28.5 cm depth, one of the highest values throughout the profile can be seen, with T reaching 1.47.

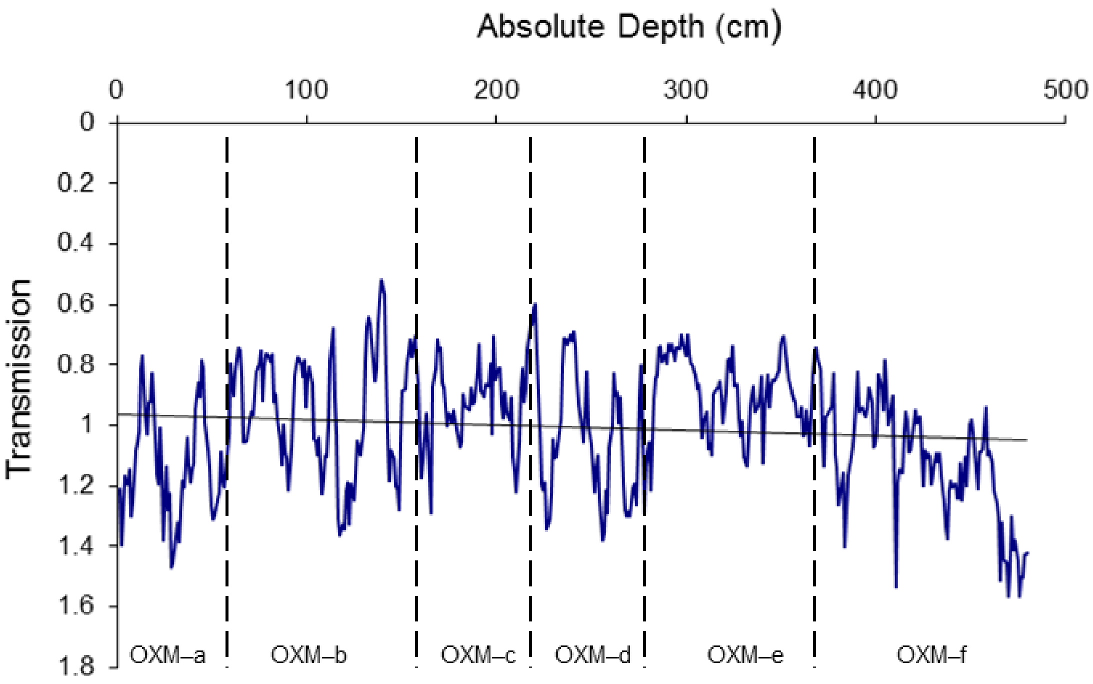


Figure 4.3: Humification (Transmission) and depth (cm) at Oxenhope Moor.

4.4.2 Interpretation

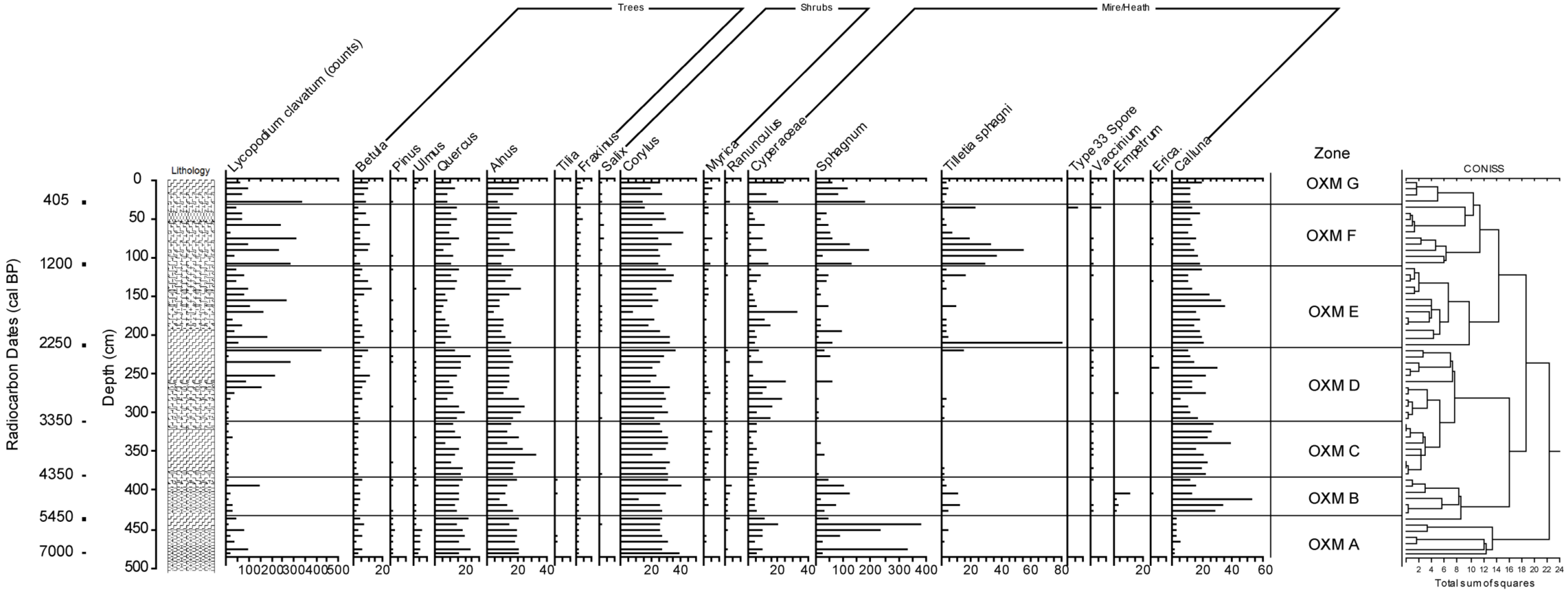
In the first zone, OXM–f, conditions appear to be generally wet in comparison to the rest of the profile, with notably wet conditions at 470 cm depth (6700 cal. BP), 383.5 cm depth (4400 cal. BP) and 410.5 cm depth (5900 cal. BP). Between 366–277 cm depth, zone OXM–e (4200–3000 cal. BP) is generally dry/warm. A rise in T in zone OXM–d (3000–2400 cal. BP) can be interpreted as wet and a fall in T at 235.5 cm depth (2600 cal. BP) can be seen to represent dry/warm conditions. The fall in T at 139.5 cm depth (1400 cal. BP) represents the driest conditions in the profile and a sustained particularly dry shift can be seen in zone OXM–c (2400–1800 cal. BP). There are 3 episodes of wetter conditions within zone OXM–a (700–-61 cal. BP/ cal. AD 1250–2012), with particularly wet conditions at 116.5 cm depth (1200 cal. BP) and at 28.5 cm depth (400 cal. BP/cal. AD 1550) consistent with the Little Ice Age.

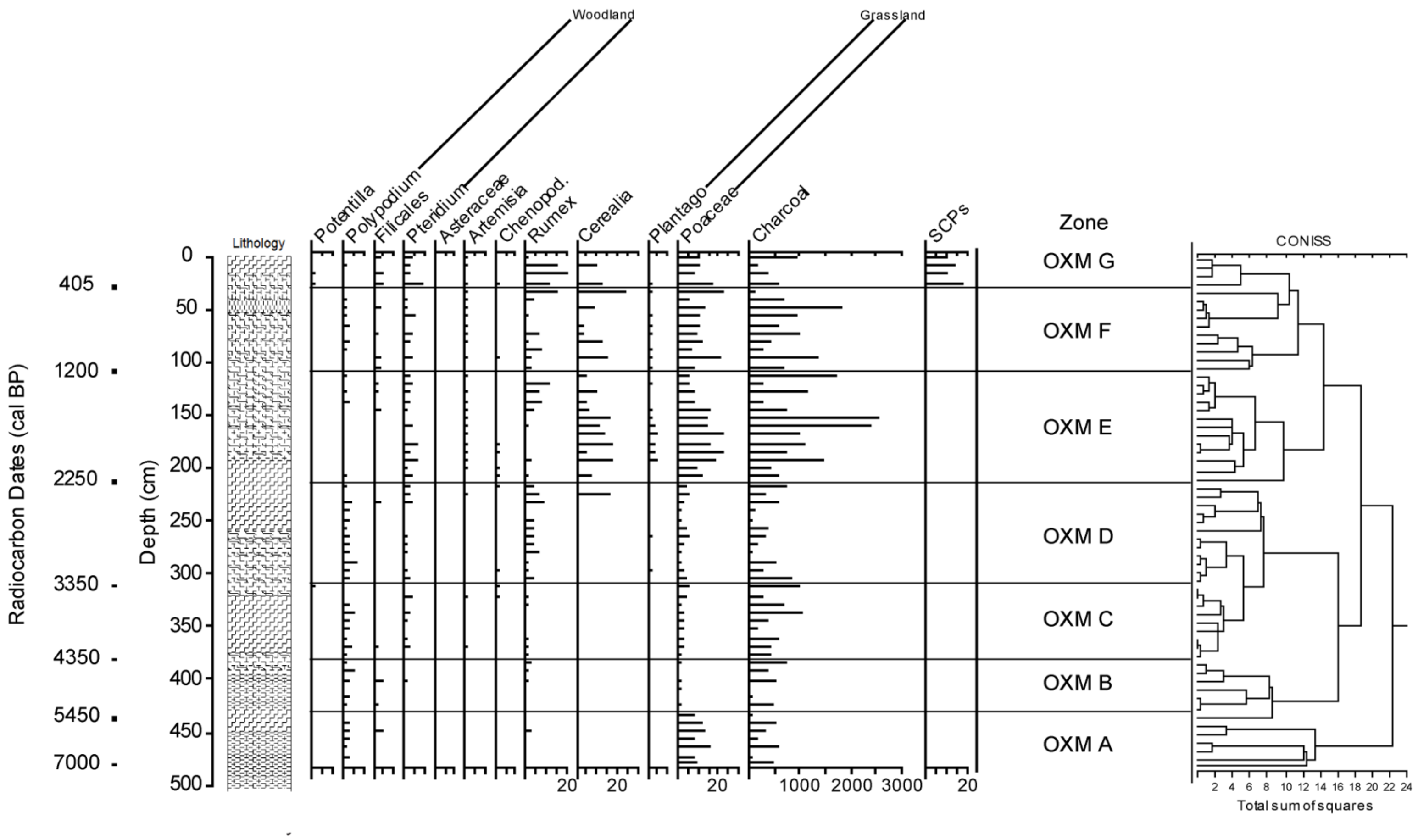
4.5 Pollen and Charcoal Analysis

4.5.1 Description

Table 4.4: Pollen zone descriptions at Oxenhope Moor using: depth (cm), radiocarbon ages (cal. BP) and humification (Wet/Dry). (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Pollen Zone	Depth (cm)	Age (cal BP)	Humification (Wet/Dry)	Description
OXM A	480–430	c. 7000–5450	Wet	Highest number of *Sphagnum* spores (upto c. 350), lowest percentage of *Calluna* (c. 5%), high percentage of *Quercus* (c. 20%), high percentage of *Corylus* (upto 40%), highest percentage of *Ulmus* throughout profile, high percentage of Poaceae (c. 15%), low number of charcoal fragments (<500).
OXM B	430–380	c. 5450–4350	Dry	Highest percentage of *Calluna* (upto 50%), highest percentage of *Empetrum*, number of *Sphagnum* spores c. 100, lowest Poaceae percentage throughout profile (<5%).
OXM C	380–310	c. 4350–3350	Dry	Highest percentage of *Alnus* (c. 30%), lowest number of *Sphagnum* spores throughout profile, *Calluna* percentage high (upto 40%), increasing charcoal fragments (c. 1000), low Poaceae percentage.
OXM D	310–210	c. 3350–2250	Dry	Low number of *Sphagnum* (c. 50) and *Tilletia sphagni* (c. <20) spores, high Cyperaceae percentage (up to c. 30%), increase in *Betula* percentage, increase in *Quercus* and *Alnus* percentages, introduction of *Cerealia*, decrease in number of charcoal fragments (<1000).
OXM E	210–105	c. 2250–1200	Dry	Highest percentage of Cyperaceae, highest number of *Tilletia sphagni* spores, fluctuating percetages of tree pollen, highest percentage of Poaceae, highest number of charcoal fragments (c. 2500).
OXM F	105–25	c. 1200–350	Wet	High number of *Tilletia sphagni* spores, high number of *Sphagnum* spores (upto 60), high percentage of Poaceae (c. 20%), high percentages of *Rumex* and *Cerealia*, introduction of SCPs.
OXM G	25–0	c. 350–-60	Wet	Highest number of SCPs, highest percentage of *Rumex* (c. 20%), lowest percentage of *Calluna* (c. 20%), high number of *Sphagnum* spores (c. 200), low number of charcoal fragments (c. <1000).





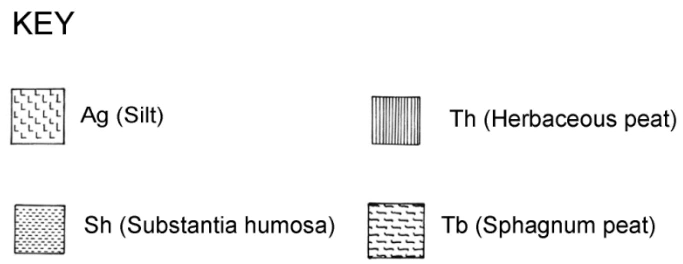


Figure 4.4 Pollen percentages at Oxenhope Moor using: depth (cm), radiocarbon ages (cal. BP), lithology (Troels-Smith, 1955), number of charcoal fragments counted(per 500 counted terrestrial pollen grains), and number of SCPs counted (per 500 counted terrestrial pollen grains).

4.5.2 Interpretation

4.5.2.1 OXM – A (480–430 cm depth) ***Quercus-Alnus-Corylus-Sphagnum-Poaceae***

The highest number of *Sphagnum* spores was counted in this zone, alongside the lowest percentage of *Calluna*, suggesting wetter conditions (Table 4.4, Figure 4.4). *Ulmus* is present at its highest percentage, perhaps suggesting a period of low anthropogenic activity as human clearance is one theory for the reduction seen in *Ulmus* from c. 4000 cal. BP onwards (Peglar and Birks, 1993). Poaceae is present at (c. 20%), perhaps indicating initial colonisation before *Calluna* becomes dominant in the following zone (OXM – B). This zone has low levels of charcoal fragments in comparison to later zones, perhaps indicating a lower level of human activity.

4.5.2.2 OXM – B (430–380 cm depth) ***Corylus-Sphagnum-Empetrum-Calluna***

This zone sees the highest percentage of *Calluna* (up to c. 55%) throughout the profile. *Empetrum* is also present, as are *Sphagnum* (c. 100 spores counted) and *Tilletia sphagni* (c. 10 spores counted). Such species are typical of dry heath (dependant on which species of *Sphagnum* are present – presence of *Tilletia sphagni* in low numbers suggests a minor presence of *Sphagnum cuspidatum* and so other hummock forming species of *Sphagnum* may be present). Numbers of charcoal fragments are slightly lower than the following zone, which may explain the presence of *Sphagnum* in this zone in comparison to OXM – C.

4.5.2.3 OXM – C (310–380 cm depth) ***Quercus-Alnus-Corylus-Calluna***

Alnus reaches its highest percentage (c. 35%) throughout the profile, suggesting damp conditions surrounding the mire. However, the mire itself does not seem to be wet at this stage, with an absence of *Sphagnum* and high percentages of *Calluna* (c. 30%), a species tolerant of dry conditions (Preston *et al.*, 2002). Cyperaceae is also much lower in this zone, suggesting that conditions were too dry to sustain it. Numbers of charcoal fragments increase in this zone when compared to the following (OXM – D) signifying drier conditions and perhaps wildfire, benefitting species such as *Calluna.* A possible *Ulmus* decline is also identified at 370 cm depth (4100 cal. BP).

4.5.2.4 OXM – D (210–310 cm depth) *Quercus-Alnus-Corylus-Cyperaceae*

This zone sees the highest levels of *Quercus, Alnus* and *Corylus* so far and the lowest levels of charcoal. This could represent a time of lower levels of anthropogenic activity. This zone also sees some of the lowest counts of *Sphagnum* and *Tilletia sphagni* and a high percentage of Cyperaceae (c. 20%), suggesting that conditions were unsuitable for sustaining *Sphagnum* but perhaps more suited to species such as *Eriophorum vaginatum* and *Calluna* (c. 30%) and tree species surrounding the mire. The top of this zone sees the introduction of *Cerealia* (220 cm depth), which indicates the beginning of intensification in human activity.

4.5.2.5 OXM – E (105–210 cm depth) *Poaceae-Cyperaceae-Calluna*

This zone sees fluctuating levels of tree pollen (*Betula, Quercus and Alnus*) and *Corylus* which all descend at the same point (170 cm depth), synchronous with a rise in Cyperaceae, which reaches 40%, the highest in the profile. At 150 cm depth, charcoal reaches the highest level in the profile with >2500 fragments counted, synchronous with an absence of *Sphagnum*, which is thought to be fire sensitive (Worrall *et al.*, 2007, Muller *et al.*, 2012), therefore signifying fire as a causal factor. *Tilletia sphagni* reaches 80 spores counted at the bottom of the zone (205 cm depth), which would suggest wet conditions, given its association with *Sphagnum cuspidatum.* However, numbers of *Sphagnum* spores are low at this depth and so this may be an anomaly. Poaceae rises in this zone, reaching the highest in the profile at approximately 25% and may have been encouraged by an increase in burning (Yeloff *et al.*, 2006, Ramchunder *et al.*, 2009, Clay, 2009). *Cerealia* and *Plantago* are also at their highest levels, indicative of anthropogenic activity.

4.5.2.6 OXM – F (25–105 cm depth) *Poaceae-Cerealia-Sphagnum*

A high number of *Sphagnum* spores coupled with a high number of *Tilletia sphagni* spores (a type of fungus usually associated with the pool species of *Sphagnum cuspidatum* (van Geel, 1978)) suggest wet conditions and the possible presence of pools, particularly at approximately 80 cm depth, where both spores are at their highest. Both then begin to decrease towards the top of the zone. A high percentage of Poaceae (c. 20%) in conjunction with a high number of charcoal fragments may suggest that certain grass species have been benefitted owing to managed burning (Yeloff *et al.*, 2006, Ramchunder *et al.*, 2009, Clay, 2009). Anthropogenic indicators *Rumex* and *Cerealia* are relatively high in this zone, indicating human influence on the landscape.

4.5.2.7 OXM – G (0–25 cm depth) *Rumex-Cyperaceae-Sphagnum*

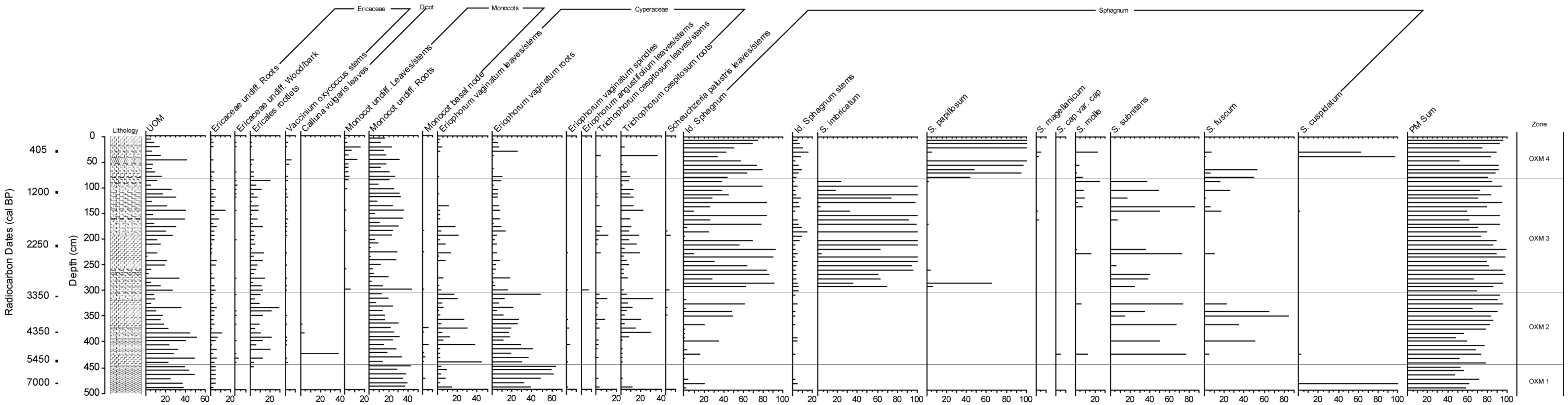
The highest percentage of *Rumex* (c. 20%), is found in this zone, indicative of anthropogenic influence. A high number of *Sphagnum* spores (c. 200) and a low number of charcoal fragments (c. <1000) perhaps suggest wetter conditions, although if the *Sphagnum* present is a hummock forming species, conditions may not have been particularly wet. Given the degraded nature of the site and the prescribed burning that takes place, it is quite unusual to see such low numbers of charcoal fragments and *Calluna* pollen. A relatively high percentage of Cyperaceae indicates that species such as *Eriophorum vaginatum* may have been thriving at the site, a species that is currently widespread at Oxenhope Moor.

4.6 Plant Macrofossil Analysis

4.6.1 Description

Table 4.5: Plant macrofossil zone descriptions at Oxenhope Moor using: depth (cm), radiocarbon ages (cal. BP) and humification (wet/dry). (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Plant Macrofossil Zone	Depth (cm)	Age (cal BP)	Humification (Wet/Dry)	Description
OXM 1	480–430	c. 7000–5200	Wet	High percentage of UOM (upto 50%), high percentage of Monocot roots (c. 40%), high percentage of *Eriophorum vaginatum* roots (60%), low percentage of identified *Sphagnum*, 100% of this being *S. cuspidatum* at 460 cm depth.
OXM 2	430–290	c. 5200–3200	Dry	High percentage of UOM (upto 50%), high percentage of *Ericales* rootlets (c. 30%), high percentage of *Calluna vulgaris* leaves at 410 cm depth (40%), high percentage of *Eriophorum vaginatum* roots (c. 40%) and *E. vaginatum* leaves (up to 50%), high *Trichophorum cespitosum* roots (upto 30%), upto 60% identified *Sphagnum* at 310 cm depth, mainly *S. subnitens* and *S. fuscum*.
OXM 3	290–80	c. 3200–1000	Dry	Low percentage of UOM (c. 30%), presence of *Ericales* rootlets (c. 10%), high percentage of Monocot roots (c. 30%), *Eriophorum vaginatum* reaches 20%, presence of *E. angustifolium* at 290 cm depth, *Trichophorum cespitosum* reaches 20%, high presence of identified *Sphagnum* (upto 90%), mainly *S. imbricatum* with some *S. fuscum* and *S. subnitens*.
OXM 4	80–0	c. 1000–-60	Wet	Low percentage of UOM (c. 20%), highest percentage of Monocot. leaves throughout the profile (15%), Monocot roots (30%), *Triochophorum cespitosum* reaches highest percentage throughout profile (40%) at 35cm depth, identified *Sphagnum* reaches upto 80%, mainly *Sphagnum papillosum*, replacing *S. imbricatum* in zone OXM 3. *S. cuspidatum* is at 100% of identified *Sphagnum* at 35cm depth.



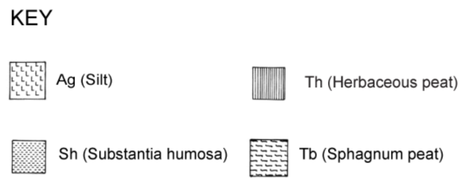


Figure 4.5 Plant macrofossil percentages at Oxenhope Moor using: depth (cm), radiocarbon ages (cal. BP), and lithology (Troels-Smith, 1955).

4.6.2 Interpretation

4.6.2.1 OXM – 1 (480–430 cm depth) *Eriophorum vaginatum-Sphagnum cuspidatum*

This zone sees high levels of UOM (up to 55%), high monocot roots (40%), high *Eriophorum vaginatum* roots (up to 60%) and low levels of *Sphagnum* (up to 20%), all indicative of dry conditions (Table 4.5, Figure 4.5). Of the *Sphagnum* identified, however, at 470 cm depth, 100% is *S. cuspidatum*, indicative of pools and very wet conditions. High UOM could be attributed not only to dry conditions but to the less favourable conditions for preservation in the catotelm and the fact that peat at this depth has had much longer to decompose than peat found towards the surface. The evidence suggests that conditions are generally dry in this zone, with a short lived episode of wetter conditions at 470 cm depth.

4.6.2.2 OXM – 2 (430–290 cm depth) *Calluna vulgaris-Eriophorum vaginatum-Sphagnum subnitens-S. fuscum*

UOM reaches its highest percentages in this zone (up to 55%), consistent with the presence of a high percentage (40%) of *Calluna vulgaris* at 405 cm depth. *C. vulgaris* becomes dominant on well-drained heaths (Clapham *et al.*, 1962) and is therefore indicative of drier conditions. The percentage of identified *Sphagnum* reduces in this zone, possibly owing to a slow establishment through the profile at this stage, whilst other species of Cyperaceae such as *Eriophorum vaginatum* (c. 30%) and *Trichophorum cespitosum* (c. 30%) thrive. The presence of hummock forming species of *Sphagnum* (*S. subnitens* and *S. fuscum*), high UOM and the presence of *Eriophorum vaginatum* and *Trichophorum cespitosum* suggest dry conditions.

4.6.2.3 OXM – 3 (290–80 cm depth) *Trichophorum cespitosum-Sphagnum imbricatum-S. subnitens*

This zone is dominated by S. *imbricatum*, which disappears at the top and is absent in zone OXM – 4. *S. imbricatum* may have disappeared owing to palaeoclimatic change, but it may also have been subject to competition from *Sphagnum papillosum*, which seems to replace *S. imbricatum* in zone OXM – 4. Mauquoy and Barber (1999) state that *S. papillosum* can grow the same amount as *S. imbricatum* in 20 days less time, thus giving it a competitive advantage. *S.*

molle, *S. subnitens* and *S. fuscum* are also present in this zone, except between 150 cm and 200 cm depth, where *S. imbricatum* is dominant. These species belong to *Sphagnum*. section. *Acutifolia* and are generally hummock forming species (Rydin *et al.*, 2006). *Trichophorum cespitosum* and *Ericales* rootlets are also present in this zone, indicating that the water table was low enough to support the development of slightly drier hummocks and species that do not thrive when sub-merged below the water table. For instance, *Trichophorum cespitosum* is associated with drier areas and drained and grazed areas (Wilson *et al.*, 2011).

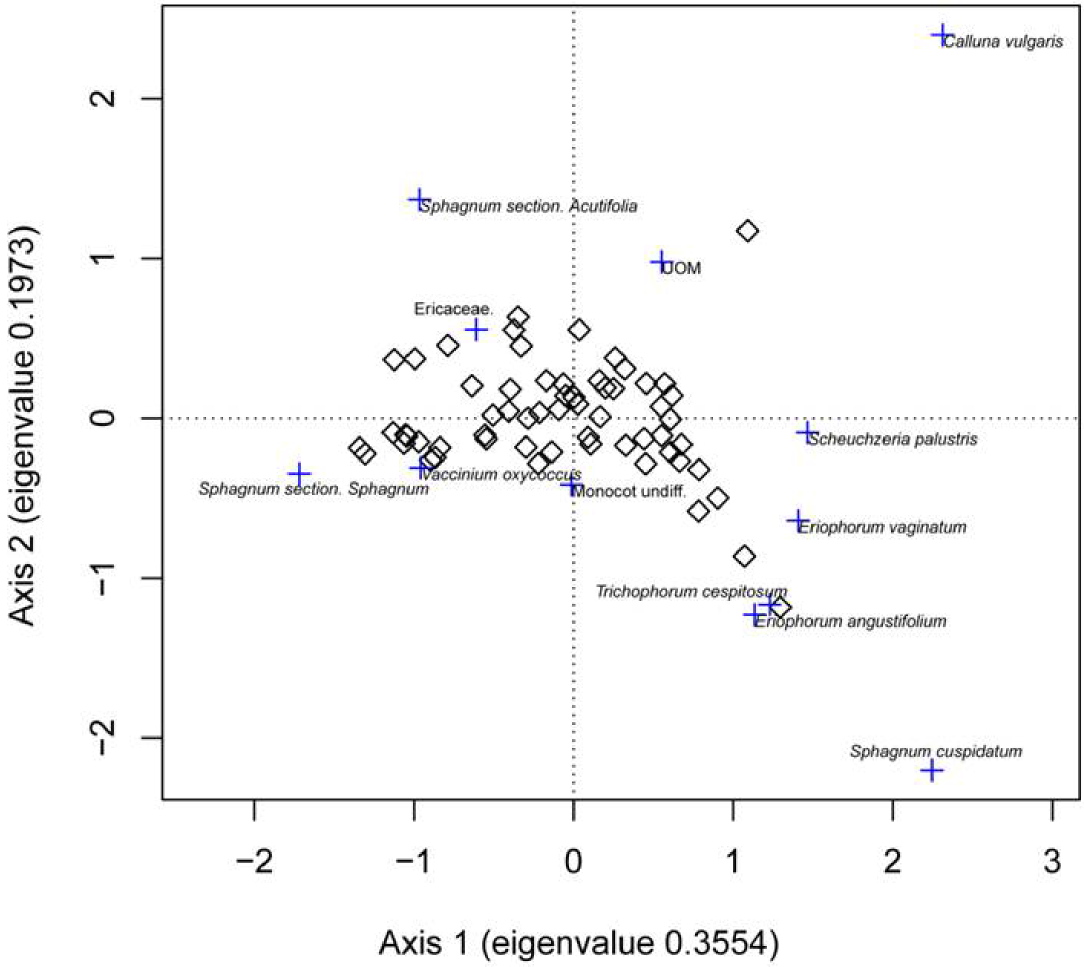
4.6.2.4 OXM – 4 (80–0 cm depth) *Sphagnum papillosum-Sphagnum cuspidatum*

This zone has the lowest UOM throughout the profile, perhaps owing to the ideal preservation conditions of the acrotelm and the fact that vegetation towards the surface has had much less time to decompose than the vegetation found at a lower depth. However, the presence of *S. cuspidatum* indicates the presence of pools and thus aerobic decomposition rates will be low and little UOM will be produced. The majority of the identified *Sphagnum* is *S. papillosum*, a hummock forming species commonly found in acid peatlands (Daniels, 1985). *S. papillosum* is one of the more ‘tolerant’ species as it has been known to ‘out-compete’ *S. imbricatum* when faced with climatic change, drainage, burning and grazing and airborne eutrophication (Mauquoy and Barber, 1999). The presence of *Eriophorum vaginatum* and *Trichophorum cespitosum* also indicate the presence of hummocks as opposed to pools. *Sphagnum cuspidatum* is present for a brief time at about 40 cm depth (500 cal. BP/cal. AD 1500), synchronous with the climatic deterioration known as the Little Ice Age (LIA). A return to dominance by *S. papillosum* follows the end of the LIA.

4.6.3 De-trended Correspondence Analysis

De-trended Correspondence Analysis was conducted on plant macrofossils using R (R Core, 2012) and “Vegan” version 2.0-9 (Oksanen, 2013) where the first and second axes of the ordination were plotted against each other (Figure 4.6). *Sphagnum imbricatum*, *S. papillosum* and *S. magellanicum* were grouped together as *Sphagnum* section. *Sphagnum* as *S. papillosum* appears to replace *S. imbricatum* in the profile. *Sphagnum* section. *Acutifolia* were also grouped for consistency. Generally, it might be expected to see taxa arranged along a hydrological gradient along axis 1 (Langdon *et al.*, 2003). However, at Oxenhope Moor, the taxon arrangement appears to be more complex. Although *Sphagnum* section. *Sphagnum* (hummock forming species) and Ericaceae are towards the left of axis 1 with low scores, other dryness indicators such as UOM and *Calluna vulgaris* do not conform to this. Similarly, although *Sphagnum cuspidatum* and *Eriophorum angustifolium* are positioned towards the right of axis 1, their location seems to be determined by axis 2 as well as axis 1. It might also be expected that *Vaccinium oxycoccus* should be plotted in close proximity to these wetness indicators.

An explanation for these results might be that some species are not present throughout the entire profile, for example, *Calluna vulgaris*, which is only present in significant amounts at c. 405 cm depth. DCA perhaps performs better on data sets where species are present throughout the profile and are seen to rise and fall. As *Calluna vulgaris* is only infrequently present, the “Vegan” package within R will not be able to associate it with any particular conditions which could in turn be interpreted as an indicator of dry or wet, hence the positioning on Figure 4.6. Likewise, *Sphagnum cuspidatum* is only present in plant macrofossil zones OXM 4 and OXM 1. One way to overcome this would be to exclude such species from DCA; however, this would mean that the analysis would only be performed on a small number of species and therefore would not be significantly reliable. Had a hydrological gradient been identified, it would have been beneficial to plot the axis 1 values alongside humification to see if the results conform. However, as a hydrological or environmental gradient has not been identified (and the main purpose of this thesis is to assess vegetation changes and likely causes), the DCA results will not be analysed further.



Key: blue crosses = species; black diamonds = samples

Figure 4.6: De-trended Correspondence Analysis: A bi-plot of the axis 1 and axis 2 scores (σ units) from the plant macrofossil results at Oxenhope Moor.

4.6.4 Dupont Hydroclimatic Index (DHI)

As the DCA ordination failed to detect the presence of a mire surface wetness gradient in the plant macrofossil data, DHI (Dupont, 1986) has been applied to the plant macrofossil data to provide a qualitative indication of changes in water table (Figure 4.7). The indices used were: UOM 8, *Ericales* rootlets 8, *Vaccinium oxycoccus* 5, *Calluna vulgaris* 8, Ericaceae undifferentiated 8, monocots undifferentiated 6, *Eriophorum vaginatum* 6, *Eriophorum angustifolium* 2, *Trichophorum cespitosum* 6, *Scheuchzeria palustris* 2, *Sphagnum imbricatum* 4, *Sphagnum papillosum* 4, *Sphagnum magellanicum* 3, *Sphagnum* section *Acutifolia* 5, *Sphagnum cuspidatum* 1, based upon the weights used in Daley and Barber (2012) and Mauquoy *et al.* (2008) and knowledge of ecological tolerances and habitat preferences of each species.

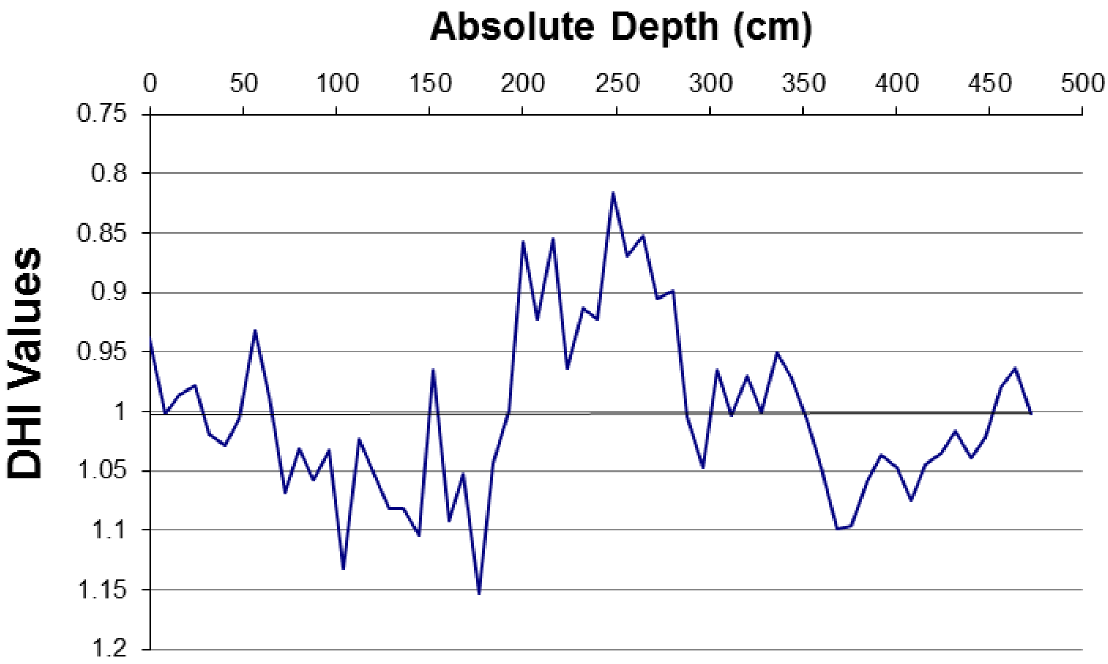


Figure 4.7: Smoothed and De-trended DHI curve for plant macrofossils from Oxenhope Moor.

The data have been de-trended, therefore meaning they are now displayed as lower values than the scores attributed to the species. Low values indicate wet conditions, therefore suggesting that the mire was wet at 465 cm (6400 cal. BP), 335–305 cm (3600–3300 cal. BP), 270–200 cm (3000–2200 cal. BP), 150 cm (1700 cal. BP), 55 cm (750 cal. BP/cal. AD 1200) and 15 cm depths (250 cal. BP/cal. AD 1700) (Figure 4.7). DHI values are particularly low between 270–200 cm depths, indicating the wettest conditions on the mire. However, this may have been exaggerated as UOM is very low at this point and as it is given a score of 8, low presence will result in a much lower DHI score. Conversely, at 465 cm depth, UOM is high, owing to higher decomposition levels at this depth in the catotelm, therefore reducing the wetness signal indicated by the presence of *Sphagnum cuspidatum* at this depth. Particularly dry and/or warm conditions are observed at 440–370 cm (5500–4200 cal. BP), 295 cm (3200 cal. BP), 175–160 cm (1900–1700 cal. BP) and 145–70 cm depths (1600 cal. BP–600 cal.BP/cal. AD 1350) as indicated by high values.

4.7 Summary of Magnetic Susceptibility, Humification, Pollen, Plant Macrofossil Data and SCP and Radiocarbon Dates

A particularly wet event is identified at 470 cm depth (6800 cal. BP) as identified by the lowest humification in the profile, low DHI values, the presence of pool species *Sphagnum cuspidatum* from the plant macrofossils and high *Sphagnum* spores, low *Calluna* and low charcoal from pollen analysis, suggesting a possible climatic cause for this deterioration (Table 4.6).

An apparent *Ulmus* decline is identified at 370 cm depth (4100 cal. BP). Before this, *Ulmus* is present fairly consistently although in small numbers. Following the identified decline, *Ulmus* does reappear but only sporadically. This could represent human activity, although it does appear to be on a smaller scale at this depth than identified elsewhere in the profile. Anthropogenic influences increase from 200 cm depth (2100 cal. BP) as indicated by a rise in charcoal, a decrease in tree pollen and an increase in *Calluna* pollen. *Sphagnum imbricatum* is still present at this depth but disappears at 80 cm depth. It is likely that landscape pressures increased over time with population growth and advances in technology, therefore explaining why certain species managed to survive for up to a thousand years before finally becoming out-competed.

At 410 cm depth (5000 cal. BP) a presence of *Sphagnum* spores, low humification and low charcoal might suggest wet conditions, however, *Calluna* is high in both the pollen and plant macrofossils at this depth and so this seems to be an anomaly. A presence of *Sphagnum* spores, low *Calluna* pollen, low charcoal and low humification at 384 cm depth (4400 cal. BP) might suggest wet conditions; however, identified *Sphagnum* from plant macrofossil analysis is low and UOM, *Ericales* and *Eriophorum vaginatum* are high, therefore suggesting that something else may have caused a change in humification and the results from the pollen diagram are perhaps indicative of regional environmental changes at this depth.

A sustained dry period, possibly caused by changes in climate is identified at 291–286 cm depth (c. 3100 cal. BP), as indicated by high UOM, high monocots, no identified *Sphagnum*, high *Eriophorum vaginatum* remains, higher DHI values and increasing charcoal. At 256 cm depth (2800 cal. BP), all proxies are in agreement and therefore suggest a climatic cause for low *Calluna*, high Cyperaceae and a presence of *Sphagnum* spores in addition to low charcoal, low humification, a high presence of *Sphagnum imbricatum*, low UOM, low *Ericales* and high DHI scores, indicating another wet episode.

A movement to drier conditions is identified at 236 cm depth (2500 cal. BP) as demonstrated by high humification, relatively high UOM, high *Calluna* pollen and identified *Sphagnum* being mainly composed of the hummock forming species *S.*

imbricatum. DHI values are still quite low at this point (possibly owing to an absence of UOM) and this suggests that the mire was not in drought (as *S. imbricatum* is still thriving) but it was in a state dry enough to support dry tolerant species, most likely *Calluna vulgaris*.

A possible wet event has been identified at 227cm depth (2400 cal. BP) as evidenced by high *Tilletia sphagni* spores, low humification, low DHI values, low *Calluna* pollen and low charcoal. There is a high presence of *Sphagnum imbricatum* on the bog at this stage, which cannot tolerate pools but is better adapted to wet conditions than species such as *Ericales*, which are low at this point.

Dry conditions are also identified at 140 cm depth (1500 cal. BP) by low humification, high UOM and high monocots, high *Trichophorum cespitosum*, low identified *Sphagnum*, mainly *S. imbricatum*, high DHI values, low *Sphagnum* pollen and relatively high charcoal. At 220 cm depth, low humification, low *Sphagnum* pollen, low charcoal, low UOM, high *Ericales* and monocots and low *Sphagnum*, again, mainly *S. imbricatum*, also indicate dry conditions. As all proxies agree, both events are likely to be climatic.

Particularly dry events have been identified at 150 cm (1600 cal. BP), 110 cm (1100 cal. BP/cal. AD 850) and 50 cm (650 cal. BP/cal. AD 1300), depths as indicated by high numbers of charcoal fragments, high *Calluna* pollen (particularly at 150 cm depth), high UOM from plant macrofossils and high humification at each depth. Each of these events could represent anthropogenic influence as increased charcoal can be associated with burning to clear land, which would benefit certain species such as *Calluna* and therefore have a drying effect on the bog, causing humification to increase. The latter two of these events correlate with the Medieval Warm Period and so climatic changes seem a likely cause.

The disappearance of *Sphagnum imbricatum* at 80 cm depth (c. 1000 cal. BP/cal. AD 950) may have been caused by increasing human disturbance around the bog; however, this event does not seem to coincide with a rising water table as found in other studies (Mauquoy and Barber, 1999, McClymont *et al.*, 2008).

All proxies from Oxenhope Moor are in agreement and suggest wet conditions on the bog between 45–40 cm depth. This is suggested by 100% of 35% identified *Sphagnum* being *S. cuspidatum* from plant macrofossils analysis, low DHI values, a relatively high number of counted *Tilletia sphagni* spores from pollen analysis and high T values from humification analysis. This wet shift is dated to 500 cal. BP/ cal. AD 1450 and is therefore consistent with the climatic deterioration known as the LIA.

From 25 cm upwards, there is an increase in MS synchronous with the introduction of SCPs. It is suggested that both are related to an increase in atmospheric pollutants. There are also high levels of *Rumex*, indicative of anthropogenic activities and Cyperaceae pollen and an increase in *Eriophorum vaginatum*, a species which frequently dominates degraded blanket mire (Chambers *et al.*, 2007c).

Table 4.6: Overall interpretation of mire surface conditions at Oxenhope Moor using: depth (cm) ages (cal. BP), humification (high/low), MS (SI), plant macrofossil description and pollen description. (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Depth (cm) and Age (cal. BP)	Humi-fication	Magnetic Susceptibility	SCPs	Plant Macrofossils	Pollen	Interpretation
480–410 cm 7000–4900 cal. BP	High (1.2). Wettest conditions throughout profile. T values rarely fall below 1.	High (-1). May be because of microscopic inclusion of minerals towards the base of profile.		High UOM and *Eriophorum vaginatum.* Low *Sphagnum* (*S. cuspidatum).*	Highest number of *Sphagnum* spores. Lowest *Calluna* percentages. High Poaceae percentages. Low numbers of charcoal fragments.	Mire in wet state as indicated by *S. cuspidatum* and highest number of *Sphagnum* spores as well as lowest *Calluna* and lowest charcoal. UOM is high, but this may be attributed to higher decomposition towards the base of the profile. Some of the least humified conditions although MS is also high, perhaps owing to the inclusion of minerals towards the base, which would cause T values to be high.
410–280 cm 4900–3000 cal. BP	Low (0.7). Sustained dry conditions. T value rarely reaches above 1.	High (-1)		High UOM, *Ericales* and *Calluna vulgaris.* 60% hummock forming *Sphagnum* species (*S. fuscum* and *S. subnitens*).	High *Calluna* percentages. Low numbers of *Sphagnum* spores. Increasing numbers of charcoal fragments.	Some of the driest conditions on the mire as indicated by the presence of *Ericales* rootlets, *Calluna vulgaris* leaves and spores and hummock forming *Sphagnum* species. UOM is high, which could be attributed to lower preservation rates in the catotelm; however, increasing charcoal suggests the occurence of fire, possibly wildfire owing to dry conditions.
280–220cm 3000–2700 cal. BP	High (1.2) indicating wet conditions.	Low (-4, but reaches as low as -5.5)		Low UOM. High percentage of hummock forming species of *Sphagnum* (*S. imbricatum* and *S. subnitens*).	Decrease in charcoal, increase in *Alnus* and Cyperaceae percentages. Low numbers of *Sphagnum* and *Tilletia sphagni* spores.	Relatively wet conditions on the mire as indicated by low UOM, an increase in Cyperaceae spores, low charcoal and some of the least humified peat. However, a high percentage of hummock forming *Sphagnum* species and an absence of *S. cuspidatum* suggests conditions were not as wet as found towards the surface. Interestingly, numbers of *Sphagnum* spores are low.
220–100 cm 2700–1100 cal. BP	Low (0.7) with lowest T value in the profile. Some fluctuation between wet and dry.	Low (3.5)		Presence of *Ericales* rootlets. High Monocots. High percentage of hummock forming *Sphagnum* species (*S. imbricatum*).	Highest percentage of Poaceae. Highest number of charcoal fragments. Fluctuating tree pollen.	Mire in a dry state as indicated by the presence of *Ericales* rootlets, high *Sphagnum imbricatum* (hummock forming species), high Poaceae spores and some of the most highly humified peat. Cause may be fire as indicated by the highest number of charcoal fragments in the profile.
100–0 cm 1100–-60 cal. BP	High (1.3). Some of the wettest conditions throughout profile	High (an average of -2, increasing up to -0.5 towards 0 cm depth, possibly caused by increasing atmospheric pollution)	Introduction at 24 cm (c. 1850 AD), second peak at 8 cm depth (c. 1950 AD)	High percentage *Sphagnum* (including *S.cuspidatum* and *S. papillosum).* Low UOM. Low Ericaceae. Highest *Trichophorum cespitosum.*	High numbers of *Tilletia sphagni* and *Sphagnum* spores. High percentage of *Vaccinium.* Low charcoal.	Wet conditions on the mire as indicated by high T values, high *Sphagnum* remains (including *S. cuspidatum*), high *Tilleta sphagni* and *Vaccinium* spores and some of the least humified conditions (although this may be attributed to the increased preservation in the acrotelm). *Sphagnum imbricatum* disappears above 80cm depth.

Chapter 5: West Arkengarthdale Results and Interpretation

This chapter covers the results and interpretation of laboratory analysis from the peat core obtained from West Arkengarthdale. The results have been consolidated and presented in tables where appropriate to aid comparison and interpretations using all the methods as evidence.

The ecological condition of West Arkengarthdale is described as blanket mire with modern day peat supporting species characteristic of NVC type M20 (Rodwell, 1998).

5.1 Lithology

The lithology of West Arkengarthdale is shown in Figures 5.5 and 5.6 alongside the pollen and charcoal and plant macrofossil results, following the Troels-Smith (1955) method and described in Table 5.1.

5.1.1 Description

Although some vegetative remains could be identified in the field, mainly *Sphagna* and sedges, the majority of the peat horizons are moderately humified (Table 5.1). Layers of *Sphagnum* peat (Tb) are observed between 0–14, 20–29 and 214–267 cm depths; *Sphagnum* was identified from plant macrofossil analysis at 0–40 and 150–190 cm depths. The rest of the peat consists of mainly Th (herbaceous sedge peat) and Sh (highly decomposed peat), with Ag (silt) at the base of the profile, dated to >6700 cal. BP. *Eriophorum vaginatum* remains were notable throughout.

Table 5.1: Description of lithology at West Arkengarthdale and depths (cm).

Depth (cm)	Description
0–14	*Sphagnum* and herbaceous peat (notably *Eriophorum vaginatum*) with some highly humified peat.
14–20	Mainly herbaceous peat (notably *Eriophorum vaginatum*) with some highly humified peat.
20–22	Mainly *Sphagnum* peat.
22–24	Mainly *Sphagnum* peat with some highly humified peat.
24–29	Mainly *Sphagnum* peat.
29–100	Herbaceous peat (notably *Eriophorum vaginatum*) and highly humified peat.
100–178	Mainly highly humified peat with herbaceous peat (notably *Eriophorum vaginatum*) and wood inclusions (*Betula*).
178–214	Herbaceous peat (notably *Eriophorum vaginatum*), highly humified peat and wood inclusions (*Betula*).
214–267	Mainly highly humified peat with some *Sphagnum* peat.
267–274	Mainly highly humified peat.
274–292	Mainly highly humified peat with some *Sphagnum* peat.
292–307	Mainly silt with some highly humified peat.
307–350	Silt.

5.2 Chronology

5.2.1 Description and Interpretation of SCPs

The introduction of SCPs can be seen at 20.5 cm depth (Figure 5.5), dated to c. cal. AD 1815 using the radiocarbon age-depth models (Figures 5.1 and 5.2). The SCP record usually starts in the mid-nineteenth century (Swindles, 2010) but given the error from the radiocarbon dates (±30 years) and varying times that the industrial revolution started across the UK, this could be accurate. The biggest peak can be seen at 8.5 cm depth, dated to cal. AD 1930 using the radiocarbon age-depth models (Figures 5.1 and 5.2), yet, the biggest rise in SCPs normally correlates with the post second world war industrial boom (Swindles, 2010) and so again, this would appear to be slightly early according to radiocarbon dates. This discrepancy between the radiocarbon and SCP profiles could be attributed to possible vertical movement of SCPs (Garnett *et al.*, 2000), however, the radiocarbon dates are calculated based on a uniform sediment accumulation rate of peat between 39.5 cm depth and the mire surface from the collection date (AD 2012). It is possible that this varied and so the relative dates inferred from the varying counts of SCPs are perhaps more reliable. This is also supported by an increase in *Pinus* (Figure 5.5), usually dated to the beginning of the 19th century (Appleby *et al.*, 1997) at 22 cm depth. The SCPs then decrease at 4.5 cm depth, which is interpreted as a decrease following the implementation of clean air acts. There was not sufficient peat available to analyse the surface sample.

5.2.2 Description and Interpretation of Radiocarbon Dates

The date obtained at 147.5 cm depth might be too young, as the sample selected may have been rootlets that have contaminated the peat from a higher level (Table 5.2). However, if the date at 182.5 cm is correct, then both dates at 147.5 cm and 159 cm depth would be too young. It is statistically more likely that one date is incorrect as opposed to two. The age-depth model produced including the two dates at 147.5 cm and 159.5 cm depth does not show consistent accumulation rates (Figure 5.1) whereas the age-depth model produced excluding the two dates shows a steadier accumulation rate (Figure 5.2). The sample from 159.5 cm depth was obtained using plant material, likely to include *Sphagnum* leaves as approximately 20% of plant macrofossil samples at this depth contained *Sphagnum*. This might be interpreted as being more reliable than dates produced using wood or peat since *Sphagnum* macrofossils provide excellent material for ^{14}C sample selection. They can be easily selected and do not provide the same problems for dating such as *Eriophorum vaginatum*, where younger roots can penetrate deeper peat causing contamination (Piotrowska *et al.*, 2011). However, given that the reasoning behind the production of both age-depth models is valid and that they are in agreement on ages towards the surface (which is of primary concern given the conservation nature of this thesis) both will be used in the interpretation of results.

Table 5.2: Radiocarbon dates from West Arkengarthdale: Depth (cm), Radiocarbon date (yr BP), Beta Analytic Lab Number, Calibrated Ages (yr BP) and Material used. *Possible outliers. Radiocarbon dates were calibrated using OxCal version 4.2 (Ramsey 2009). All samples were dated using the fraction of plant material extracted from samples of peat by Beta Analytic. (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Depth (cm)	Radiocarbon Date (yr BP)	Lab Number	Calibrated Age (yr BP)*	Material
289.5	5610 ± 30 BP	379808	6487 (6393.5) 6300	peat
260.5	4820 ± 30 BP	379807	5645 (5556.5) 5468	peat
182.5	3320 ± 30 BP*	379806	3685 (3567.5) 3450	peat
159.5	3640 ± 30 BP*	385278	4089 (3965) 3841	plant material
147.5	3410 ± 30 BP*	379805	3828 (3695.5) 3563	wood
100.5	1780 ± 30 BP	385277	1822 (1696) 1570	plant material
39.5	300 ± 30 BP	381604	485 (320.5) 156	plant material

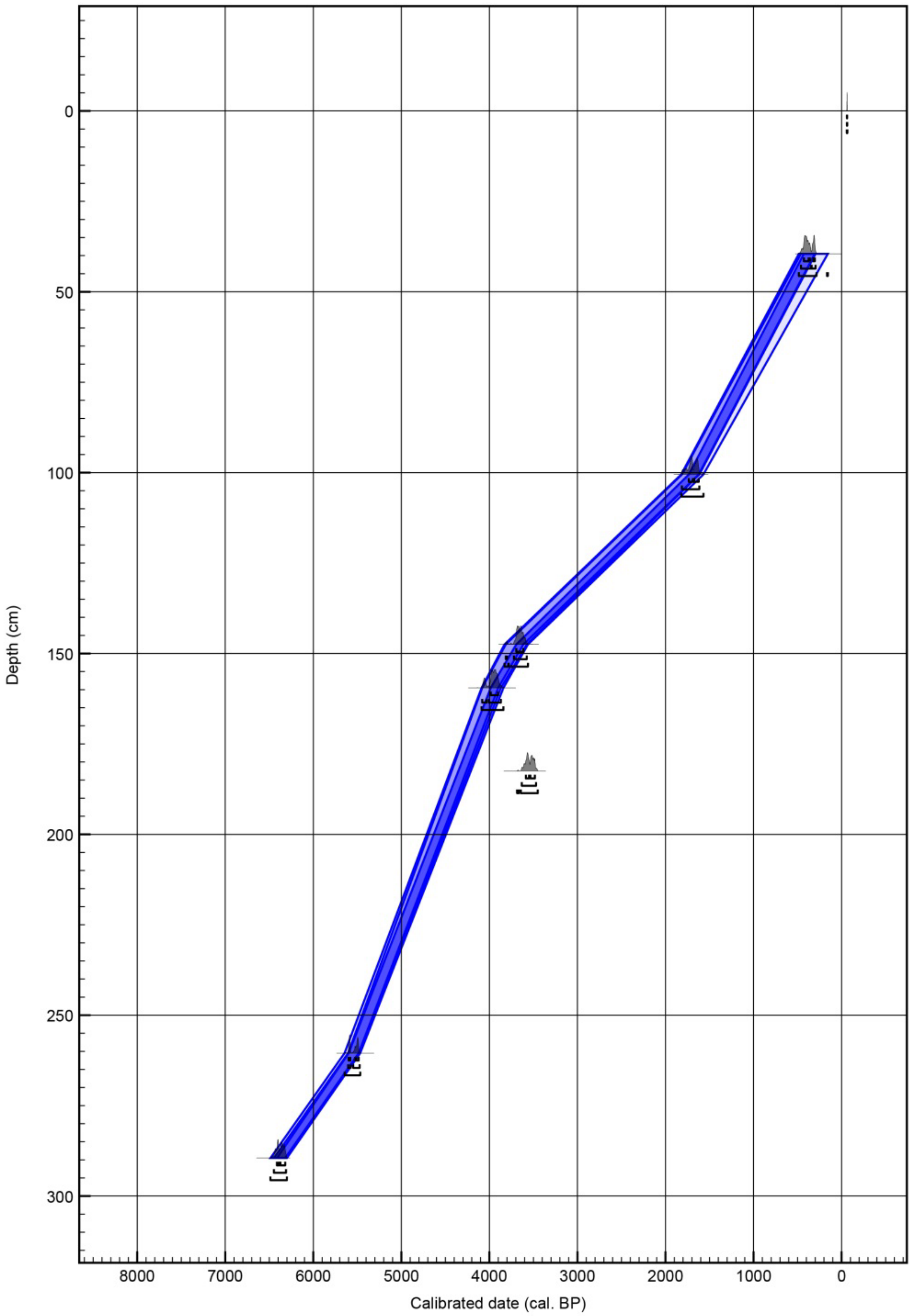


Figure 5.1: Bayesian (P_Sequence) age-depth model 1 for West Arkengarthdale from 6 accepted and 1 rejected (excluded from blue line) AMS radiocarbon dates constructed using OxCal version 4.2 software (Ramsey, 2009) and calibrated using INTCAL13 (Reimer *et al.*, 2013).

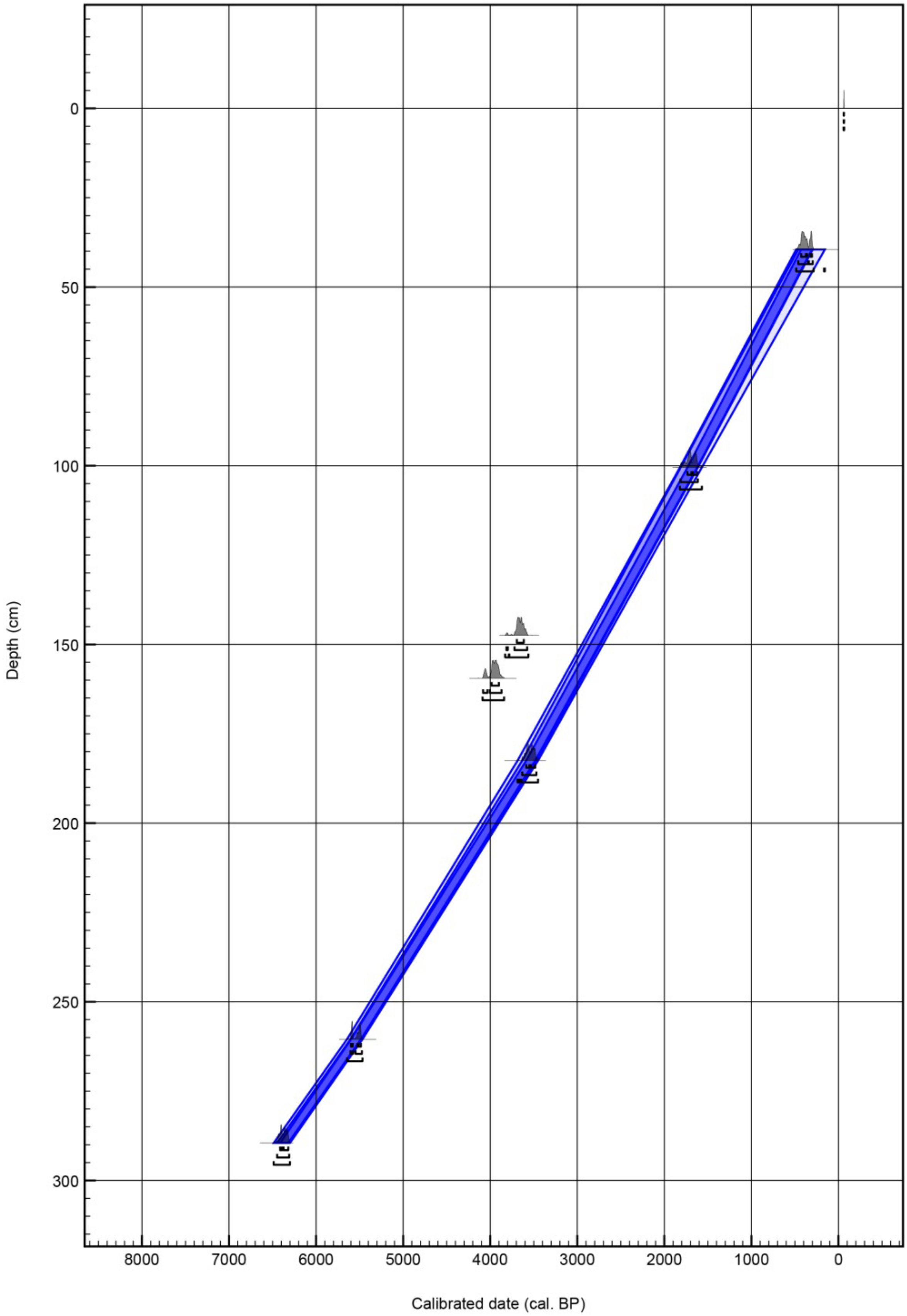


Figure 5.2: Bayesian (P_Sequence) age-depth model 2 for West Arkengarthdale from 5 accepted and 2 rejected (excluded from blue line) AMS radiocarbon dates constructed using OxCal version 4.2 software (Ramsey, 2009) and calibrated using INTCAL13 (Reimer *et al.*, 2013).

5.3 Magnetic Susceptibility

5.3.1 Description

The magnetic susceptibility curve can be sectioned into three zones based on changes in values. These are: 350–290 cm, 290–120 cm and 120–0 cm depths (Figure 5.3). In the first zone, values are high, reaching c. 2.5 at 340 cm depth. Values do not drop below 0 in this zone. In the second zone, values are generally lower, reaching 0.5 at 190 cm depth and a low of -3 at 140 cm depth. In the final zone, values fluctuate between c. -4.5 and c. -2.5 before rising to -0.5 towards the surface. A minimum value of c. -5 can be seen at approximately 60 cm depth and a maximum of c. 0.6 just before 120 cm depth.

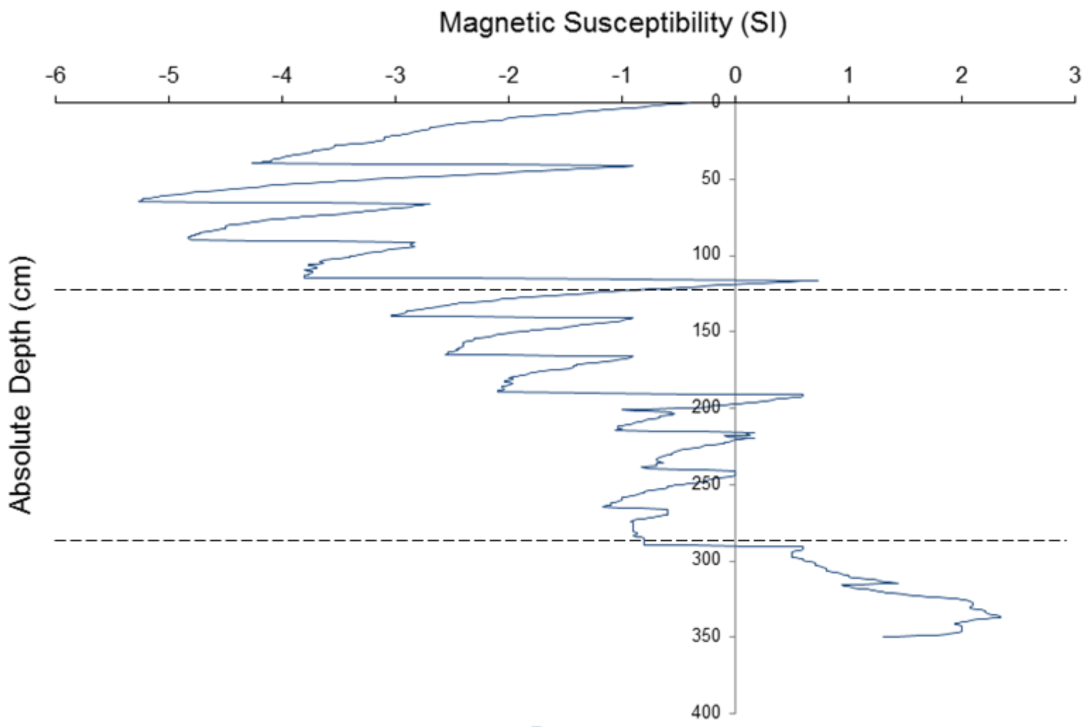


Figure 5.3: Magnetic Susceptibility (SI) and depth (cm) at West Arkengarthdale.

5.3.2 Interpretation

Towards the base of the profile in the first zone (350–290 cm depth) much higher values than seen in the rest of the profile could be caused by increasing minerogenic content. Clay was identified by eye from 290 cm depth onwards, meaning it is possible that small amounts not visible to the eye were present further up the core. Relatively high MS values between 290–120 cm may be related to fast accumulation rates, reflected in very low numbers of *Lycopodium clavatum* spores. MS values are generally much lower and highly fluctuating towards the surface between 120–0 cm depth and this may be explained by slow accumulation rates, as evidenced by a higher number of and fluctuation of *L. clavatum* spores (Figure 5.5). However, values do increase from 40 cm depth to the surface, which may be attributed to atmospheric pollutants (Oldfield *et al.*, 1981, Petrovský *et al.*, 2000) or increased burning (Gale and Hoare, 1991).

5.4 Humification

Humification was only measured to 300 cm depth, owing to the high mineral concentration below this. The raw percentage transmission results were exponentially smoothed in MS Excel and then de-trended using a linear regression model to remove any long-term trends; hence, transmission is no longer expressed as a percentage, but as a number.

5.4.1 Description

The humification curve can be sectioned into four zones based on changes in transmission values. These are: ARK–d (300–240 cm), ARK–c (240–155 cm), ARK–b (155–55 cm) and ARK–a (55–0 cm) (Figure 5.4). In ARK–d, values are generally high and increase towards the base of the profile, reaching a maximum of c. 2.1. In ARK–c, fluctuations through the trend-line from high to low values can be seen, ranging from a high of c. 1.2 at 210 cm depth, to a low of c. 0.5 at 190 cm depth and again a high of c. 1.2 at 155 cm depth. ARK–b has lower values in comparison to ARK–c, varying between a low of c. 0.3 at 85 cm depth, the lowest value in the profile and a high of c. 1 at the end of the zone. ARK–a has typically high values, ranging from a high of c. 2.3 to a low of c. 1.

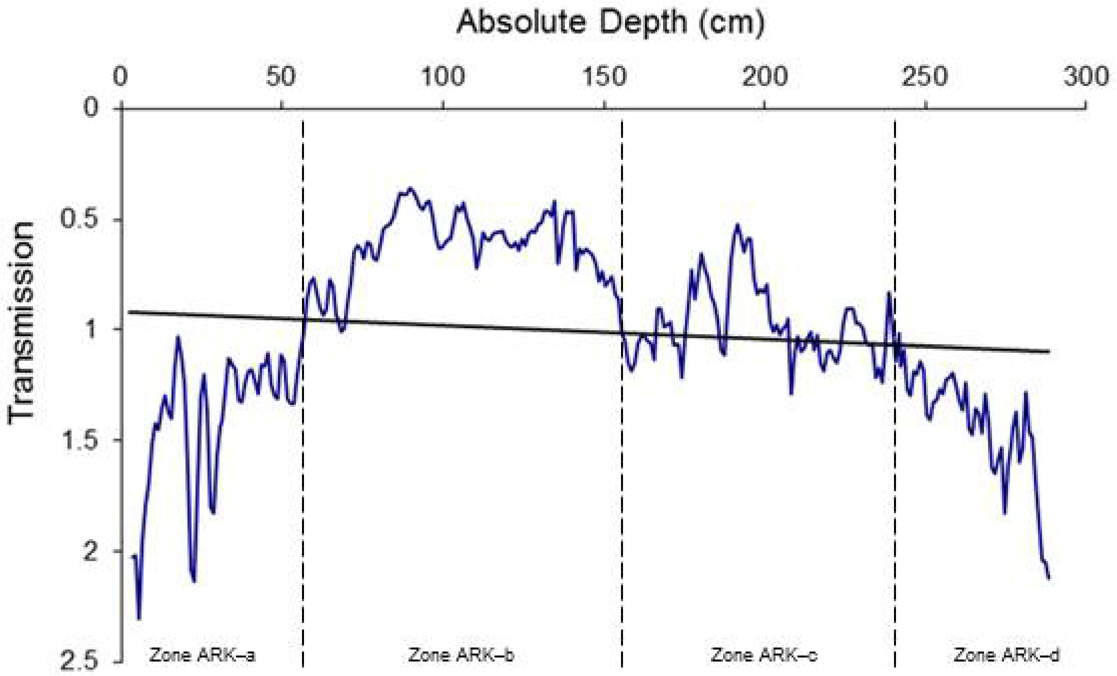


Figure 5.4: Humification (Transmission) and depth (cm) at West Arkengarthdale.

5.3.2 Interpretation

The first zone, ARK–d can be described as generally wet with high T values, all being below the trend-line. Conditions are progressively wetter towards the base of this zone, the wettest being at 290 cm depth (6400 cal. BP). Zone ARK–c sees more fluctuations between wet and dry, with wet conditions at 235 cm, 225–205 cm, 175–155 cm and 190 cm depths and dry conditions in between.

Zone ARK–b is much drier in comparison to ARK–c with values rarely nearing the trend-line, with the exception of 70 cm depth, where values reach 1. Dry conditions are sustained between c. 3800/2800–650 cal. BP depending on which age model is used (Figures 5.1 and 5.2).

Zone ARK–a can be described as wet as the values stay below the trend-line. One particularly wet episode can be identified at 26–20 cm depth (cal. AD 1820–1760) and could be interpreted as the Little Ice Age (LIA). The bog is then slightly drier subsequently up until approximately 5 cm depth (cal. AD 1964) with a return to wetter conditions. However, peat at this depth has had much less time to decompose than the layers of peat below and therefore the high values in this zone may be a reflection of this.

5.5 Pollen Analysis

5.5.1 Description

Table 5.3: Pollen zones, depth (cm), radiocarbon ages 1 and 2 (cal. BP), humification (Wet/Dry) and pollen zone descriptions at West Arkengarthdale. (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Pollen Zone	Depth (cm)	Age 1 (cal BP)	Age 2 (cal BP)	Humification (Wet/Dry)	Description
ARK A	300–260	c. 6700–5450	c. 6700–5451	Wet	High percentage of *Betula* (upto 45%), *Potentilla* (upto 25%), *Quercus* (c. 10%), *Alnus* (upto 20%) and *Corylus* (upto 35%). Percentages of Poaceae (<5%) and *Calluna* (<10%) are low, as is the number of charcoal fragments (upto 200).
ARK B	260–185	c. 5450–4300	c.5450–3500	Mainly dry.	High percentages of *Betula* (upto 30%), *Quercus* (upto 20%), *Alnus* (upto 40%) and *Corylus* (upto 40%) with a presence of *Ulmus*, *Tilia*, *Salix* and *Myrica*. *Calluna* decrease from 20% at the top of the zone to <5% at the bottom. *Filicales* and *Polypodium* increase in this zone and numbers of charcoal fragments and *Sphagnum* spores are low.
ARK C	185–150	c. 4300–3700	c.3500–2800	Mainly dry. Some wet.	High concentration of *Lycopodium* spores, high percentages of *Quercus* (upto 20%), *Alnus* (upto 25%) and *Corylus* (upto 40%) and high numbers of *Sphagnum* (upto 300) and *Tilletia sphagni* spores (upto 45). Decreasing percentage of *Calluna* (mostly 10% with a high of 40%) and a slight increase in Poaceae (c. 10%) compared to zones D and B. Low charcoal.
ARK D	150–51	c. 3700–700	c.2800–700	Dry	Percentages of *Betula*, *Quercus*, *Alnus* and *Corylus* all increase towards the base of the zone. High percentages of Cyperaceae (upto 30%) and *Calluna* (upto 80%) although the latter decreases towards the base of the zone. Relatively high numbers of *Sphagnum* spores (upto 100) at the top of the zone but these decrease towards the base. High charcoal fragments (upto 900).
ARK E	51–0	c.700–-60	c.700–-60	Wet	High concentration of *Lycopodium* spores, high percentage of Cyperaceae (upto 25%), *Erica.* (upto 25%), *Calluna* (upto 90%), *Rumex* (c. 5%) and Poaceae (upto 60%). High number of *Sphagnum* spores (200) at 40 cm depth. Low percentages of *Betula* (<5%) and all other tree pollen despite a slight rise in *Pinus* towards the surface. High numbers of charcoal fragments (upto 1000).

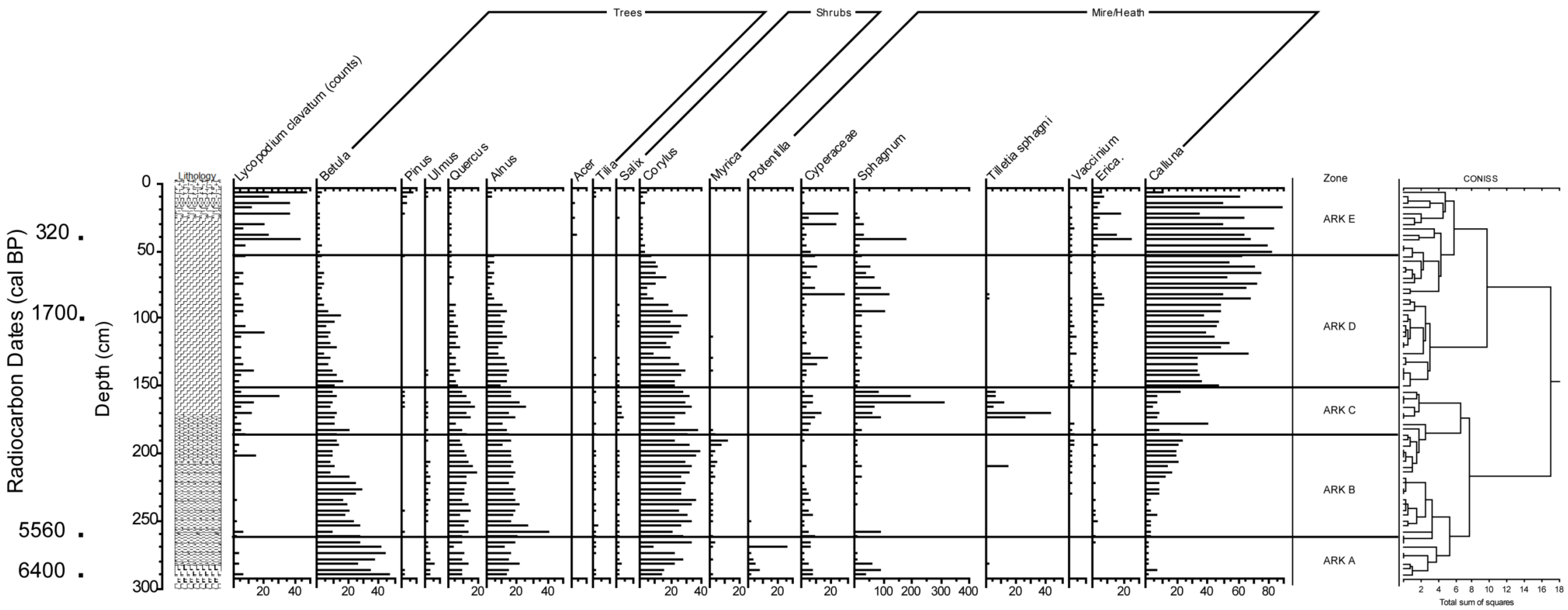
5.5.2 Interpretation

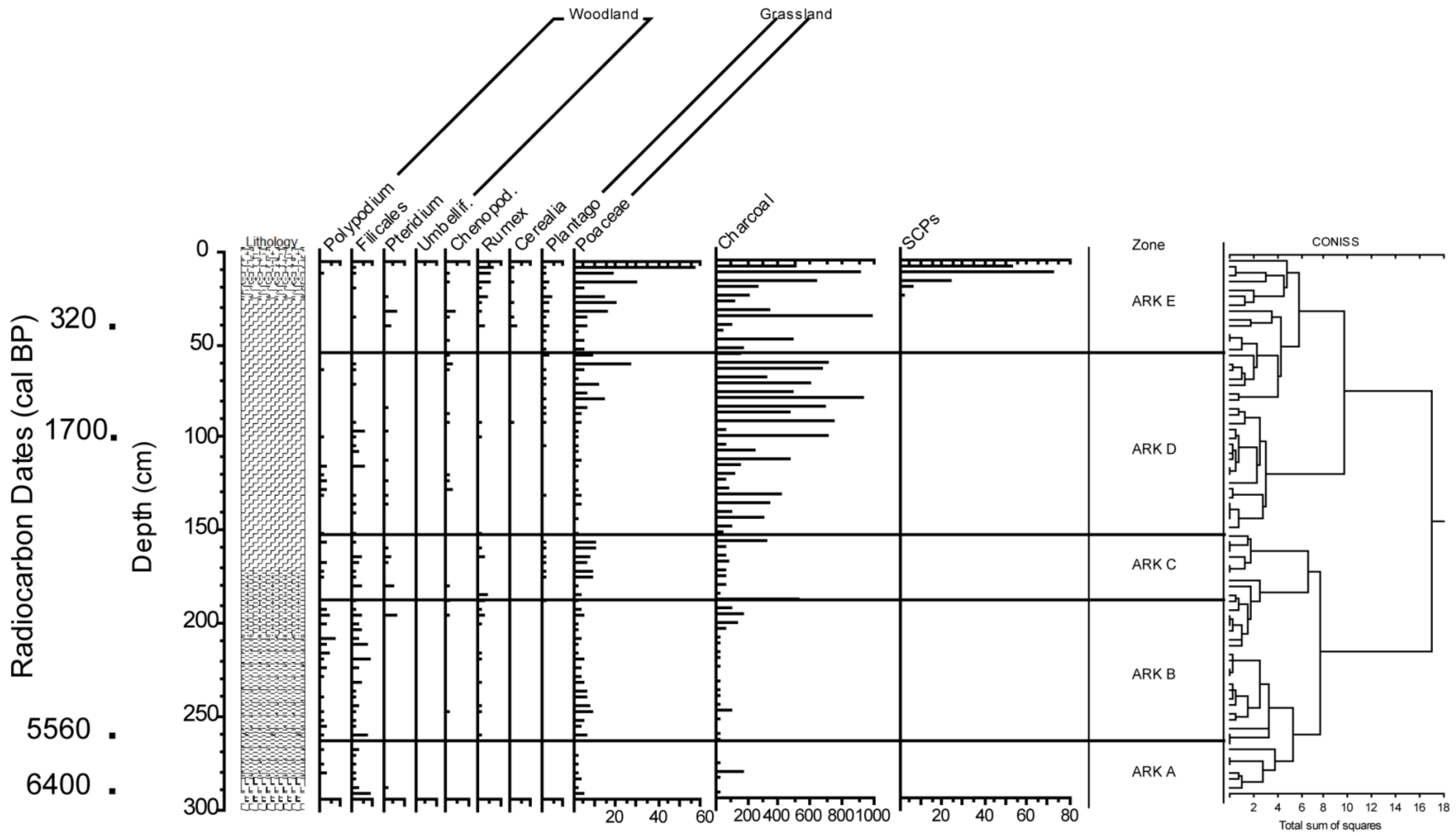
5.5.2.1 ARK – A (300–260 cm depth) *Betula-Corylus-Potentilla*

Potentilla is present in this zone, most likely *P. erecta*, which is widespread in the British Isles and is often very common in acid habitats, being found in heath, grassland, mire and woodland (Richards, 1973) (Table 5.3, Figure 5.5). *P. erecta* is not uncommonly found with *Betula*, which reaches its highest percentage throughout the profile in this zone, perhaps growing on the fen/bog at this stage. *Calluna* and Poaceae are very low, possibly because conditions were too wet to sustain their growth, as indicated by low numbers of charcoal fragments and the presence of *Sphagnum* spores, most likely pool species such as *S. cuspidatum*.

5.5.2.2 ARK – B (260–185 cm depth) *Betula-Quercus-Alnus-Corylus*

Betula and *Alnus* increase towards the base of this zone, suggestive of decreased anthropogenic influence when compared to overlying zones. *Quercus* and *Corylus* are also higher, as is *Myrica*. *Calluna* decreases through the zone and numbers of





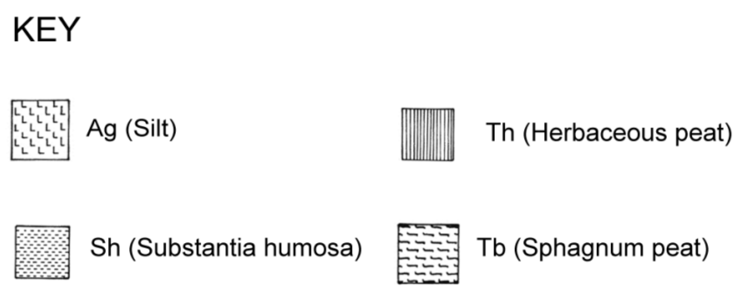


Figure 5.5 Pollen percentages at West Arkengarthdale using: depth (cm), radiocarbon ages (cal. BP), lithology (Troels-Smith, 1955), number of charcoal fragments counted(per 500 counted terrestrial pollen grains), and number of SCPs counted (per 500 counted terrestrial pollen grains).

Sphagnum are low, consistent with a decrease in the number of charcoal fragments. This may all be indicative of relatively dry conditions; however, without the occurrence of wildfire. There is a possible '*Ulmus* decline' at 210 cm depth, dated to 4700 cal. BP or 4000 cal. BP depending on which age model is used (Figures 5.1 and 5.2). If this is indeed the '*Ulmus* decline', 4000 cal. BP would be more appropriate.

5.5.2.3 ARK – C (185–150 cm depth) *Sphagnum-Corylus-Alnus*

High numbers of *Sphagnum* and *Tilletia sphagni* spores are indicative of wet conditions in this zone. This is consistent with a decrease in *Calluna* and low numbers of charcoal. Tree pollen increases in this zone when compared to the previous and this may demonstrate that man is having less of a marked influence on the landscape at this stage in time than further up the profile. *Ulmus* pollen is also present in this zone but disappears at 161 cm depth, dated to 4000 cal. BP or 3000 cal. BP depending on which age model is used (Figures 5.1 and 5.2).

5.5.2.4 ARK – D (150–51 cm depth) *Calluna-Corylus-Cyperaceae-Sphagnum*

The decrease in *Betula, Quercus, Alnus* and *Corylus* from the bottom of this zone to the surface can again be attributed to clearance by man, possibly with the use of fire as indicated by the high number of counted charcoal fragments. This seems to have benefited *Calluna* and Poaceae*,* which increase towards the top of the zone. Cyperaceae and *Sphagnum* increase towards the top of the zone, perhaps indicative of wetter conditions on the bog at 82 cm depth (1000 cal. BP).

5.5.2.5 ARK – E (51–0 cm depth) *Calluna-Poaceae-Erica-Cyperaceae*

The highest percentages of *Rumex*, *Cerealia* and *Plantago* are found in this zone, indicative of anthropogenic influence. Poaceae, *Calluna* and *Erica* also reach their highest percentages, perhaps encouraged by increased burning, indicated by a high number of fragments of charcoal. *Pinus* is present from c. 20 cm depth (cal. AD 1800) towards the surface and is indicative of recent pine plantations; as an increase in *Pinus* associated with extensive reforestation usually predates the beginning of the 19th Century (Appleby *et al.*, 1997). The *Lycopodium clavatum* count is high, indicating a slow peat accumulation rate, probably owing to a lower presence of peat-forming species such as *Sphagnum* and *Eriophorum vaginatum.* *Sphagnum* and Cyperaceae are almost absent between 20–0 cm depth, supporting this theory. It is likely that these species were affected by increased burning and atmospheric pollution, the latter indicated by the introduction of SCPs at 20 cm depth (AD 1800). Tree pollen is very low throughout this zone, perhaps owed to human clearance.

5.6 Plant Macrofossil Analysis

5.6.1 Description

Table 5.4: Plant macrofossil zones, depth (cm), radiocarbon ages 1 and 2 (cal. BP), humification (wet/dry) and plant macrofossil zone descriptions at West Arkengarthdale. (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Plant Macrofossil Zone	Depth (cm)	Age 1 (cal BP)	Age 2 (cal BP)	Humification (Wet/Dry)	Description
ARK 1	300–260	c.6700–4700	c.6700–4250	Wet	High percentage of UOM (upto 60%), Ericaceae (upto 20%), Monocot roots (upto 50%), *Trichophorum cespitosum* (upto 30%) and *Nymphaea* leaves (upto 30%). Also, a high number of *Nymphaea* seeds were counted (upto 30). There is also a high percentage of quartz grains (60%) at the base of the profile. No *Sphagnum*.
ARK 2	260–195	c.4700–4500	c.4250–3900	Mainly dry.	No *Sphagnum*, high percentages of *Equisetum fluviatile* (upto 40%), *Trichophorum cespitosum* (upto 40%), *Eriophorum vaginatum* (upto 30%), UOM (upto 40%) and a presence of *E. angustifolium* and *Betula* at 250 cm depth.
ARK 3	195–151	c.4500–3700	c.3900–2800	Mainly dry. Some wet.	High percentage of *Trichophorum cespitosum* (upto 30%), low percentage of Ericaceae (<5%), low *Eriophorum vaginatum* in comparison to ARK 4 and ARK 2 (upto 30%), low UOM (c. 20%), high percentage of identified *Sphagnum* (upto 60%), most of which is *S. cuspidatum* between 160 cm and 170 cm depth.
ARK 4	151–45	c.3700–400	c.2800–400	Dry	Low percentage of identified *Sphagnum*, low *Trichophorum cespitosum* (upto 10%), high percentage of *Scheuchzeria palustris* (upto 20%), high *Equisetum fluviatile* (upto 20%) and *Betula* (upto 20%) towards base of zone, high *Eriophorum vaginatum* (upto 50%), high Monocots (upto 40%) and the only occurence of *Erica tetralix* throughout the profile at 120cm depth.
ARK 5	45–0	c.400–-60	c.400–-60	Wet	Highest percentage of *Polytrichum commune* (upto 20%), low percentage of *Eriophorum vaginatum* (c. 10%) and UOM (c. 20%), high percentage of Ericaceae (upto 10%) and *Calluna vulgaris* (upto 10%). Highest percentage of identified *Sphagnum* (upto 90%). *S. papillosum* is present at the surface (100%), whilst *S. molle* and *S. fuscum* make up the majority between 20 cm and 45 cm depth. Presence of *Eriophorum angustifolium* at 40 cm depth.

5.6.2 Interpretation

5.6.2.1 ARK – 1 (300–260 cm depth) *Trichophorum cespitosum-Equisetum fluviatile-Nymphaeae*

The high percentage of UOM in this zone may be partly explained by the length of time that plant material at this depth has had to decompose (Table 5.4, Figure 5.6). However, there is also a high percentage of Ericaceae roots, indicative of dry conditions. *Eriophorum vaginatum* and *Trichophorum cespitosum* are present but at lower levels when compared with the zones above. *Equisetum fluviatile* is present, suggestive of wet conditions, as is *Nymphaea*, with a high percentage of leaves and stems as well as a considerable amount of seeds. *Nymphaea* is an

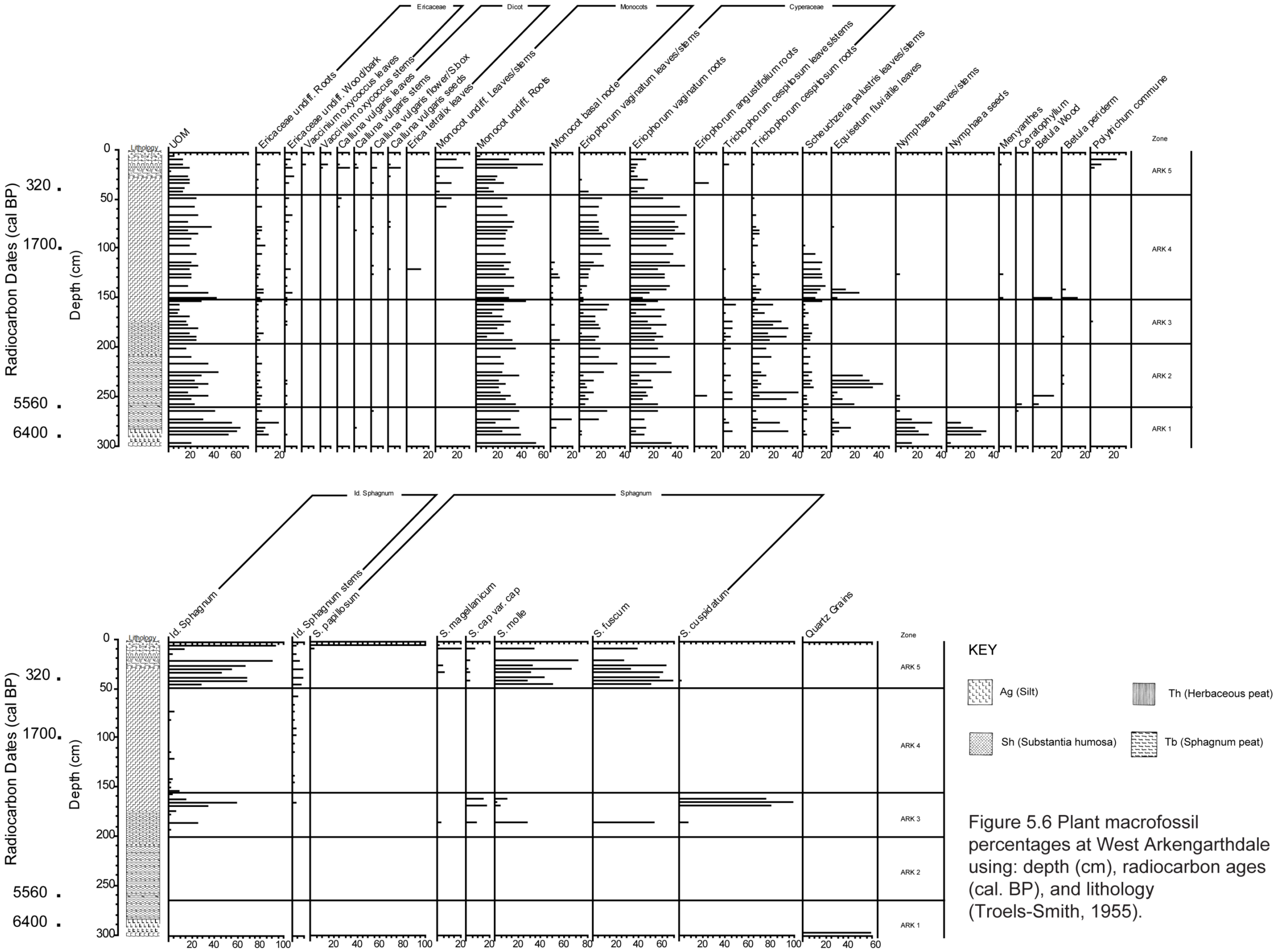


Figure 5.6 Plant macrofossil percentages at West Arkengarthdale using: depth (cm), radiocarbon ages (cal. BP), and lithology (Troels-Smith, 1955).

aquatic species; usually found floating in standing water, suggesting that the mire was very wet at this time, with the presence of pools.

5.6.2.2 ARK – 2 (260–195 cm depth) *Eriophorum vaginatum-Trichophorum cespitosum-Equisetum fluviatile*

The presence of *Equisetum fluviatile* in this zone would suggest an increased water table; however, the presence of *Betula* wood and periderm, indicates drier conditions and possibly fen hummocks, which is also supported by high levels of UOM and an increasing percentage of *Trichophorum cespitosum* when compared with the following zone (ARK – 3). However, the aquatic species *Nymphaea* and *Ceratophyllum* are present towards the base of the zone, suggesting a wet environment as is *Eriophorum angustifolium*, which is tolerant of standing water. This may suggest the presence of two communities in this locality; the pool as evidenced by aquatic species and the surrounding telmatic community.

5.6.2.3 ARK – 3 (195–151 cm depth) *Eriophorum vaginatum-Trichophorum cespitosum-Sphagnum cuspidatum*

Sphagnum is present in this zone, notably *S. cuspidatum* towards the top of the zone, which is indicative of wet conditions given that it normally grows in pools. A decrease in UOM is consistent with this, as increased UOM signifies higher decomposition rates and therefore drier conditions (Chambers *et al.*, 2013b). There is also a lower presence of Ericaceae and an absence of *Calluna vulgaris* and *Erica tetralix*, suggesting very wet conditions on the bog. *Eriophorum vaginatum* is present in lower amounts than the previous zone and *Trichophorum cespitosum* increases towards the base where the dominant *Sphagnum* species is *S. fuscum,* a hummock forming species. Both *Eriophorum vaginatum* and *Trichophorum cespitosum* are usually associated with drier areas on bogs but have been known to occur on wet lawns (Lamentowicz *et al.*, 2010).

5.6.2.4 ARK – 4 (151–45 cm depth) *Eriophorum vaginatum-Scheuchzeria palustris*

Sphagnum is almost absent in this zone and instead there are higher percentages of UOM and *Eriophorum vaginatum*, suggesting drier conditions. Ericaceae and *Erica tetralix* are also present, supporting this. There is an increase in *Trichophorum cespitosum*, also preferring drier hummocks. There is an increase in

Scheuchzeria palustris, a pool species, towards the base of the zone, thick layers of which usually precede *Sphagnum* growth, which becomes established in the next zone (ARK – 5). Again, this suggests the presence of pools and hummocks in close proximity. *Scheuchzeria palustris* became extinct in the UK at approximately AD 1900 (Preston *et al.*, 2002) possibly owing to drainage and increased pollution and so its presence here indicates a more diverse, less anthropogenically affected and wetter environment, consistent with a slight decrease in *Eriophorum vaginatum* at this depth.

5.6.2.5 ARK – 5 (45–0 cm depth) *Polytrichum commune-Sphagnum papillosum-S. molle-S. fuscum*

Low UOM and the presence of *Eriophorum angustifolium*, *Polytrichum commune* and *Sphagnum papillosum*, *S. fuscum* and *S. molle* would suggest relatively wet conditions; however not wet enough to form pools as the species mentioned would usually be found forming hummocks. *S. papillosum* replaces *S. fuscum* and *S. molle* towards the surface suggesting a change in conditions, perhaps becoming slightly drier as *S. papillosum* is more drought tolerant. There is an absence of *Sphagnum* at 20 cm depth, consistent with an increased presence of *Calluna vulgaris*, indicative of dry conditions. Following this, *Polytrichum commune* increases, tolerant of dry conditions.

5.6.3 De-trended Correspondence Analysis

De-trended Correspondence Analysis was conducted on plant macrofossils using R (R Core, 2012) in an attempt to derive a bog surface wetness index from the plant macrofossil data (Langdon *et al.*, 2003). DCA was performed using “Vegan” version 2.0-9 (Oksanen, 2013) and the first and second axes of the ordination were plotted against each other (Figure 5.7). The eigenvalue of axis 1 (0.84) is much greater than axis 2 (0.37) and only covers a range of approximately 2 σ units. However, it does not seem to display any variance as most species are plotted around the 0 value with the exception of *Sphagnum papillosum*. However, there does seem to be some variation on axis 2, which has an usually high eigenvalue and covers a range of approximately 4.5 σ units. The presence of *Sphagnum cuspidatum* at one end possibly relates to its presence under wet conditions and the high values on axis 2 of *S. molle* and *S. fuscum* perhaps relate to their tolerance of lower water tables. The presence of monocots and UOM towards the centre of axis 2 could be explained by a bimodal distribution along the hydrological gradient. However, if this were the case, it would be expected that Ericaceae and *Calluna vulgaris* would have higher scores as they are associated with drier conditions than *Eriophorum angustifolium* and *Sphagnum* section *Acutifolia*, which are more tolerant of wet conditions than axis 2 would suggest.

Furthermore, the plotted DCA Axis 2 values (Figure 5.8) do not conform to the humification values, as DCA suggests that the bog was particularly dry towards the surface whereas humification analysis suggests otherwise. However, DCA does suggest that the water table was at its highest at c. 160 cm depth, also defined as a wetter period according to humification, although perhaps not the wettest. However, it might be expected that DCA values would be at their lowest towards the base of the profile where aquatic species *Nymphaea* is present. The values indicating a low water table towards the surface of the profile may be a reflection of the presence of dry tolerant and hummock forming species *Calluna vulgaris* and *Sphagnum* section *Acutifolia*. Owing to the unreliability of these results and the unusual distribution across axis 2, DCA will not be further interpreted.

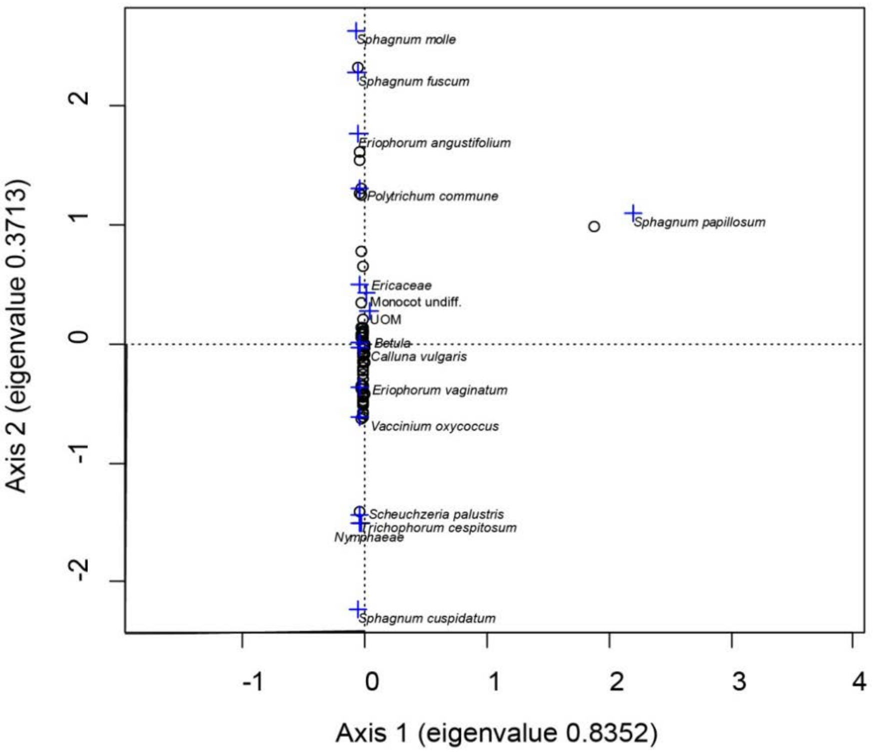


Figure 5.7: De-trended Correspondence Analysis: A bi-plot of the axis 1 and axis 2 scores (σ units) from the plant macrofossil results at West Arkengarthdale. Blue crosses=species; black circles=samples.

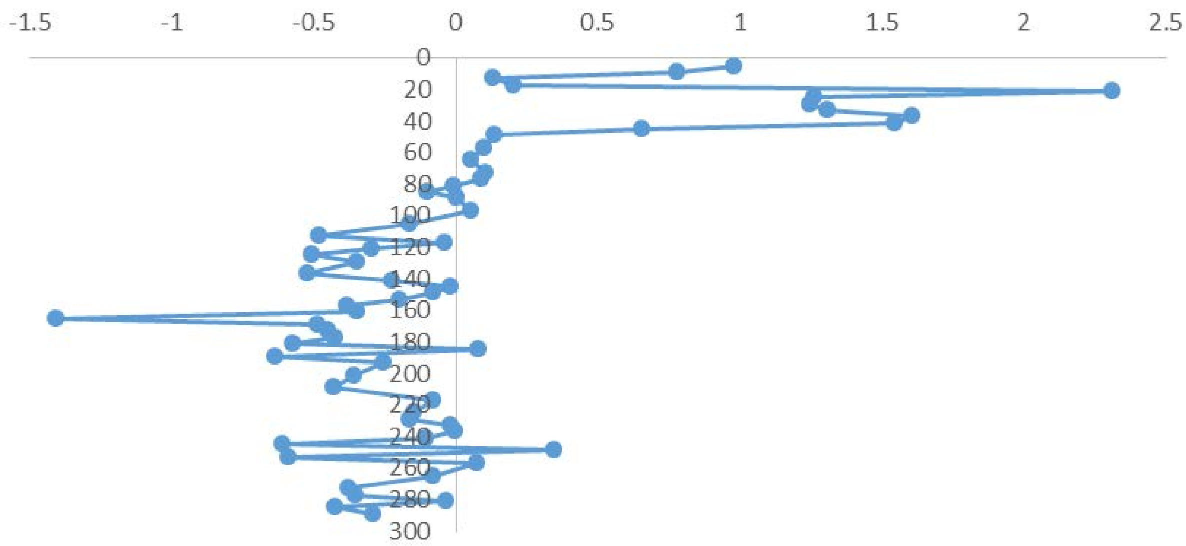


Figure 5.8: DCA Axis 2 values and depth (cm) at West Arkengarthdale.

5.6.4 Dupont Hydroclimatic Index (DHI)

As the DCA ordination failed to detect the presence of an undeniable mire surface wetness gradient in the plant macrofossil data, DHI (Dupont, 1986) has been applied to the plant macrofossil data to provide a qualitative indication of changes in water table (Figure 5.9). The indices used were: UOM 8, *Vaccinium oxycoccus* 5, *Calluna vulgaris* 8, Ericaceae undifferentiated 8, monocots undifferentiated 6, *Eriophorum vaginatum* 6, *Eriophorum angustifolium* 2, *Trichophorum cespitosum* 6, *Scheuchzeria palustris* 2, *Nymphaea* 1, *Menyanthes* 3, *Ceratophyllum* 1, *Betula* 7, *Polytrichum commune* 7, *Sphagnum papillosum* 4, *Sphagnum magellanicum* 3, *Sphagnum* section *Acutifolia* 4, *Sphagnum cuspidatum* 1, based upon the weights used in Daley and Barber (2012) and Mauquoy *et al.* (2008) and knowledge of ecological tolerances and habitat preferences of each species.

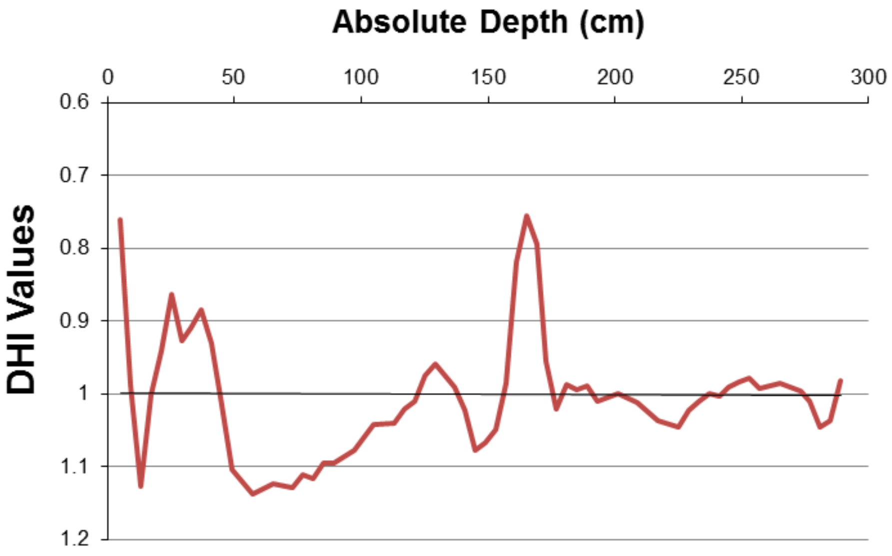


Figure 5.9: Smoothed and De-trended DHI curve for plant macrofossils from West Arkengarthdale.

The data have been de-trended, therefore meaning they are now displayed as lower values than the scores attributed to the species (Figure 5.9). Low values indicate wet conditions and these suggest that the mire was wet at 289 cm, 270–240 cm, 185–180 cm, 165 cm, 125 cm, 33–21 cm and 9–5 cm depths. Conversely, the mire was drier and/or warmer at 285–270 cm, 230–190 cm, 145 cm, 113–49 cm and 13 cm depths. The DHI curve shows similar results to the humification curve, with the exception of the apparent identified wet shift at 125 cm depth, caused by the presence of aquatic species *Nymphaea* and *Ceratophyllum*. However, both curves agree that the mire surface was wet at 289 cm (6400 cal. BP), 270–240 cm (5800–5100/5000 cal. BP), 185 cm (4300/3500 cal. BP), 165 cm (4000/3100 cal. BP) and generally wetter from 50–0 cm depths.

5.7 Summary of Magnetic Susceptibility, Humification, Pollen, Plant Macrofossil Data and SCP and Radiocarbon Dates

The mire surface at West Arkengarthdale is particularly wet between 289–245 cm depth (6400–5300/5100 cal. BP), as indicated by low charcoal, high *Potentilla*, the presence of *Sphagnum* pollen, (despite an absence of *Sphagnum* in the plant macrofossils) and low *Calluna* pollen (Table 5.5). The DHI values are low between 289–285 cm depth (6400–6300 cal. BP) and the presence of aquatic species *Nymphaea* at these depths suggests the presence of standing water. All proxies are in agreement; however, this is interpreted as the beginning of a natural vegetation succession and initiation of the peat growth and therefore may not necessarily have been caused by a climatic deterioration.

The evidence suggests dry and/or warm conditions at 239 cm depth (5200/5000 cal. BP), as indicated by high UOM, *Trichophorum cespitosum*, *Eriophorum vaginatum* and *Betula* wood in the plant macrofossils. Both *Trichophorum cespitosum* and *Eriophorum vaginatum* are unreliable indicators for reconstructing water tables as they can withstand a variety of ecological conditions (Blaauw *et al.*, 2004); however, the surface of the mire would have to have been dry enough to support the growth of *Betula*. DHI values are also high at this point, supporting that conditions were dry at this time.

The mire may have been wet at 235 cm depth (5100/4900 cal. BP) as evidenced by low humification and the presence of *Equisetum fluviatile*. However, DHI values do not support this and there is little evidence for wet conditions from pollen analysis with the exception of low charcoal. Therefore, it is suggested that conditions were only wet locally on the bog and not regionally. Similarly, the environment seems to be wet between 220–208 cm depth (4800/4500–4700/4250 cal. BP), as suggested by relatively low humification values, very low charcoal, low *Calluna* and the presence of aquatic species, *Scheuchzeria palustris*. However, DHI values are still high at this point, suggesting that although conditions may be wetter than identified at other depths in the profile, these are certainly not the wettest conditions.

All evidence does support a climatic deterioration between 175–158 cm depth (4100/3350–3900/3000 cal. BP), as evidenced by relatively low humification values, the introduction of *Sphagnum* onto the bog, particularly pool species *S. cuspidatum* between 170–160 cm depths (4100/3250–3900/3000 cal. BP), high *Sphagnum* spores as well as *Tilletia sphagni*, low charcoal, low *Calluna* and low DHI values. The bog then seems to become particularly dry between 150–72 cm depths (3700/2800–1000 cal. BP), supported by highly humified peat, high *Calluna* pollen, high charcoal, high tree pollen, no *Sphagnum*, high UOM and the inclusion of *Betula wood* towards 150 cm depth.

Conditions also become drier at 55 cm depth (700 cal. BP/cal. AD 1250), coinciding with the Medieval Warm Period. This is supported by increasing humification, high *Calluna*, Poaceae and tree pollen, high charcoal and the disappearance of *Sphagnum* from the plant macrofossil record, consistent with an increase in UOM and *Eriophorum vaginatum*.

At 28 cm depth, there is a wet shift dated to cal. AD 1750 as evidenced by low humification, a presence of *Sphagnum* pollen, lower Poaceae, slightly lower charcoal, presence of *S. molle* and *S. fuscum*, low UOM and low DHI values. Similarly, at 20 cm depth, there is a wet shift dated to cal. AD 1850, as evidenced by some of the lowest humified peat, relatively low DHI values, low UOM and presence of *Sphagnum papillosum*. However, charcoal is relatively high, as are *Calluna* and Poaceae pollen. Most of the evidence seems to suggest a climatic cause for this apparent wet shift and both events coincide with the LIA.

Table 5.5: Overall interpretation of mire surface conditions at West Arkengarthdale using: depth (cm), ages (cal. BP), humification (high/low), MS (SI), plant macrofossil description and pollen descriptions. (Table describes from oldest to youngest, as with stratigraphy, for ease of reading).

Depth (cm) and Age (cal. BP)	**Humification**	**Magnetic Susceptibility**	**SCPs**	**Plant Macrofossils**	**Pollen**	**Interpretation**
300–250 cm 6700–5300/ 5350 cal. BP	High, reaching above 2. Some of the wettest conditions in the profile.	High, reaching a high of 2, possibly owing to increasing mineragenic content towards base of profile.		High percentage of UOM, *Ericaceae*, Monocot roots, *Trichophorum cespitosum* and *Nymphaea* leaves and seeds. High quartz grains at base of profile. No *Sphagnum*.	High *Betula*, *Potentilla*, *Quercus*, *Alnus* and *Corylus*. Low Poaceae and *Calluna,* low charcoal.	Very wet as evidenced by the presence of *Nymphaea*, high transmission values and low charcoal.
250–210 cm 5300/5350–5700/4300 cal. BP	Wetter, mid-range and fluctuating; as low as 0.8 and as high as 1.3.	Medium. Fluctuates around 0 to -1.		No *Sphagnum*, high *Equisetum fluviatile*, *Trichophorum cespitosum*, *Eriophorum vaginatum*, UOM and a presence of *E. angustifolium* and *Betula* at 250 cm depth.	High *Betula, Quercus, Alnus* and *Corylus*. Presence of *Ulmus, Tilia, Salix, Myrica, Cyperaceae Polypodium* and *Filicales*. Low *Sphagnum*, *Calluna,* Poaceae and charcoal.	Relatively dry as indicated by *Betula* growing on the bog, high UOM and low charcoal. Area surrounding bog likely to be wooded as indicated by the presence of tree pollen and woodland indicators.
210–150 cm 5700/4300–3700/2800 cal. BP	Mid-range and fluctuating; as low as 0.5 and as high as 1.2.	Medium. -2.5 at 160 cm depth, 0.5 at 190 cm depth.		High *Trichophorum cespitosum*, low *Ericaceae*, low *Eriophorum vaginatum*, low UOM, high identified *Sphagnum*, mostly *S. cuspidatum* between 160 cm and 170 cm depth. No *Sphagnum* below 185 cm depth.	High *Lycopodium*, high *Quercus*, *Alnus* and *Corylus* and high *Sphagnum* and *Tilletia sphagni* until 165 cm depth. Lower *Calluna,* increase in Poaceae. Low charcoal. Presence of *Ulmus*, *Tilia*, *Salix* and *Myrica*. *Filicales* and *Polypodium* increase.	Mire in wet state as indicated by presence of *Sphagnum cuspidatum* and *Tilletia sphagni*, lower *Calluna*, low charcoal and low UOM. Increased woodland surrounding the mire as evidenced by increasing tree pollen and woodland indicators.
150–50 cm 3700/2800–550 cal. BP	As low as 0.3, the driest conditions in the profile.	Low-Medium. -5 at 60 cm depth, 0.6 at 125 cm depth.		Low identified *Sphagnum*, low *Trichophorum cespitosum*, high *Scheuchzeria palustris*, high *Equisetum fluviatile* and *Betula* towards base, high *Eriophorum vaginatum*, high Monocots and occurence of *Erica tetralix*.	Increase in *Betula*, *Quercus*, *Alnus* and *Corylus* towards base. High Cyperaceae and *Calluna*. High *Sphagnum* at top of zone but decrease towards base. High charcoal.	Dry conditions on the mire as evidenced by low *Sphagnum*, high *Betula*, *Eriophorum vaginatum,* Monocots, *Erica tetralix* and high charcoal. Some of the most humified conditions on the mire.
50–0 cm 550–-60 cal. BP	High, reaching above 2. The wettest conditions in the profile.	Low-Medium. As low as -4 at 40 cm depth but increases towards the surface, possibly owing to increased atmospheric pollution or burning.	Introduction of SCPs at 20.5 cm depth (AD 1850) with biggest peak at 8.5 cm depth (AD 1950). Decrease at 4.5 cm depth (AD 1990). Surface sample could not be analysed owing to lack of material.	High *Polytrichum commune*, low *Eriophorum vaginatum* and UOM, high Ericaceae and *Calluna vulgaris*. Highest identified *Sphagnum*. *S. papillosum* present at surface, *S. molle* and *S. fuscum* between 20 cm and 45 cm depth. Presence of *Eriophorum angustifolium*.	High *Lycopodium* spores, high Cyperaceae, *Erica*, *Calluna*, *Rumex* and Poaceae. High *Sphagnum* at 40 cm depth. Low low tree pollen. Slight rise in *Pinus* towards surface. High charcoal.	Wet conditions on the mire as evidenced by high T values, low UOM, presence of *Eriophorum angustifolium* and high *Sphagnum*. The least humified conditions on the mire although the high preservation of the acrotelm may be responsible for an aspect of this. High MS values and SCPs towards the surface indicate anthropogenic influences, as does an increase in charcoal and presence of grasses and *Calluna vulgaris*.

Chapter 6: Discussion

This chapter discusses the effectiveness of the methods employed, the vegetation changes identified at each site and possible causes including climatic, successional and anthropogenic, any other results noted worthy of discussion and how this information combined can be used to advise conservation.

6.1 Evaluation of Methods

6.1.1 Magnetic Susceptibility of Peat

The magnetic susceptibility at each site appears to show changes in accumulation rates, increases in minerogenic content towards the base of the profile and increasing content of atmospheric pollutants towards the surface (Figures 3.3, 4.2 and 5.3). MS does not seem to show much more than this and this is probably owing to the high water content of the peat. Water dilutes the concentration of magnetic minerals and also contributes to a negative initial magnetic susceptibility (Sandgren and Snowball, 2001). Furthermore, the concentration per unit volume of organic rich sediments can be very low. It may therefore be necessary to remove the water through oven or freeze drying to concentrate the magnetic materials (Sandgren and Snowball, 2001). However, this would require sub-sectioning of the core and possible destruction of samples which is problematic given the amount of sediment that can be collected in a 5 cm diameter Russian corer.

Furthermore, although mineral concentration is often considered the principal factor driving MS, this is often not the case. MS is commonly not a simple reflection of ferrimagnetic concentration as magnetic properties are not uniform across grain sizes or magnetic mineralogies (Hatfield, 2013). MS can be diluted by diamagnetic minerals and often more magnetic measurements are necessary to govern what is driving MS. Magnetic minerals accumulating in sedimentary environments are regularly assumed to be representative of the properties that reflect their original source materials and processes of deposition. In areas with high organic matter accumulation and/or in low oxygen environments, organic material may be buried before fully oxidizing, promoting bacterially mediated reduction diagenesis. This can result in partial loss of the deposited magnetic signal and is therefore a significant issue for interpretation of MS records (Hatfield, 2013). Given that the MS results were not likely to contribute to answering the research questions on their own, it was not imperative for this study.

6.1.2 Humification Analysis

Humification analysis has been criticised in recent years given that differential preservation and representation of bog surface vegetation may arise (Yeloff and Mauquoy, 2006) and taxonomical difficulties are exacerbated where peat decomposition increases (Swindles *et al.*, 2013). Furthermore, decay may be controlled by a number of parameters and in some cases, secondary decay may be a problem (Hughes *et al.*, 2012). Owing to the reservations expressed as to the derivation and meaning of peat humification data (e.g. Yeloff & Mauquoy 2006), it is recommended that the technique be used alongside others, such as analysis of plant macrofossils, whenever possible (Chambers *et al.*, 2011a). The humification signals from each of the sites (Figures 3.4, 4.3 and 5.4) seem to demonstrate changes in bog surface wetness and relate well to other proxies, despite changes in species composition noted at Oxenhope Moor and West Arkengarthdale (Tables 4.1 and 5.1).

6.1.3 Pollen Analysis

Pollen analysis has the advantage that the same level of taxonomic separation can be achieved throughout the profile and the preservation of most pollen types is similar in the acrotelm and catotelm (Chambers *et al.*, 2007b). Pollen analysis at all three sites has shown a general decrease in tree pollen over time (Figures 3.5, 4.4, 5.5), which is to be expected owing to woodland clearance by man. At Mossdale Moor, *Sphagnum* decreases from 700 cal. BP towards the present day, consistent with a rise in Poaceae pollen, also indicative of increasing anthropogenic activity, most likely in the form of burning as indicated by increasing charcoal fragments. Similarly, at West Arkengarthdale, an increase in *Calluna*, Poaceae and Ericaceae pollen is consistent with a decrease in tree pollen, particularly from 650 cal. BP, again, indicative of anthropogenic woodland clearance. However, at Oxenhope Moor, *Betula* actually increases over time, and *Calluna*, Poaceae and charcoal can be seen to decrease suggesting that

Oxenhope Moor is the most ‘pristine’ of the sites when in fact it appeared the most degraded when conducting fieldwork. These concerns were somewhat dispelled by the adoption of plant macrofossil analysis, where the plant macrofossils identified a recent shift in dominance from *Sphagnum imbricatum* to *S. papillosum* (1000 cal. BP) and an increase in *Eriophorum vaginatum* and *Trichophorum cespitosum* from 700 cal. BP towards the surface, indicative of anthropogenic activity including grazing of sheep and possible drainage for grouse management.

6.1.4 Lack of recent SCP declines

At all three sites, the SCP record begins almost synchronously with the industrial revolution and tracks increasing combustion of fossils fuels (Figures 3.5, 4.4 and 5.5). However, the SCP record is usually expected to decrease towards the surface (Parry *et al.*, 2013, Swindles, 2010), which is not the case at each of the sites. This could be a result of a build-up of SCPs at the surface as the mires may no longer be actively peat forming or the accumulation rate may have slowed, allowing SCPs to collect on the surface (Rose *et al.*, 1995). Nevertheless, the use of SCPs is valuable given that the start of the SCP record is a useful dating feature and SCPs are much less mobile in peat than ^{210}Pb, a dating technique that has been shown to be of varying reliability (Yang *et al.*, 2001).

6.1.5 Plant Macrofossil Analysis

Plant macrofossil analysis has been successful at Oxenhope Moor and West Arkengarthdale as both records are mostly in agreement with the pollen analysis (Figures 4.5 and 5.6). For example, at Oxenhope Moor, when *Sphagnum* spores are identified in the pollen record, *Sphagnum* is also identified within the plant macrofossil samples, as is generally the case at West Arkengarthdale. In contrast, at Mossdale Moor, there is a lack of identified *Sphagnum* where *Sphagnum* spores have been counted in the pollen between 165–65 cm depths (Figure 3.5). Furthermore, the amount of UOM substantially increases down the profile from 65 cm depth, wither fewer plant remains being identified. When describing the lithology at Mossdale Moor (Table 3.1), much of the peat was heavily degraded and this may explain why plant macrofossils have not been as well preserved at this site in comparison to Oxenhope Moor and West Arkengarthdale.

6.1.6 DCA and DHI

DCA did not perform well at any of the sites analysed. This may be owing to the incorporation of both *Sphagnum*-dominated and *Eriophorum*/ericaceous-dominated sections with the profiles (Turner *et al.*, 2014, Daley and Barber, 2012). DCA of the plant macrofossil data at West Arkengarthdale produced an eigenvalue of 0.8 along axis 1 (Figure 5.7), greater than the desired value of >0.5 (ter Braak, 1995) and the distribution of species scores exceeded 5 standard deviations along the first axis, which might suggest a lack of overlap between species of different hydrological preferences (Roland *et al.*, 2014); however, the data are not arranged this way on the bi-plot and seem to not function well owing to the presence of *Sphagnum papillosum* towards the surface. DCA could have performed better were *S. papillosum* removed from the analysis but given the fluctuation between *Sphagnum*-dominated and *Eriophorum*/ericaceous-dominated sections within the profile, it is likely that it still would not perform well.

DCA of the plant macrofossil analysis at Oxenhope Moor produced an eigenvalue of 0.3 along axis 1 (Figure 4.6), lower than the desired value of >0.5 (ter Braak, 1995) and therefore is statistically unreliable. Similarly, the fluctuation between *Sphagnum*-dominated and *Eriophorum*/ericaceous-dominated sections within the profile may have caused the DCA not to function adequately.

DHI has been shown to produce more replicable BSW reconstructions in some instances when compared with the more commonly applied DCA (Amesbury *et al.*, 2012a, Amesbury *et al.*, 2012b, Turner *et al.*, 2014, Daley and Barber, 2012, Mauquoy *et al.*, 2008). Daley and Barber (2012) compared the BSW indices derived from DHI and DCA to testate amoebae and peat humification from the same core and found a statistically better fit to the DHI index, supporting its use in several recent studies (Amesbury *et al.*, 2012a, Amesbury *et al.*, 2012b, Turner *et al.*, 2014).

DCA has been more successful on plant macrofossils where *Sphagnum* remains are dominant throughout, as in a study by Langdon *et al.* (2003) where a BSW gradient was successfully reconstructed using DCA on plant macrofossils from Temple Hill Moss, Scotland. It would seem as though the choice of statistical analysis should depend on the species composition at the site and this has been the case at the three sites studied for this research project, where DHI has been more successful than DCA (See Figures 3.7, 4.7 and 5.9). Not only is DHI an alternative where species dominance varies, but also at sites where a short section of the profile is being analysed, as was the case for Amesbury *et al.* (2012b) where BSW was being reconstructed on an 86-year timescale at Fågelmossen, Värmland, Sweden.

6.2 Mossdale Moor

This section will discuss the initiation of peat growth, the possible climatic changes interpreted from the palaeoecological data, anthropogenic activity and recent management. The implications for conservation will be discussed in section 6.7.

6.2.1 Peat Formation – 6000 cal. BP

The possible initiation of peat growth by human activity at approximately 6000 cal. BP (Innes *et al.*, 2013) implies that Mossdale Moor has always been affected by anthropogenic influences. This possibility leads to the question of how the moor should best be managed in the future, by either restoration to a pre-human state or by changing to either a more flood resistant condition or a better carbon sink.

6.2.2 Possible Climatic Changes Interpreted from Palaeoecology

6.2.2.1 Wetter Conditions (2700–1900 cal. BP).

Higher numbers of *Sphagnum* spores occur from 135 cm depth (c. 2700 cal. BP) upwards accompanied by low humification. At 125 cm (c. 1900 cal. BP), there is a rise in *Sphagnum* spores (400 spores counted) and the humification curve falls below the trend line; these are all indications of wetter conditions. The presence of *Vaccinium oxycoccus*, *Scheuchzeria palustris* and *Equisetum fluviatile* (Table 3.4, Figure 3.6) in the plant macrofossils also support wetter conditions at this time. Wetter periods have also been identified by Barber *et al.* (2003) from peat bog records in Northern England and Ireland at 2750-2350 cal. BP and Langdon *et al.* (2003) at 2800–2450 cal. BP from Temple Hill Moss in southeast Scotland, suggesting that periods of wetter climate existed across Northern England and Scotland during this time.

6.2.2.2 Drier Conditions (1300–1200 cal. BP).

A substantial dry shift is apparent between 107 and 95 cm depth (1300–1200 cal. BP). Evidence for this includes high humification, an absence of *Sphagnum* and high levels of UOM in the plant macrofossils (Figures 3.5, and 3.6 and Tables 3.3 and 3.4). Lower *Sphagnum* spores, increasing *Calluna*, decreasing tree pollen and a slight decrease in *Corylus* can be seen from the pollen record as well as increasing charcoal (Figure 3.5 and Table 3.3). This particular phase does not overlap with any regional wet shifts identified by other research projects, therefore suggesting that it was drier at this time. Nevertheless, this time period does coincide with Anglo-Saxon land-clearance in the nearby Lake District (Chiverrell *et al.*, 2007) and so the decreasing tree and shrub pollen may be attributed to anthropogenic activity. This however, would not explain the high humification and absence of wetness indicators in the plant macrofossil record. It is possible that this observed signal is a combination of a drier climate and land clearance by man.

6.2.2.3 Wetter Conditions (700–600 cal. BP).

At 45 cm depth (700 cal. BP) [AD 1250], there is evidence for wetter conditions regionally, indicated by low humification and large numbers of *Sphagnum* and *Tilletia sphagni* spores, suggestive of presence of *Sphagnum cuspidatum*, a wet loving species (Atherton, 2010). However, *Sphagnum* remains compose less than 20% of the total plant macrofossils at this depth and *S. cuspidatum* is not present (Figure 3.6). There are also low levels of charcoal and *Calluna* spores at this point, both indicative of dry conditions (Preston *et al.*, 2002).

At 40 cm depth (600 cal. BP), *Sphagnum* spore numbers drop markedly, before an increase in Poaceae pollen and charcoal at 35 cm depth (550 cal. BP). There is also an increase in *Calluna* pollen and a decrease in tree pollen at this depth. However, remains of *Sphagnum* in the plant macrofossil record reach a maximum, suggesting wet conditions locally. At 40 cm depth, humification is beginning to increase following a peak in wetness at 42 cm depth, suggesting that conditions are becoming drier but are still classed as wet at this point in time. This is consistent with deteriorating conditions associated with the onset of the Little Ice Age. Wetter conditions have been identified at 600 BP by low chironomid-inferred July temperatures and wet-shifts in the plant macrofossils and the testate amoebae at Talkin Tarn, Cumbria, England (Barber and Langdon, 2007). Charman *et al.* (2006) also recognise 600 BP as being a period of higher water tables in northern Britain. According to radiocarbon dates, Mossdale Moor seems to be getting wetter slightly earlier than other ombrotrophic bogs in Northern England and Ireland. Whilst it is important to consider the robustness of radiocarbon dating when discussing changes over decades, it is also possible that the changes occurring at Mossdale Moor are not climatic but may be driven by natural vegetation succession. This is of particular relevance considering that the pollen record suggests drier conditions compared to the locally wetter conditions indicated by the humification and plant macrofossil record.

6.2.3 Increased Anthropogenic Activity (1200 cal. BP).

During the late Holocene it can be difficult to identify and differentiate between natural and anthropogenic patterns of vegetation change (van der Linden and van Geel, 2006). It is not clear whether some of the vegetation changes at Mossdale Moor were driven by climate or other factors. However, human-induced changes are identified at 95 cm depth (c. 1200 cal. BP) where human clearance by fire is indicated by a charcoal fragment spike and an increase in *Calluna* pollen (Figure 3.5). It is proposed that from 95 cm depth upwards, anthropogenic effects are more significant. At Mossdale Moor, humification is also high at this point, although it decreases again after 350 cal. BP. *Sphagnum* spore numbers are very low at this point as it cannot survive in dry, burnt areas whereas *Calluna* is known to thrive following burning (Atherton, 2010).

6.2.4 Recent (past <400 years) Management

The start of the SCP increase at 20 cm is dated to c. cal. AD 1800. The SCPs remain relatively level despite a small peak at 13 cm depth (c. cal. AD 1906) until a more substantial peak at 6 cm depth (c. cal. AD 1960) and a final peak at 3 cm depth (c. cal. AD 1990). Similar evidence has also been found in other projects.

For example, Chambers *et al.* (2007c) found a rise in SCPs at Hirwaun Common and Mynydd Llangatwg at similar depths. The decline in SCPs in the top 1 cm is most likely a result of clean air policies introduced in recent decades and according to the deposition-rate curve dates to approximately AD 1990; this was also found in Chambers *et al.* (2007c) where the decline in SCPs was thought to post-date a Clean Air Act of 1968.

A substantial increase in charcoal particles can be seen towards the top of the profile between 20–0 cm depth. This can be interpreted as recent (<200 years) management practices by man using burning to control the growth of certain species on the moor. Numbers of charcoal particles throughout the rest of the profile are much lower, thus indicating the greater impact of humans today compared with previous human impacts recorded by charcoal peaks lower in the profile. At 16 cm depth, dated at c. cal. AD 1870, *Calluna* pollen slightly decreases whilst *Quercus, Alnus* and *Corylus* pollen decrease to very low percentages. Poaceae pollen and charcoal begin to increase throughout the zone, suggesting that the resulting vegetation changes may be due to the occurrence of fire. The charcoal peak at 9 cm depth is dated to c. cal. AD 1940 and the charcoal peak at 5 cm depth is dated to c. cal. AD 1975. The presence of *Plantago* pollen and grasses also point to a period of intense human influence which may include much higher levels of grazing brought about by the Common Agricultural Policy causing more graminoid communities to dominate.

The vegetation changes towards the surface of the profile at Mossdale Moor are similar to results found in other projects (Chambers *et al.*, 2007c, Chambers *et al.*, 1999). There is a rise in Poaceae pollen in zone MDM2-E from 35 cm depth, consistent with a drop in tree and shrub species and *Sphagnum* spores, which may be related to higher grazing activity relating to the wool industry. However, charcoal increases as this happens, which implicates fire as a causal factor. This is not a very recent change as it happened at approximately 550 cal. BP (AD 1400); indicating man's marked impact on the landscape even before the industrial revolution.

The peat is less humified towards the top of the profile, suggesting wetter conditions. However, this may not be the case as this reflects the difference between the catotelm and acrotelm in the peat. The changes in humification levels, therefore, are probably not accountable for the vegetation changes seen in pollen zone MDM2-E. Consequently, other factors need to be considered as causal factors, such as human activity. Changes in grazing regime, burning, drainage and atmospheric pollution can cause vegetation changes (Chambers *et al.*, 1999). The high levels of charcoal from 15 cm upwards would suggest that fire had a relatively strong impact on the vegetation composition. Pollution from surrounding industrial areas may have had an influence on Mossdale Moor; the peat in the upper levels of the core was almost black in colour, indicative of the pollution. *Sphagnum* spores decrease rapidly in this zone and *Sphagnum* plant macrofossils are absent. A similar decline is found in *Sphagnum* spores at Hirwaun Common, which are reduced in abundance towards the close of zone HC-c (Chambers *et al.*, 2007c). Atmospheric input of pollutants could have benefited certain grass species at the expense of other species sensitive to pollution including *Sphagnum* (Tallis, 1964) and high grazing numbers on the moor are also likely to have influenced this also. An increase in both *Trichophorum cespitosum* and *Polytrichum commune* remains in recent times, both of which are more typical of wet heath, supports the view that the vegetation is changing from mire to heath.

6.3 Oxenhope Moor

This section will discuss peat initiation and the possible climatic changes interpreted from the palaeoecological data, the disappearance of *Sphagnum imbricatum*, the *Ulmus* decline, anthropogenic activity and recent management. The implications for conservation will be discussed in section 6.7.

6.3.1 Possible Climatic Changes Interpreted from Palaeoecology

6.3.1.1 Wetter Conditions and Peat Formation – 6800 cal. BP

A particularly wet event is identified at 470 cm depth (6800 cal. BP) (Figure 4.1) as identified by the lowest humification in the profile (Figure 4.3), low DHI values (Figure 4.7), the presence of pool species *Sphagnum cuspidatum* from the plant macrofossils (Figure 4.5, Table 4.5) and high *Sphagnum* spores, low *Calluna* and low charcoal from pollen analysis (Figure 4.4, Table 4.4), suggesting a possible climatic cause for this deterioration. Similarly, a wet interval is recorded between c. 7800 and c. 6800 cal. BP at Walton Moss, where peat initiation began (Hughes *et al.*, 2000). Peat initiation is also dated to c. 6800 cal. BP for Oxenhope Moor (Figure 4.7, Table 4.4), which is typical for a UK blanket bog, given that most started forming between 7500 and 5000 BP (Cubizolle *et al.*, 2012). Cooler conditions have also been identified at 6800 cal. BP from a peat bog in Hungary and coincide with the short-term climatic oscillations presented by Feurdean *et al.* (2008) using pollen-based climate reconstruction methods (Jakab and Sümegi, 2010). Therefore, it seems likely that this wet shift has a climatic cause and was present in northern Britain and Europe.

6.3.1.2 Wetter Conditions – 5000 cal. BP

At 410 cm depth (5000 cal. BP) a presence of *Sphagnum* spores, low humification and low charcoal might suggest wet conditions. Conversely, *Calluna* is high in both the pollen and plant macrofossils at this depth. However, wet conditions have been identified at c. 4950 cal. BP from humification analysis of peat in northwest Scotland (Anderson, 1998) and by Barber and Langdon (2007) who identified 5000 cal. BP as being a period of wetter conditions in northern Britain as identified at Walton Moss and Talkin Tarn. *Calluna vulgaris* is capable of tolerating some moisture; however, its presence reaches 40% at this depth in the plant macrofossils, the highest in the profile. Despite this, given that humification is low and *Sphagnum* is present at this depth, it cannot be ruled out that a regional climatic deterioration has been identified.

6.3.1.3 Wetter Conditions – 4400 cal. BP

A presence of *Sphagnum* spores, low *Calluna* pollen, low charcoal, low humification and low DHI values at 384 cm depth (4400 cal. BP) suggest wet conditions. However, identified *Sphagnum* from plant macrofossil analysis is low and UOM, *Ericales* and *Eriophorum vaginatum* are relatively high at this point. Despite this, proxy reconstructions from Temple Hill Moss indicate a wet shift commencing at c. 4500 cal. BP, which, within the limits of the site chronology, could also be related to the c. 4400 cal. BP event at Oxenhope Moor. Other peat-based climatic reconstructions indicate a number of wet shifts around this time including Hughes *et al.* (2000) who identified a phase of increased wetness at Walton Moss between c. 4410 and 3990 cal. BP. Therefore, it is likely that the event recorded in the pollen and identified by low humification is in fact an indication of regional climatic deterioration. *Eriophorum vaginatum* has been described as being a poor indicator of water table depth given its wide range of tolerances (Blaauw *et al.*, 2004) and the *Ericales* rootlets may in fact belong to species more tolerant of wetter conditions such as *Vaccinium myrtillus*. Furthermore, there may be a delayed response on the mire to the proposed climatic deterioration, a possible explanation as to why the plant macrofossils are not in agreement at this depth.

6.3.1.4 Drier Conditions – 3100 cal. BP

A sustained dry period, possibly caused by changes in climate, is identified between 291–286 cm depth (c. 3100 cal. BP), as indicated by high UOM, high monocots, no identified *Sphagnum*, high *Eriophorum vaginatum* remains, higher DHI values and increasing charcoal. This is supported by Holocene proxy-climate records from the British Isles covering the last 4500 years where a series of key temperature changes are proposed based on speleothem δ18O and chironomid inferred July temperature records with conditions being relatively cool before c. 3100 years BP and warmer between 3100 cal. BP and 2000 cal. BP (Charman, 2010). A period of increased surface wetness is identified in a peatland in Estonia at c. 3100 cal. BP, but this period includes a burning event causing a spread of *Eriophorum vaginatum* to the sampling site and an increase in *Sphagnum balticum*, signifying that the wet zone did not develop directly as the result of the colder episode in climate, but as a response to bog burning, which disturbed the hydrological functioning of the bog by reducing its vertical elevations and causing a rise in water tables (Sillasoo *et al.*, 2007). Given that the period of increased surface wetness in Estonia was a local occurrence, it seems likely that the identified dry event at c. 3100 cal. BP is of a climatic origin and present on a regional scale.

6.3.1.5. Wetter Conditions – 2800 cal. BP

At 256 cm depth (2800 cal. BP), all proxies are in agreement and therefore suggest a climatic cause for low *Calluna*, high Cyperaceae and a presence of *Sphagnum* spores in addition to low charcoal, low humification, a high presence of *Sphagnum imbricatum*, low UOM, low *Ericales* and low DHI scores, indicating another wet episode. A wet phase is also identified from the Temple Hill record in south-east Scotland at this time (Langdon *et al.*, 2003) and an event at 2800 BP has also been recorded from ocean cores in the North Atlantic, representing phases when cold ocean waters advanced further south (Bond *et al.*, 1997), therefore suggesting a link between the sea surface temperatures of the North Atlantic and the climate of northern Britain. Cool temperatures are also recorded in three sites from northern Britain at c. 2800 cal. BP using lacustrine records of chironomid- inferred summer temperatures (Barber *et al.*, 2013). The high degree of correspondence between these three records and the similarity of shift timing with the wider chironomid literature is suggestive that in each case the chironomid assemblages are reacting primarily to variations in regional temperature rather than local catchment dynamics (Barber *et al.*, 2013). It has also been proposed that reduced solar activity between 2800 and 2710 cal. BP, inferred from the ^{14}C calibration curve, caused widespread climatic deteriorations in both hemispheres (van Geel *et al.*, 1996, van Geel and Renssen, 1998). Hence, it seems likely that the identified event is climatic in nature and occurred as a wet shift on a regional scale in northwest continental Europe (van Geel *et al.*, 1996, van Geel and Renssen, 1998, Chambers *et al.*, 2007a).

6.3.1.6. Drier Conditions – 2500 cal. BP

A movement to drier conditions is identified at 236 cm depth (2500 cal. BP) as demonstrated by high humification, relatively high UOM, high *Calluna* pollen and identified *Sphagnum* being mainly composed of the hummock-forming species *S. imbricatum*. DHI values are still quite low at this point (possibly owing to an absence of UOM) and this suggests that although the mire was not in drought (as *S. imbricatum* is still thriving) it was in a state dry enough to support dry tolerant species, most likely *Calluna vulgaris*. Although a study of land-use change from the British palynological record does note an increase in Poaceae, Cyperaceae and *Calluna* pollen at c. 2500 BP (Dark, 2006), no evidence can be found for dry conditions during this time. Therefore, it would seem that this is just a phase of slightly drier conditions between wet conditions experienced at 2800 cal. BP and 2400 cal. BP.

6.3.1.7 Wetter Conditions – 2400 cal. BP

A possible wet event has been identified at 227cm depth (2400 cal. BP) as evidenced by high *Tilletia sphagni* spores, low humification, low DHI values, low *Calluna* pollen and low charcoal. There is a high presence of *Sphagnum imbricatum* on the bog at this stage, which cannot tolerate pools but is better adapted to wet conditions than some species within monocots, which are low at this point, as is UOM. A wet shift spanning 2750–2350 cal. BP has been identified by Barber *et al.* (2003) from three profiles in Ireland and England, which overlaps with the identified wet shift at Oxenhope Moor, suggesting climatic changes on a regional scale. O'Brien *et al.* (1995) also interpret abrupt increases in the concentrations of soluble impurities in ice cores as phases of significant general cooling with an event spanning c. 3100–2400 BP, which incorporates the event identified here.

6.3.1.8. Drier Conditions – 1500 cal. BP

Dry conditions are identified at 140 cm depth (1500 cal. BP) by high humification, high UOM and high monocots, high *Trichophorum cespitosum*, low identified *Sphagnum*, mainly *S. imbricatum*, high DHI values, low *Sphagnum* pollen and relatively high charcoal. Anderson *et al.* (1998) also identified this as a dry shift in northern Scotland from palaeoecological analysis of peatlands. However, no other evidence of a dry shift could be found in the literature. Furthermore, no evidence could be found of any wet episodes and so this time period is interpreted as representing a stable climate, similar to that identified at 236 cm depth (2500 cal. BP).

6.3.1.9 Drier Conditions – 1600 cal. BP, 1100 cal. BP and 650 cal. BP

Particularly dry events have been identified at 150 cm (1600 cal. BP), 110 cm (1100 cal. BP/cal. AD 850) and 50 cm (650 cal. BP/cal. AD 1300) depths, as indicated by high numbers of charcoal fragments, high *Calluna* pollen (particularly at 150 cm depth), high UOM from plant macrofossils and high humification at each depth. Each of these events could represent anthropogenic influences as increased charcoal can be associated with burning to clear land, which would benefit certain species such as *Calluna* and therefore have a drying effect on the bog, causing humification to increase. The dry shift at 1600 cal. BP is likely a local occurrence as Holocene peatland palaeo-water table reconstructions from northern Britain identified 1600 cal. BP as a pronounced change to wet conditions (Charman *et al.*, 2006). The high charcoal fragments and a reduction in tree pollen at this depth are therefore likely indicators of anthropogenic clearance.

Signals from ombrotrophic mires in Britain are indicative of reduced peat-accumulation rates and drier surface conditions in early Medieval or pre-Medieval times (Wells and Wheeler, 1999). The dry shift reported in northwest Scotland by Andersen (1998) between c. 1550 and 1100 cal. BP is thought to represent the onset of warmer, drier climatic conditions. Barber (1981) and Tallis (1985) documented dry phases at approximately AD 1100–1300 (850–650 BP) in bogs in northern England and such dry phases have often been interpreted as relating to the Medieval Warm Period (MWP), a climatic episode between c. AD 900 to 1300 (1050–650 BP) (Wells and Wheeler, 1999). It is widely accepted that there is the existence of extended periods of warmer and drier conditions within the mentioned time-frame on the basis of biological, glaciological and documentary evidence (Wells and Wheeler, 1999). It is therefore suggested that the two dry shifts identified at 1100 cal. BP and 650 cal. BP are likely representative of the MWP.

6.3.1.10 Wetter Conditions (500 cal. BP) – the Little Ice Age

All proxies from Oxenhope Moor are in agreement and suggest wet conditions on the bog between 45–40 cm depth. This is suggested by 100% of 35% identified *Sphagnum* being *S. cuspidatum* from plant macrofossils analysis, low DHI values, a relatively high number of counted *Tilletia sphagni* spores from pollen analysis and high T values from humification analysis. This wet shift is dated to 500 cal. BP/ cal. AD 1450 and is therefore consistent with the climatic deterioration known as the LIA (c. 600–150 cal. BP) (Swindles *et al.*, 2012). Wetter conditions have also been identified by Baker *et al.* (1999) at 500–600 BP and correlate with Maunder and Sporer sunspot minima and climate deterioration recognised in other peat records. Charman *et al.* (2006) also describe a minor climatic deterioration in northern Britain at 550 cal. BP and Charman *et al.* (2012) identify an overall downward trend in the composite carbon accumulation rates from AD 1000 to 1850 implying reduced peat accumulation during the LIA from northern peatlands.

6.3.2 The disappearance of *Sphagnum imbricatum*

The disappearance of *Sphagnum imbricatum* (Figure 4.5) at 80 cm depth (c. 1000 cal. BP/cal. 950 AD) may have been caused by increasing human disturbance around the bog. The disappearance of *S. imbricatum* has coincided with rising water tables in other studies (Mauquoy and Barber, 1999, McClymont *et al.*, 2008, McClymont *et al.*, 2009). Several other studies in Britain and Europe have identified a climatic deterioration at c. 1000 BP (Barber *et al.*, 2003, Hughes *et al.*, 2000, Langdon *et al.*, 2003) and therefore increasing wetness could be a cause. However, at Oxenhope Moor, although DHI values are high, humification values are decreasing. Other research suggests that *S. imbricatum* may have disappeared as a result of increased dryness (Green, 1968) which seems more likely at Oxenhope Moor given the fact that humification is high, suggestive of dry conditions. Today, *S. imbricatum* occupies dry hummocks but in the past, it was found to inhabit the wettest areas and so this seems a likely cause. The initial drying of the peat surface was perhaps not caused only by human action, as charcoal is not particularly high at this point, nor is there a decrease in tree pollen but humans were likely present in the area at this time and so their influence should not be ruled out. The decline of *S. imbricatum* from two ombrotrophic mires (Bolton Fell Moss and Walton Moss) is dated to cal. AD 1030–1400 and may have been due to interspecific competition between *Sphagnum* species during the ‘Early Medieval Warm Period’ and the ‘Little Ice Age’ (Mauquoy and Barber, 1999). It seems likely that that is also the case here, as *S. imbricatum* is out-competed by *S. papillosum*, which can grow the same amount as *S. imbricatum* in 20 days less time, thus giving it a competitive advantage (Mauquoy and Barber, 1999).

6.3.3 The *Ulmus* Decline

Ulmus is present fairly consistently (although in small numbers) from the base of the profile until approximately 370 cm depth (4100 cal. BP) where an apparent *Ulmus* decline is identified (Figure 4.4, Table 4.4). Following the identified decline, *Ulmus* does reappear but only sporadically. This decline could have been caused by anthropogenic clearance as evidenced by a rise in charcoal, but other tree species do not decline at this point, and so disease or changes in climate seem a more likely cause. Many suggestions have been made as to the cause, with most recent authors suggesting disease had at least a partial role in the *Ulmus* decline (Grant *et al.*, 2011, Peglar and Birks, 1993).

6.3.4 Increased Anthropogenic Influences

Anthropogenic influences increase from 200 cm depth (2100 cal. BP) as indicated by a rise in charcoal, a decrease in tree pollen and an increase in *Calluna* and *Cerealia* pollen. *Cerealia* pollen is indicative of agriculture and the rise in charcoal is suggestive of burning, perhaps used for woodland clearance and the rise in *Calluna* pollen is likely a response to this (Atherton, 2010). *Sphagnum imbricatum* is still present at 200 cm depth but disappears at 80 cm depth (1000 cal. BP). It is likely that landscape pressures from humans increased over time with population growth and advances in technology, therefore explaining why species such as *S. imbricatum* managed to survive for up to a thousand years before finally becoming out-competed by better adapted species.

A particularly marked event occurs at 150 cm depth (1600 cal. BP), most likely anthropogenic influence, again indicated by high charcoal fragments, a decrease in tree pollen and the presence of *Cerealia* pollen. These changes indicate a spread of forest clearance in the areas surrounding Oxenhope Moor accompanied by agriculture within the period of the Iron Age. Similar results were found at Rishworth, West Yorkshire by Bartley (1975) dated 1920 BP.

It is commonly thought that human actions such as sheep or cattle grazing, burning and draining of peat encourage species such as *Calluna vulgaris* to thrive; yet, in the plant macrofossil and pollen record from Oxenhope Moor, *Calluna* is seen to decrease from the base of the profile to the surface. Nevertheless, other species do increase, such as *Trichophorum cespitosum* and *Eriophorum vaginatum*, possibly as a result of human actions, as these species are tolerant of dry conditions caused by drainage and burning. For instance, *Trichophorum cespitosum* has shown a markedly greater abundance where sheep occur within drained areas on a Welsh upland bog (Wilson *et al.*, 2011).

6.3.5 Recent (<400 years) Management

From 25 cm upwards, there is an increase in Magnetic Susceptibility (Figure 4.2) synchronous with the introduction of SCPs, both related to the introduction of and increase in atmospheric pollutants. There are also high levels of *Rumex*, indicative of anthropogenic activities, Cyperaceae pollen and an increase in *Eriophorum vaginatum*, a species which frequently dominates degraded blanket mire (Chambers *et al.*, 2007c). There is also an increase in monocots, associated with degraded peatlands (Chambers *et al.*, 2013a) and *Sphagnum papillosum*, a species which occurs in communities with high N deposition, which has increased from the 1950s and peaked around 1990 (Payne, 2014).

6.4 West Arkengarthdale

This section will discuss peat initiation, the possible climatic changes interpreted from the palaeoecological data, the *Ulmus* decline, anthropogenic activity and recent management. The implications for conservation will be discussed in section 6.7.

6.4.1 Peat Formation – 6400 cal. BP

The DHI values are low between 289–285 cm depth (6400–6300 cal. BP) (Figures 5.1, 5.2 and 5.9) and the presence of aquatic species *Nymphaea* at these depths (Figure 5.6) suggests the presence of standing water. Furthermore, the presence of quartz grains in the plant macrofossils and silt identified in the sediment description (Table 5.1) at this depth suggests that peat has not yet begun to form and so the presence of an aquatic environment is identified. All proxies are in agreement; however, this is interpreted as the beginning of a natural vegetation succession and initiation of the peat growth and therefore may not necessarily have been caused by a climatic deterioration. Generally, in Great Britain and Ireland, blanket bogs mainly appeared between 7500 and 5000 BP (Cubizolle *et al.*, 2012) and so this date is reasonable. Conversely, warmer conditions associated with the Holocene Thermal Maximum (c. 7000–6000 BP) may have prompted the peat growth, allowing some of the water to evaporate and the standing areas of water to accumulate plant remains and eventually lead to the growth of peat found overlying the silty sediments.

6.4.2 Possible Climatic Changes Interpreted from Palaeoecology

6.4.2.1 Wetter Conditions – 6400–5300/5100 cal. BP

The mire surface at West Arkengarthdale is particularly wet between 289–245 cm depth (6400–5300/5100 cal. BP), as indicated by low charcoal, high *Potentilla*, the presence of *Sphagnum* pollen (despite an absence of *Sphagnum* in the plant macrofossils) and low *Calluna* pollen (Figure 5.5). Minor wet episodes were recorded at Bolton Fell Moss, Lancashire during this time at around 6200, 5700, 5420 and 5250 cal. BP (Barber *et al.*, 2003). Wet episodes were also identified in peatlands in northern Scotland between 6500 and 6000 cal. BP by Anderson *et al.* (1998), therefore suggesting a regional climatic deterioration across northern Britain and Scotland at this time.

6.4.2.2 Drier Conditions – 5200/5000 cal. BP

The evidence suggests dry and/or warm conditions at 239 cm depth (5200/5000 cal. BP), as indicated by high UOM, *Trichophorum cespitosum*, *Eriophorum vaginatum* and *Betula* wood in the plant macrofossils. Both *Trichophorum cespitosum* and *Eriophorum vaginatum* are unreliable indicators for reconstructing water tables as they can withstand a variety of ecological conditions (Blaauw *et al.*, 2004). Nevertheless, the surface of the mire would have to have been dry enough to support the growth of *Betula*. DHI values are also high at this point, supporting that conditions were dry at this time. Despite this, research on Achill Island in Ireland suggests that this may have in fact been a period of extreme climatic conditions including storminess, as evidenced by the deposition of an extensive layer of silt across the blanket peat (Caseldine *et al.*, 2005). This wet shift has also been identified by humification data from peat as far away as Norway (Vorren *et al.*, 2012), suggesting that the observed dry conditions at West Arkengarthdale are most likely local.

6.4.2.3 Wetter Conditions – 5100/4900 cal. BP

The mire may have been wet at 235 cm depth (5100/4900 cal. BP) as evidenced by low humification and the presence of *Equisetum fluviatile*. Conversely, DHI values do not support this and there is little evidence for wet conditions from pollen analysis with the exception of low charcoal. However, wet conditions have also been identified at c. 4950 cal. BP from humification analysis of peat in northwest Scotland (Anderson, 1998). Barber and Langdon (2007) also identified 5000 cal. BP as being a period of wetter conditions in northern Britain as identified at Walton Moss and Talkin Tarn. DHI values may not be in agreement as a result of high UOM content with increasing decomposition with depth but low charcoal from the pollen record does support that this may indeed be a regional climatic deterioration that has been identified.

6.4.2.4 Wetter Conditions – c. 4700 cal. BP

Similarly, the environment seems to be wet between 220–208 cm depth (4800/4500–4700/4250 cal. BP), as suggested by relatively low humification values, very low charcoal, low *Calluna* and the presence of aquatic species, *Scheuchzeria palustris*. However, DHI values are still high at this point, suggesting that although conditions may be wetter than identified at other depths in the profile, these are certainly not the wettest conditions. Reconstructions from Temple Hill Moss indicate that there is a wet shift commencing at c cal. 4500 and Langdon *et al.* (2003) also found that other peat-based climatic reconstructions indicated a number of wet shifts around this time. Hughes *et al.* (2000) describe a phase of increased wetness between c cal. 4410 and 3990 BP that also support wet conditions on a regional scale at this time.

This could also coincide with a climatic deterioration identified between 175–158 cm depth (4100/3350–3900/3000 cal. BP), as evidenced by relatively low humification values, the introduction of *Sphagnum* onto the bog, particularly pool species *S. cuspidatum* between 170–160 cm depths (4100/3250–3900/3000 cal. BP), high *Sphagnum* spores as well as *Tilletia sphagni*, low charcoal, low *Calluna* and low DHI values. It is difficult to know for certain whether this event does correlate with the wet phase described by Hughes *et al.* (2000) given the difficulties encountered with radiocarbon dating.

6.4.2.5 Drier Conditions – 3250–1000 cal. BP

The bog then seems to become particularly dry between 150–72 cm depths (3700/2800–1000 cal. BP), supported by highly humified peat, high *Calluna* pollen, high charcoal, high tree pollen, no *Sphagnum*, high UOM and the inclusion of *Betula* wood towards 150 cm depth. Conversely, 3200 BP is identified as a wet shift in peat records in England and Ireland as identified by Barber *et al.* (2003). In Germany, a long dry period from c. 4500–3200 cal. BP has been identified from the Dosenmoor proxy climate record, implying a stable dry and/or warm climate until this point (Barber *et al.*, 2004). A wet shift is also identified at 3200 cal. BP in Norway by Vorren *et al.* (2012). However, a relatively dry period is identified from the Dosenmoor proxy climate record between 2500 and 1950 cal. BP but there is a return to wetter conditions from 1950 to 900 cal. BP, which does not correspond with the identified dry conditions at West Arkengarthdale. It is generally drier around this time period than found in many other European bogs (Barber *et al.* 2003) and the increasing and continuous charcoal record through pollen zone ARK–D (Figure 5.3) may reflect that factors other than climate are responsible. These could include autogenic changes in the bog itself, such as catastrophic drainage in response to a very high water table, resulting in gullying and the drying out of the peat mass (Barber *et al.*, 2004). Furthermore, prehistoric people may also have burnt parts of the bog, although the charcoal remains are microscopic in size and therefore capable of having been blown in from surrounding areas.

6.4.2.6 Drier Conditions – (700 cal. BP) Medieval Warm Period

Conditions also become drier at 55 cm depth (700 cal. BP/cal. AD 1250), coinciding with the Medieval Warm Period. This is supported by increasing humification, high *Calluna*, Poaceae and tree pollen, high charcoal and the disappearance of *Sphagnum* from the plant macrofossil record, consistent with an increase in UOM and *Eriophorum vaginatum*. This is also identified at Temple Hill Moss by Langdon *et al.* (2003) and Svanemose and Dosenmoor by Barber *et al.* (2004) and many other authors in the UK and Europe.

6.4.2.7 Wetter Conditions (450–200 cal. BP) – the Little Ice Age

A reintroduction of *Sphagnum* is identified at 45 cm depth (450 cal. BP) as well as increasing transmission values and decreasing DHI values which may be consistent with the beginning of the LIA. Specifically at 28 cm depth, there is a wet shift dated to cal. AD 1750 as evidenced by low humification, a presence of *Sphagnum* pollen, lower Poaceae, slightly lower charcoal, presence of *S. molle* and *S. fuscum*, low UOM and low DHI values. Similarly, at 20 cm depth, there is a wet shift dated to cal. AD 1850, as evidenced by some of the least humified peat, relatively low DHI values, low UOM and presence of *Sphagnum papillosum*. However, charcoal is relatively high, as are *Calluna* and Poaceae pollen. Most of the evidence seems to suggest a climatic cause for this apparent wet shift and both events coincide with the LIA (c. 600–150 cal. BP) (Swindles *et al.*, 2012). This climatic deterioration is also identified by Langdon *et al.* (2003) and Barber *et al.* (2004) and is found in many other proxy records from the UK and Europe.

6.4.3 The *Ulmus* Decline

Identifying the *Ulmus* decline at West Arkengarthdale is problematic owing to the difficulties encountered with the radiocarbon dating. Three possible *Ulmus* declines have been identified at 265 cm depth (5600 cal. BP), 210 cm depth (4700/4000 cal. BP) and at 161 cm depth (4000/3000 cal. BP) (Figure 5.5). Of these, the decline at 265 cm depth seems most likely to be primary as the presence of *Ulmus* before this is consistent, whereas its presence after is sporadic. Other species of trees and shrubs do not decrease at this point, suggesting that the decline is not climatic and therefore may be due to anthropogenic clearance or disease. Furthermore, the date at 265 cm depth fits better with the reviewed timings of the *Ulmus* decline in England (5600–4500 BP) (Parker *et al.*, 2002).

6.4.4 Increased Anthropogenic Activity

It is likely that humans were affecting the landscape during Mesolithic times, as can be seen by occasional decreases in tree pollen consistent with increases in charcoal and shrub and heath pollen. A gradual reduction in tree pollen is noted throughout the profile but a marked reduction is evident at 150 cm depth (3700/2800 cal. BP) consistent with an increase in charcoal, Ericaceae and *Calluna* pollen (Figure 5.5, Table 5.3) and is likely indicative of increased anthropogenic activity. Before this, *Calluna* is less prevalent and *Myrica* is present, likely to be growing on the mire. There were many more trees growing in the areas surrounding the mire, with tree pollen reaching between 40 and 60% of the total pollen.

6.4.5 Recent (<500 years) Management

There is a very recent initiation of *Sphagnum papillosum* towards the surface (Figure 5.4), a species which occurs in communities with high N deposition, which has increased from the 1950s and peaked around 1990 (Payne, 2014). There is also an increase in Ericaceae, *Calluna* and Poaceae pollen consistent with high charcoal from 50 cm depth (500 cal. BP) towards the surface. The increase in charcoal is indicative of burning, which has increased in the last few hundred years with the introduction of rotational burning for the management of grouse (Lee *et al.*, 2013). Grazing of sheep is also known to encourage the growth of grasses at the expense of species such as *Sphagnum* (Wilson *et al.*, 2011). *Pinus* plantations in the area surrounding West Arkengarthdale from 22 cm depth (c. cal. AD 1800) are also indicative of recent management. The increasing occurrence of monocots and *Polytrichum commune* from 30 cm depth (200 cal. BP) towards the surface are also indicative of recent management practices as monocots are associated with degraded blanket mire (Chambers *et al.*, 2013a) and *Polytrichum commune* with heath.

6.5 Climatic Inferences from Mossdale Moor, Oxenhope Moor and West Arkengarthdale and Comparison across Wider Literature

6.5.1 5000 cal. BP

Wetter conditions have been identified at West Arkengarthdale at 5100/4900 cal. BP (as evidenced by low humification, presence of *Equisetum fluviatile* and low charcoal). At Oxenhope Moor at 5000 cal. BP a presence of *Sphagnum* spores, low humification and low charcoal suggests wet conditions (Table 6.1). Similar conditions have also been identified at c. 4950 cal. BP from humification analysis of peat in northwest Scotland (Anderson, 1998) and Barber and Langdon (2007) identified 5000 cal. BP as being a period of wetter conditions in northern Britain (Walton Moss and Talkin Tarn). The evidence identified in this study as well as previous research in areas of Scotland and northern Britain would suggest a climatic deterioration on a regional scale. Such an event is not identified at Mossdale Moor, perhaps owing to lower sensitivity at this site, given that fewer palaeoclimatic events have been identified in comparison to Oxenhope Moor and West Arkengarthdale and that Mossdale Moor seems to have been particularly affected by past human activity.

6.5.2 4400 cal. BP

At Oxenhope Moor, the presence of *Sphagnum* spores, low *Calluna* pollen, low charcoal, low humification and low DHI values at 4400 cal. BP suggest wet conditions. At West Arkengarthdale, the environment seems to be wet between 4800/4500–4700/4250 cal. BP as suggested by relatively low humification values, very low charcoal, low *Calluna* and the presence of aquatic species, *Scheuchzeria palustris*. Proxy reconstructions from Temple Hill Moss indicate a wet shift commencing at c. 4500 cal. BP (Langdon *et al.*, 2003), which, within the limits of the site chronology, could also be related to the events at Oxenhope Moor and West Arkengarthdale.

Other peat-based climatic reconstructions indicate a number of wet shifts around this time including Hughes *et al.* (2000) who identified a phase of increased wetness at Walton Moss between c. cal. 4410 and 3990 BP. Therefore, it is likely that the event recorded is in fact an indication of regional climatic deterioration. This could also coincide with a climatic deterioration identified between 4100/3350–3900/3000 cal. BP at West Arkengarthdale, as evidenced by relatively low humification values, the introduction of *Sphagnum* onto the bog, particularly pool species *S. cuspidatum*, high *Sphagnum* spores as well as *Tilletia sphagni*, low charcoal, low Calluna and low DHI values. However, as previously mentioned, it is difficult to know for certain whether this event does correlate with the wet phase described by Hughes *et al.* (2000) given the difficulties encountered with radiocarbon dating.

6.5.3 2400 cal. BP

At Oxenhope Moor, wetter conditions have been identified at 2400 cal. BP as evidenced by high *Tilletia sphagni* spores, low humification, low DHI values, low *Calluna* pollen and low charcoal. There is a high presence of *Sphagnum imbricatum* on the bog at this stage, which cannot tolerate pools but is better adapted to wet conditions than some species within monocots, which are low at this point, as is UOM. Similarly, at Mossdale Moor, higher numbers of *Sphagnum* spores occur from c. 2700 cal. BP accompanied by low humification.

A wet shift spanning 2750–2350 cal. BP has been identified by Barber *et al.* (2003) from three profiles in Ireland and England, which overlaps with the identified wet shift at Oxenhope and Mossdale Moors, suggesting climatic changes on a regional scale. O'Brien *et al.* (1995) also interpret abrupt increases in the concentrations of soluble impurities in ice cores as phases of significant general cooling with an event spanning c. 3100–2400 BP, which incorporates the event identified here. Wetter periods have also been identified by Langdon *et al.* (2003) at 2800–2450 cal. BP from Temple Hill Moss in southeast Scotland, suggesting that periods of wetter climate existed across Northern England and Scotland during this time. This event has not, however, been recorded at West Arkengarthdale where conditions are much drier as evidenced by an increasing and continuous charcoal record, perhaps reflecting that factors other than climate are responsible. These could include autogenic changes in the bog itself, such as catastrophic drainage in response to a very high water table, resulting in gullying and the drying out of the peat mass (Barber *et al.*, 2004) or perhaps, prehistoric people may also have burnt parts of the bog.

6.5.4 'The Little Ice Age' (LIA)

At Mossdale Moor, the LIA is identified at 600 cal. BP, as evidenced by remains of *Sphagnum* in the plant macrofossil record reaching a maximum, suggesting wet conditions locally. Similarly, all proxies from Oxenhope Moor are in agreement and suggest wet conditions on the bog at 500 cal. BP as suggested by 100% of 35% identified *Sphagnum* being *S. cuspidatum*, low DHI values, a relatively high number of counted *Tilletia sphagni* spores and high T values from humification analysis. At West Arkengarthdale, a reintroduction of *Sphagnum* is identified at 450 cal. BP as well as increasing transmission values and decreasing DHI values, which may be consistent with the beginning of the LIA. Specifically at cal. AD 1750, there is a wet shift as evidenced by low humification, a presence of *Sphagnum* pollen, lower Poaceae, slightly lower charcoal, presence of *S. molle* and *S. fuscum*, low UOM and low DHI values. Similarly, at cal. AD 1850, there is a wet shift as evidenced by some of the least humified peat, relatively low DHI values, low UOM and presence of *Sphagnum papillosum*.

The wet shift identified across all three sites is consistent with the climatic deterioration known as the LIA (c. 600–150 cal. BP) (Swindles *et al.*, 2012). Wetter conditions have also been identified at 600 BP by low chironomid-inferred July temperatures and wet-shifts in the plant macrofossils and the testate amoebae at Talkin Tarn, Cumbria, England (Barber and Langdon, 2007). Charman *et al.* (2006) also recognise 600 BP as being a period of higher water tables in northern Britain. Wetter conditions have also been identified by Baker *et al.* (1999) at 500–600 BP and correlate with Maunder and Sporer sunspot minima and climate deterioration recognised in other peat records. Charman *et al.* (2012) identify an overall downward trend in the composite carbon accumulation rates from AD 1000 to 1850 implying reduced peat accumulation during the LIA from northern peatlands. This climatic deterioration is also identified by Langdon *et al.* (2003) from Temple Hill Moss, south-east Scotland and Barber *et al.* (2004) from northern Germany and Denmark and is found in many other proxy records from the UK and Europe.

Table 6.1 Overall Interpretation of main climatic inferences from Mossdale Moor, Oxenhope Moor, West Arkengarthdale and the Wider Literature using: Age (cal. BP), palaeoecological records and wider literature reviewed in Chapter 1, section 1.4. Key: Green = identified, Red = Unidentified.

	Main Climatic Inferences				
Age (cal. BP)	**Mossdale Moor**	**Oxenhope Moor**	**West Arkengarthdale**	**Wider Literature**	**Scale**
LIA	Green	Green	Green	Identified in Cumbria by Barber and Langdon (2007); northern Britain by Charman *et al*. (2006); north Yorkshire by Swindles *et al*., (2012); northwest Scotland by Baker *et al*., (1999) and in 'northern' peatlands by Charman *et al*. (2012).	Continental (UK and Europe)
2400	Green	Green	Red	Identified by Barber *et al*. (2003), in Ireland and England, O'Brien *et al*. (1995) from Greenland and Langdon *et al*. (2003) in southeast Scotland.	Regional (northern Britian/Scotland)
4400	Red	Green	Green	Identified by Hughes *et al*. (2000) in northern Britain.	Regional (northern Britain)
5000	Red	Green	Green	Identified by Andersen (1998) in northwest Scotland and Barber and Langdon (2007) in northern Britain.	Regional (northern Britain/Scotland)

6.6 Vegetation and Land-use History in Yorkshire and Northern English Uplands

Several studies have focussed on anthropogenic land clearance and use of fire in northern England providing similar findings to all three sites in the present study, where increases in charcoal are consistent with decreases in tree pollen and increases in Poaceae and shrub pollen, indicating that fire during the mid-Holocene was a highly significant source of woodland disturbance at these Yorkshire sites. Chiverrell *et al.* (2008) found evidence for an extensively forested landscape and evidence from high values of polyaromatic hydrocarbons (PAHs) for frequent and sustained occurrence of fire in summit areas of the Pennines during a period of Mesolithic occupation. This study and a number of others (Innes *et al.*, 2013, Innes and Simmons, 2000) demonstrate that fire played a role in the Mesolithic woodland history in northern England, and have suggested that fire was part of woodland management strategy to increase animal concentration in the post-fire disturbed areas.

Furthermore, Innes and Simmons (2000) examined charcoal and the pollen stratigraphy at North Gill for the mid-Holocene and found that detailed charcoal stratigraphies at varying resolutions are capable of interpretation in terms of local, regional and intermediate fire history. They provide palynological evidence for the North York Moors from the mid-Holocene and identify that fire was a highly significant source of woodland disturbance. At many sites, major reductions in tree pollen frequencies and their replacement by ruderal weed and open habitat taxa, and then a range of heliophyte successional vegetation, reflect phases of woodland opening and subsequent regeneration. Similar to the results found in the present study, an association of many of these phases with charcoal implicates fire as the cause of disturbance.

Evidence from Mossdale Moor suggests that peat growth may have been initiated by human clearance, a common occurrence at approximately 6000 cal. BP (Innes *et al.*, 2013). At many sites macroscopic charcoal is found in the pre-peat soil and in the base of the peat, as though fire were coincident with, and perhaps responsible for, peat initiation. At the site scale, the ubiquity of macroscopic charcoal across the area shows that fire was locally a highly significant force in the ecological history of the North York Moors (Innes and Simmons, 2000). Although not stated whether this could be anthropogenically caused fire, it cannot be ruled out given the effect that humans were having on such landscapes during this time and therefore, this tentatively allows for comparison with Mossdale Moor.

Fires in Mesolithic woodlands could also have been caused by drier climatic conditions and surface wetness data from peat bogs across northern England (Hughes *et al.*, 2000, Charman *et al.*, 2006) suggests that Mesolithic times (before 8500–8200 cal. BP) were comparatively dry. However, rising *Calluna* pollen values at Mossdale Moor and West Arkengarthdale from 1250 cal. BP and c. 3800 cal. BP respectively, consistent with rising charcoal fragments suggest anthropogenic clearance using fire.

The event at 3800 cal. BP at West Arkengarthdale is characterised by intensification in woodland clearance with an increase in *Calluna*, replacing tree pollen and an increase in charcoal fragments, indicating fire as a causal factor. This can be compared to similar findings from Sutton Common, South Yorkshire, where Gearey *et al.* (2009) found evidence for local woodland clearance in the early Bronze Age at a date of c. 3800–3600 cal. BP. Gearey *et al.* (2009) also suggest that clearance of local *Tilia* dominated woodland began after 3100–2600 cal. BP and was complete by c. 2750–2400 cal. BP, suggesting an intensification of anthropogenic activity from the middle Bronze Age into the early Iron Age.

It is also stated that other pollen diagrams from the Humberhead levels show that woodland clearance was rapid and extensive at the start of the Iron Age, consistent with substantial increases in *Plantago lanceolata*. Their research suggests that possible intensification of arable activity took place in c. 2100–1800 cal. BP (Gearey *et al.*, 2009). Similarly, at Oxenhope Moor, an increase in *Plantago lanceolata* can be seen from c. 2000 cal. BP and 1700 cal BP at West Arkengarthdale, in-line with a possible intensification of arable activity on a wider scale during this time.

A particularly marked event occurs at 1600 cal. BP at Oxenhope Moor, most likely anthropogenic influence, again indicated by high charcoal fragments, a decrease in tree pollen and the presence of *Cerealia* pollen. These changes indicate a spread of forest clearance in the areas surrounding Oxenhope Moor accompanied by agriculture within the period of the Iron Age. Similar results were found at Rishworth, West Yorkshire by Bartley (1975) dated 1920 BP, indicated by a general reduction in tree pollen, therefore implying that this is not an isolated event at Oxenhope Moor, but a regional phenomenon.

Other studies focus on climatic changes, an example of which is humification from Harold’s bog, North Yorkshire, which shows evidence of a climatic deterioration at 1400 cal. BP, also identified across other sites in Europe (Blackford and Chambers, 1991). Conversely, evidence from Mossdale Moor and Oxenhope Moor suggest dry conditions during this time and Chiverrell *et al.* (2007) have identified the time period of 1400-1300 cal. BP as coinciding with Anglo-Saxon land-clearance in the nearby Lake District.

Evidence in the form of vegetation changes, particularly from *Sphagnum* composition from Mossdale Moor and West Arkengarthdale demonstrate that comparable practices were taking place across the Yorkshire region. This can be compared to results found by Blundell and Holden (2015) at Keighley Moor Reservoir Catchment in northern England which focusses on changes in vegetation and has shown that the present vegetation at the site has only been characteristic for the last c. 100 years. Previously, *Sphagnum* moss was an important historic contributor to the vegetation cover between 1500 years ago and the early 1900s. *Sphagnum* occurrence fluctuated with evidence of fire, routinely returning after fire demonstrating good resilience of the ecosystem until the early 1990s. However, *Sphagnum* levels declined severely, at the beginning of the 20th

century, initially coincident with a wildfire event. Levels of *Sphagnum* remained exceptionally reduced as a result of regular managed burning to support grouse moor management where practitioners prefer a dominance of heather. Blundell and Holden suggest that any intention to alter land management at the site to raise water tables and encourage greater *Sphagnum* abundance would be in line with peatland development at the site that has occurred over the past 1500 years. Comparisons can be made with Mossdale Moor, where *Sphagnum* is seen to disappear from c. 100 cal. BP, also attributed to management practices and an increase in charcoal fragments from the pollen record. Similarly, at West Arkengarthdale, *S. papillosum* becomes dominant in very recent (<50) years, coincident with an increase in charcoal. However, at Oxenhope Moor, *S. papillosum* replaces *S. imbricatum* at c. 1000 cal. BP, which is much earlier than can be seen at Keighley Moor, thus highlighting differences in timing of the disappearance of *S. imbricatum* (McClymont *et al.*, 2008) that can occur between sites.

The vegetation changes towards the surface of the profile at Mossdale Moor are similar to results found in other projects in northern England, such as Astley Moss and Danes Moss in northern England where a major decline in *Sphagnum* and an increase in Ericales, monocot and wood remains can be seen towards the surface of these profiles (Davis and Wilkinson, 2004). A rise in Poaceae pollen at 550 cal. BP from Mossdale Moor, consistent with a drop in tree and shrub species and *Sphagnum* spores may be connected to land use changes in the form of higher grazing activity relating to the wool industry. However, charcoal also increases as this happens, which implicates fire as a causal factor. This is similar to data from Sandford Mire, Cumbria where Stringer *et al.* (2014) note that trees are uncommon throughout the 35 cm of core, showing that this area has not been wooded over the last few hundred years. They also note declines in heather and bog-myrtle after the mid-nineteenth century, suggesting a more intensive use of the mire surface, likely from an increase in agricultural use and grazing.

Recent vegetation history in Yorkshire and the surrounding areas also includes responses to increases in levels of pollution. Pollution from surrounding industrial areas may have had an influence on Mossdale Moor as the peat in the upper levels of the core was almost black in colour. *Sphagnum* spores decrease rapidly and *Sphagnum* plant macrofossils are absent at this point. Atmospheric input of pollutants could have benefited certain species at the expense of others sensitive to pollution such as *Sphagnum* (Tallis, 1964) and high grazing numbers on the moor are also likely to have influenced this. Similarly, from 25 cm upwards at Oxenhope Moor, there is an increase in magnetic susceptibility synchronous with the introduction of SCPs, both of which are related to the introduction of and increase in atmospheric pollutants. There are high levels of *Rumex*, indicative of anthropogenic activities, Cyperaceae pollen and an increase in *Eriophorum vaginatum*, a species which frequently dominates degraded blanket mire (Chambers *et al.*, 2007c). Comparisons can be made with Astley Moss and Danes Moss, northwest England, where Davis and Wilkinson (2004) found that near-surface assemblages at both sites are dominated by species of testate amoebae that have been shown to be highly tolerant of pollutants, signifying that pollution may also be an important factor in the composition of the present assemblages at these sites. They also found high levels of metal pollutants in the upper levels of all cores, consistent with an absence of *Sphagnum*-loving testate amoebae species. The evidence from Mossdale and Oxenhope Moors as well as Astley and Danes Moss suggest that recent changes in vegetation and testate amoebae assemblages are likely influenced by increases in pollutants from the surrounding region.

6.7 How the Palaeoenvironmental Findings can Contribute to Modern Conservation

Recently there has been increasing focus on the need for conservation of ecological and evolutionary processes in the face of climate change (Willis *et al.*, 2010). Key areas where palaeoecology can contribute to conservation goals include the determination of rates and nature of biodiversity response to climate change; the climate processes responsible for ecological thresholds; the identification of ecological resilience to climate change; and the management of different ecosystems (Willis *et al.*, 2010). Palaeoecological analysis can examine the complex inter-relationships between impact of disturbance and migration rates of species in conjunction with climate change to predict future plant community composition (Froyd and Willis, 2008), as discussed in section 1.4.

Although similarities have been identified across the three sites studied and other sites in Yorkshire and the northern English uplands, the evidence also identifies individual site responses and has important implications in understanding site processes, therefore affecting the practice of conservation. This study has identified a difference in the timing and degree of responses to changes in climate and of responses to anthropogenic burning and clearance. Therefore, the findings from each site should primarily be used to assist with setting targets for that site; however, the combined information across the three sites might be used to make inferences about peatlands in the region on a wider scale. For instance, it is apparent from the data in this study and others in Yorkshire and the northern English uplands that fire and human disturbance has played a large role in the state that these sites occupy today. An example of this is a change in the composition of *Sphagnum* cover from *S. imbricatum* to *S. papillosum* at Oxenhope Moor and a general reduction in woodland cover at all three sites in this study and other sites within the region. Therefore, it might be recommended that a site with no *Sphagnum* or a high proportion of *S. papillosum* be 'restored' to *S. imbricatum* dominance. However, *S. imbricatum* may struggle to thrive in areas affected by pollution and high N deposition as the palaeoecological record has shown such changes in the last century have resulted in loss of certain species in many peatlands and emphasize that certain species will survive over others given these recent changes.

Despite the long history of intervention by humans at Mossdale Moor, recent human land management processes have affected the area and caused deterioration in terms of species richness and vegetation cover. A more ecologically diverse environment existed before 1200 cal. BP with more tree coverage in the surrounding areas. From 1200 cal. BP onwards, an increase in charcoal and *Plantago lanceolata* pollen are indicative of anthropogenic activity, the former of burning and the latter of grazing. From 570 cal. BP onwards, high charcoal, high Poaceae and an increase in *Plantago lanceolata* indicate more intense anthropogenic activity and therefore emphasize the competitive qualities essential for continued existence in recent (<500) years. The numbers of *Eriophorum* species and other monocots appear to have declined recently, which is positive given that many sites have seen a recent spread of grasses and single taxa such as *Molinia caerulea* (Chambers *et al.*, 2007b, Chambers *et al.*, 2007c, Chambers *et al.*, 1999). This trend may accelerate if the monocots can be replaced by plants such as *Sphagna* as opposed to *Calluna*. The question then is whether such species can survive given the predictions of a highly variable and different climate (Worrall *et al.*, 2006).

Despite recent reductions in charcoal and a general decreasing trend in *Calluna* throughout the Oxenhope Moor profile, recent human land management processes have affected the area and caused deterioration in terms of species richness and vegetation cover. The decline in *Calluna* pollen coincides with a general increase in Poaceae pollen, suggesting a replacement of heather with grass species, a phenomenon seen at many peatland sites across northern Britain (Chambers *et al.*, 1999, Grant *et al.*, 1996, Chambers *et al.*, 2007b, Chambers *et al.*, 2007c). A rise in *Rumex* is evident in recent (<500) years, which is known to resist increasing grazing pressures (Evju *et al.*, 2006), also reflective of an intensification in management practices. However, the presence and increase in *Sphagnum* in recent (<500) years may indicate some sort of 'recovery'; having said this, *S. papillosum* is the dominant species and is a more resilient species than other types of *Sphagnum* (Mauquoy and Barber, 1999). The palaeoecological evidence suggests that, generally, a more ecologically diverse environment existed before 2100 cal. BP with greater species biodiversity and more tree coverage in the surrounding areas.

At West Arkengarthdale, reductions in tree pollen and subsequent increases in charcoal, *Calluna*, Poaceae and monocots suggest that recent human land management processes have affected the area and caused deterioration in terms of species richness and vegetation cover. A rise in *Rumex* during the last 300 years is indicative of increased grazing pressure at the site (Evju *et al.*, 2006) and a very recent appearance of *Sphagnum papillosum* during the last 50 years could demonstrate high levels of N deposition (Payne, 2014). A more ecologically diverse environment existed before 3700/2800 cal. BP (dependant on which age model is used) with a marked reduction in tree pollen evident at 150 cm depth. Before this, tree pollen suggests that there was significantly more tree coverage in the surrounding areas. However, the recent changes at West Arkengarthdale are the most extreme, with a combination of factors including burning, grazing and pollution contributing to the identified changes in species composition.

All three sites have been affected by a multitude of land-use changes, including land clearance by burning varying from c. 3000 cal. BP at West Arkengarthdale, 2100 cal. BP at Oxenhope Moor and 1200 cal. BP at Mossdale Moor. The vegetation record from each site also shows alteration owing to increased grazing pressures, intensification of burning from recent management practices and increasing levels of pollution. Therefore, it seems unlikely that the sites could be restored to a previous state unless anthropogenic pressures are reduced. Given the tolerance of *Sphagnum papillosum* to such management practices and pollution, if *Sphagnum* cover is desired, it might be recommended that this species is encouraged.

Furthermore, feasible targets for conservation management need to be financially reasonable; if expenditure were less of a concern; it might be recommended that more trees are planted in the areas surrounding West Arkengarthdale, Oxenhope and Mossdale Moors to recreate a more ‘natural’ environment. This would be undertaken in conjunction with continuing to fill drainage ditches to re-wet the surface of the mire and thus provide a more suitable environment for species adapted for water-logged conditions.

The numbers of *Eriophorum* species and other monocots appear to have increased recently and the spread of *Sphagnum papillosum* is a recent phenomenon at West Arkengarthdale and Oxenhope Moor. Ideally, this trend should be discouraged and alternatively, other species of *Sphagnum* should be encouraged with the re-wetting of the bog including *S. cuspidatum* and *Vaccinium oxycoccus*. However, there is a need to consider changes in management in relation to farming, grouse management, carbon storage, water quality and water storage for flooding management, how these can be integrated and whether species such as *S. cuspidatum* would be able to thrive if management practices do not change.

Considering the predicted heightened sensitivity of such sites to climate change and increasing erosion, it is important that an understanding of processes occurring at site level is gained. Carbon is sequestered in peatlands so long as formation of new peat exceeds decay losses of all peat accumulated previously

(Clymo *et al.*, 1998).With many sites being described as degraded and dominated by graminoids with reduced levels of *Sphagna*, it is likely that more carbon will be released than sequestered. In understanding past vegetation and encouraging the return to environments rich in *Sphagna* and species such as *Vaccinium oxycoccus*, such sites may be capable of becoming carbon sinks as opposed to carbon sources.

6.8 Limitations and Uncertainties in using Palaeoecology to Advise Conservation

There are limitations to this approach including uncertainties in extrapolation beyond a single site given the variation identified between the three sites in this study and sites from other studies. Furthermore, given the predictions for a highly variable and different future climate and the levels of pollution that peatlands are exposed to, palaeoecological reconstructions are unlikely to provide a precise picture of future conditions. In addition to this, it is important to note that each site has a varying sensitivity, demonstrated by the apparently more degraded appearance of Oxenhope Moor on site investigation when palaeoecological reconstruction did not wholly reflect this. However, palaeoecological reconstructions do provide evidence of past changes that make long-term evidence a useful tool for conservation. For example, each of the sites from this study has experienced recent vegetation changes in the form of increased levels of monocots and Poaceae and reduced biodiversity. Given the recent changes that have occurred at each site, it is recommended that the data from this study be used in conjunction with monitoring studies and perhaps experimental studies (to monitor vegetation responses to differing types of grazing or burning, for instance) to measure current degradation in order to assess better the sites in both a continuing and long-term manner.

Chapter 7: Conclusions and Further Research

Research questions formulated in conjunction with the YPP have enabled palaeoecological data to provide evidence for the previous vegetation, its development, past changes, timing of the changes and the relationship with climate at three degraded peatland sites in Yorkshire. This research project has identified various changes in vegetation composition throughout each profile and has determined, where possible, the causes of these changes. This has supported understanding of the causes of vegetation degradation in an area where palaeoecological knowledge was previously lacking and it is intended that these findings be used to aid understanding of the previous habitat and whether and how it can be restored.

7.1 Climatic Deteriorations

Vegetation changes most likely caused by climatic deteriorations have been identified at each site. These are: Mossdale Moor, c. 2700–1900 and 700–600 cal. BP; Oxenhope Moor, 6800, 5000, c. 4400, 2800, 2400 and 500 cal. BP; and West Arkengarthdale, 6400–2500, 5000, 4650–4475, 3700–3500 and 450–200 cal. BP. Of these, three climatic deteriorations have been identified at more than one site and these are c. 2400 cal. BP at Mossdale Moor and West Arkengarthdale and 5000 and c. 4400 cal. BP at West Arkengarthdale and Oxenhope Moor.

7.1.2 The 'Little Ice Age' (LIA)

The evidence suggests that the LIA has been identified at each of the sites but with differing ages. At Mossdale Moor, it is dated to 700–600 cal. BP, at Oxenhope Moor, 500 cal. BP and at West Arkengarthdale, 450–200 cal. BP. This may be owing to differing response times of the vegetation communities at each of the sites, for instance, there is a high percentage of *Sphagnum papillosum* at Oxenhope Moor compared to *Sphagnum* section *Acutifolia* at Mossdale Moor and West Arkengarthdale. Monocots and *Eriophorum vaginatum* are present at all three sites in varying amounts and *E. vaginatum* is ecologically tolerant in a range of environments and therefore perhaps has varying response times at different locations. An additional contributing factor may be variations in geographical location. For instance, Oxenhope Moor is located at a lower altitude and further south than Mossdale Moor, thus possibly explaining a delayed response time in comparison to the latter. Conversely, West Arkengarthdale sees the latest onset of the LIA although it is located furthest north; however, it is situated at the lowest altitude of the three sites. Dating uncertainties may also play a role in the differences seen between sites and a possible way to resolve this would be to obtain 210Pb dates from Oxenhope Moor and West Arkengarthdale.

7.2 Anthropogenic Activity

None of the sites are completely natural and each has a long history of human influence and therefore, the current structure of each is determined largely by past management practices. Anthropogenic activity has been identified at each of the sites with increased human activity recognised at Oxenhope Moor from 2100 cal. BP and from c. 3250 cal. BP at West Arkengarthdale, evidenced by decreasing tree pollen and increasing charcoal fragments. Human influence becomes particularly intense following the beginning of the industrial revolution, with the intensification of burning evidenced by increasing charcoal and draining for management purposes and grazing of sheep. The effects include changes in the dominant species of *Sphagnum* (from *S. imbricatum* at Oxenhope Moor and from *Sphagnum* section *Acutifolia* at West Arkengarthdale to *S. papillosum*, positively influenced by increasing N deposition associated atmospheric pollution), or the disappearance of *Sphagnum* altogether at Mossdale Moor. Sites become species poor with an increase in monocots and *Eriophorum vaginatum* at each site and increases in *Calluna vulgaris* at Mossdale Moor and West Arkengarthdale.

7.3 Palaeoecology in Conservation

This palaeoecological study has allowed the reconstruction of ecological processes on a timescale much longer than is possible from monitoring studies. There has been a recent shift in the expansion of monocots and the graminaceous species *Eriophorum vaginatum* since the industrial revolution, as found in other similar studies (Chambers, 2001a, Chambers and Daniell, 2011) and a reduction in the number of species of *Sphagna* present. Conservation preference is often given to Callunetum but this should be reconsidered as it is now understood that it may not have always been present (Davies and Bunting, 2010). *Calluna*-dominated communities are part of a relatively recent shift at West Arkengarthdale, as has been found in other studies (Chambers *et al.*, 2007b, Chambers *et al.*, 2007c, Chambers *et al.*, 1999). However, at Oxenhope Moor, *Calluna* has in fact decreased over time and at Mossdale Moor, has decreased in recent (<500) years.

It may be conceivable to restore a site to a number of states within a succession rather than it only being possible to restore a site to a state it has previously occupied (Davis and Wilkinson, 2004). Furthermore, ecologically, the concept of restoration has often been to return the site back to its 'original' state (before human intervention) but if this were the case at Mossdale Moor, which may have been initiated by human action, then this would suggest that the peat should be removed. Rather, the site should be restored depending on its intended use, with a view to encourage the return to environments rich in various types of *Sphagna* and species such as *Vaccinium oxycoccus* allowing such sites to become more biodiverse. The concern then is that once these sites are restored, they will again be at risk from human pressures that are difficult to control and therefore again, susceptible to predicted changes in climate.

7.4 Further Research

There are several aspects of this research project that could be further developed. Firstly, multiple cores could be taken from each site, allowing a comparison of profiles that could support or reject claims of climatic signals only found in one site. The use of testate amoebae could also assist in the identification of climatically driven changes (Booth *et al.*, 2010).

Secondly, the use of lipid analysis could be used to understand if traces of *Sphagnum* are present despite the absence in the plant macrofossils at Mossdale Moor. The lack of *Sphagnum* remains observed may suggest high decomposition rates causing the loss of preservation of plant material at these depths (below 65 cm depth), also supported by high levels of UOM (Loisel and Yu, 2013). Previous studies on the lipid analysis of both modern bog vegetation and peat samples have revealed *n*-alkane distributions for *Sphagnum* species displaying enhanced abundances of lower chain length homologues (Nott *et al.*, 2000, Xie *et al.*, 2004, Bingham *et al.*, 2010, McClymont *et al.*, 2008). *n*-alkane distributions of *Sphagnum* species have successfully been used to reconstruct palaeoclimate (Bingham *et al.*, 2010, Nott *et al.*, 2000), palaeohydrology (Nichols *et al.*, 2006), to establish a molecular proxy for identifying *Sphagnum* derived organic matter (Vonk and Gustafsson, 2009) as well as to explain the disappearance of *Sphagnum imbricatum* from Butterburn Flow (McClymont *et al.*, 2008). As yet, no such study has been used in an applied manner, specifically to advise organisations directly involved in peatland conservation even though it is theoretically possible to track variations in the assemblage of peat-forming plants using the relative chain lengths of *n*-alkanes to establish if *Sphagnum* was present. Concentrations of 5-*n*-alkylresorcinols and triterpenols could also be analysed to reconstruct any other species that may have been present such as in the families' Cyperaceae, Ericaceae and Poaceae, which would perhaps make an ideal post-doctoral project.

Finally, whilst a reasonably secure chronology has been provided for Mossdale and Oxenhope Moors, there are discrepancies between dates at West Arkengarthdale. Further radiocarbon dates could be obtained if finances permitted; however, tephrochronology is a useful dating method that can develop chronologies from peat sequences and exam inter-site records across specific isochrones. This, therefore, allows the spatial synchroneity of environmental changes to be examined (Swindles *et al.*, 2010). Tephrochronology may also prove helpful during periods when the chronological precision of ^{14}C is limited, as is the case at West Arkengarthdale.

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