McCarroll, Julia, Chambers, Frank M ORCID logoORCID: https://orcid.org/0000-0002-0998-2093, Webb, Julia C ORCID logoORCID: https://orcid.org/0000-0002-1652-965X and Thom, Tim (2017) Application of palaeoecology for peatland conservation at Mossdale Moor, UK. Quaternary International, 432 (A). pp. 39-47. doi:10.1016/j.quaint.2014.12.068

Official URL: http://dx.doi.org/10.1016/j.quaint.2014.12.068
DOI: http://dx.doi.org/10.1016/j.quaint.2014.12.068
EPrint URI: https://eprints.glos.ac.uk/id/eprint/1339

Application of palaeoecology for peatland conservation at Mossdale Moor, 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 and was conducted on a degraded blanket mire in Yorkshire, UK, in collaboration with a field-based moorland restoration agency. High-resolution, multiproxy palaeoecological analyses on a peat core from Mossdale Moor reconstructed mid to late-Holocene vegetation changes. Humification, pollen, plant macrofossil and charcoal analyses carried out throughout the peat profile 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, most likely clearance by fire, and between 20–0 cm depth where a substantial charcoal increase is interpreted as recent (<400 years) management practices using burning to encourage browse on the moor. The long-term ecological history of the moor, derived using palaeoecological techniques, will be used to inform conservation practice and to help set feasible targets for restoration and conservation at Mossdale Moor.

Key words: Palaeoecology, conservation, peatlands, Yorkshire, multiproxy, moorland management

1. Introduction

1.1 Peatland Formations and their Degradation

Globally, peatlands cover 3-4% of Earth's surface (Gore, 1983); most originate within the Holocene epoch and contain within their deposits a record of their vegetation development. 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 best expressed at altitudes above 400 m and in areas currently with >1250 mm annual precipitation. The area covered by blanket mire alone in the UK is approximately 25,000 km^2, 10% of the world total (Tallis, 1997).

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, Evans, 2007). 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).

Peatlands also play a role in regulating the atmospheric concentration of carbon dioxide and methane (Klinger et al., 1996). Human disturbance of these ecosystems is depleting carbon stores and causing a transfer of carbon to the atmosphere as the greenhouse gases carbon dioxide and methane, which some believe may be contributing to climate change (Garnett et al., 2000).

Peatland ecosystems in the UK are considered to be of national and international importance (Lindsay et al., 1988, Bain et al., 2011) and it is predicted that peatlands 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., 2007b).

1.2 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 a recognition amongst palaeoecologists that the long-term datasets generated through palaeoecological techniques could be of use in nature conservation (Birks, 1996, Birks, 2012, Willis et al., 2010, Davies and Bunting, 2010, Froyd and Willis, 2008, Hjelle et al., 2012). Palaeoecology can provide the long-term ecological background needed to answer questions about changes during recent times of principal interest to conservationists (Chambers and Daniell, 2011, Seddon et al., 2014). Few studies have used palaeoecological techniques to advise conservationists explicitly, but over recent decades there have been studies involving collaboration in England and Wales between conservation agencies and palaeoecologists in which palaeoecological data have been generated from mires that might then inform conservation practice (Chambers et al., 1999, Chambers et al., 2007a, Chambers et al., 2007b, Chambers et al., 2013, Chambers and Daniell, 2011).

2. Study Area: Mossdale Moor

2.1 Aims of the Palaeoecological Research at Mossdale Moor

The Mossdale Moor study was conducted in collaboration with the Yorkshire Peat Partnership (an organisation restoring and conserving upland peat resources in order to ensure the long-term future of these ecosystems). The aim was to support and inform moorland conservationists by determining the former vegetation of the now degraded peatland. Palaeoecological data provide evidence of the previous vegetation, its development, past changes, when the changes occurred and any relationship with climate change. The project aimed to answer research questions formulated in conjunction with the Yorkshire Peat Partnership. This would aid understanding of the causes of vegetation degradation in an area where previous palaeoecological knowledge was lacking. Ultimately, this information will aid understanding of the previous habitat, whether and how it can be restored, and the likely consequences of restoration practices.

2.2 Site description

Mossdale Moor is degraded blanket mire located in Upper Wensleydale, North Yorkshire, UK (Latitude: 54.300292N, Longitude: -2.315507W; see Figure 1). The coring site is located on a small plateau at the bottom of the north side of Widdale Fell. There are small-scale erosional landforms (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*, *Scirpus 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.

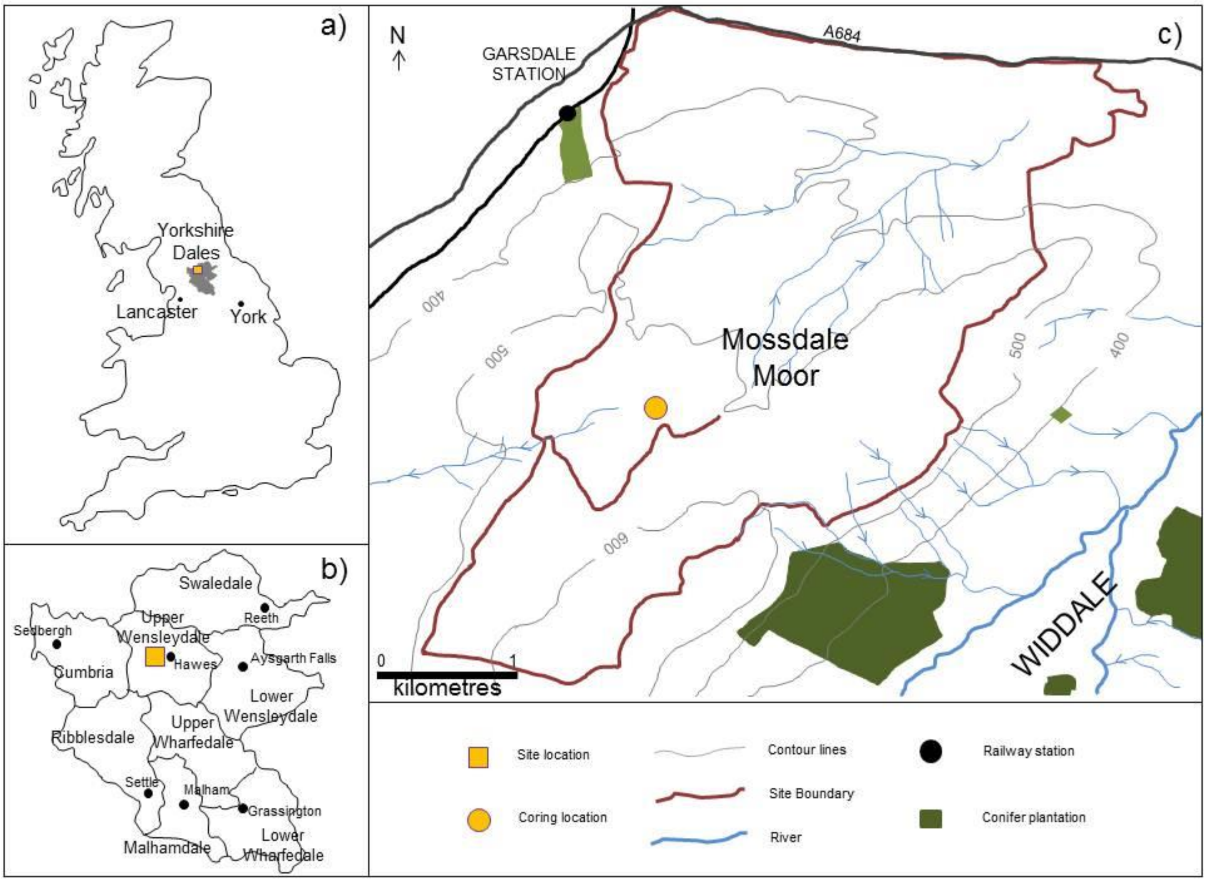

Figure 1: a) Map of United Kingdom showing location of the Yorkshire Dales in relation to the cities of Lancaster and York. **b)** Map of the Yorkshire Dales showing location of Upper Wensleydale, the village of Hawes and Mossdale Moor. **c)** Map of Mossdale Moor showing exact coring location at Latitude: 54.300292N, Longitude: -2.315507W.

3. Methods

3.1 Sampling Method

The coring protocol was based on the method used in the ACCROTELM Research Project (ACCROTELM, 2006, De Vleeschouwer et al., 2010b, De Vleeschouwer et al., 2010a) whereby overlapping, adjacent cores were extracted, 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.

3.2 Laboratory Methods

A range of palaeoecological methods was used, following protocols developed specifically for peats, including magnetic susceptibility, pollen analysis, humification analysis, plant macrofossil analysis, charcoal analysis and analysis of Spheroidal Carbonaceous Particles (SCPs).

Magnetic susceptibility was measured in the laboratory using the Bartington MS2 System at every 0.5 cm before the sub-sampling of the cores at 1 cm intervals. Fossil pollen was prepared and analysed in at least 4 cm intervals, using a modified methodology based on that of Bas van Geel (1978) and the pollen protocol used by Chambers et al. (2011b) with points of interest being analysed more frequently. SCPs were also counted alongside fossil pollen (Swindles, 2010). Humification analysis was measured at 1 cm intervals according to the protocol outlined in Chambers et al. (2011) using an alkali extraction and colorimetric technique, whereby humic acids produced during decomposition were extracted. The results were then smoothed exponentially and de-trended in MS Excel. Plant macrofossils were analysed at a 4 cm resolution according to the protocol developed by Mauquoy et al. (2010) using the quadrat and leaf count (QLC) method of macrofossil analysis described by Barber et al. (1994). Seeds were counted as numbers rather than percentages. Daniels and Eddy (1985) was used to identify *Sphagna* and Smith (2004) was used for non-*Sphagnum* bryophytes. Charcoal was counted in both pollen (the total number of charcoal fragments identified was counted until 500 terrestrial pollen grains had been counted) and plant macrofossil samples (the total number of charcoal fragments identified within the plant macrofossil sample) to infer local and regional fires (Mooney and Tinner, 2011). The data are displayed on both the pollen and plant macrofossil diagrams (see Figures 2 and 5).

Mossdale Moor sediments were dated using accelerator mass spectrometry (AMS) radiocarbon dates on samples of *Polytrichum commune* and monocot leaves (selected avoiding rootlets) as no *Sphagnum* leaves or stems were available. A bulk sample of peat was used at the base of the profile where no visible plant macrofossils were available (Piotrowska et al., 2011). ^{210}Pb samples were analysed every 1 cm for the first 32 cm depth at the University of Exeter according to the protocol outlined in He and Walling (1997).

The age-depth model was produced using OxCal version 4.2 (Ramsey, 2009) with calibration of the radiocarbon ages to calendar years conducted using INTCAL13 (see Figure 3). Pollen and plant macrofossil diagrams were produced using TILIA v.1.7.16 and TILIA*GRAPH (see Figures 2 and 5) (Grimm, 1991).

4. Results and Interpretation

4.1 Lithostratigraphy

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.

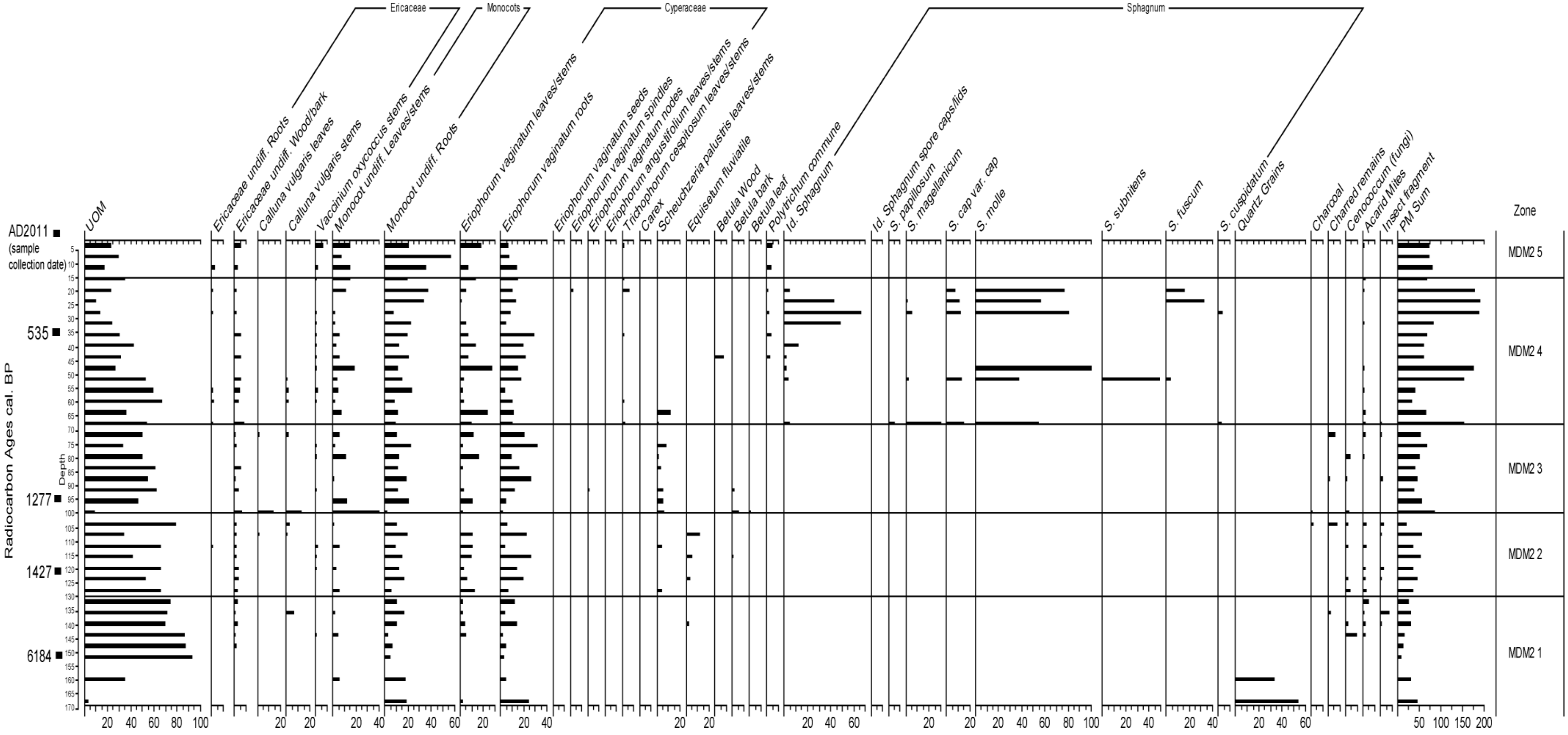

Figure 2: Percentage plant macrofossils (including Unidentified Organic Matter), charcoal (number of fragments per sample), charred remains (number), Cennococcum fungi (number), Acarid mites (number), insect fragments (number) and radiocarbon ages diagram, Mossdale Moor.

4.2 Plant Macrofossils

Table 1: Plant macrofossil zones, depths (cm), ages (cal. BP), humification (wet/dry) and plant macrofossil zone descriptions.

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

Table 1: Plant macrofossil zones, depths (cm), ages (cal. BP), humification (wet/dry) and plant macrofossil descriptions.

4.2.1 Plant Macrofossil Percentage Diagram

The plant macrofossil diagram was divided into 5 biostratigraphic zones (Figure 2) based on changes in species composition noted by eye.

Zone MDM2-1 is characterised by high UOM (above 80% at 150 cm depth), monocot roots (approximately 17% at 160-170 cm depth) and quartz grains (above 50% at 170 cm depth). Monocot leaves/stems and *Eriophorum vaginatum* roots are also present and numbers of *Cennococcum* fungi are higher in this zone than any other.

In zone MDM2-2, UOM fluctuates and reaches a high of 85% at 105 cm and a low of 35% at 107 cm depth. *Eriophorum vaginatum* roots reach approximately 30% at 115 cm depth and *Scheuchzeria palustris* is also present at 125 cm and 110 cm depths at 5%. Monocot roots rise throughout the zone, starting at approximately 10% at 127.5 cm depth and increasing to 30% at 107 cm depth. *Equisetum fluviatile* is also present in this zone.

Calluna vulgaris is present in zone MDM2-3, reaching 20% at 100 cm depth and is not present to this extent at any other point throughout the profile. *Eriophorum vaginatum* increases to approximately 30% at 70 cm depth and *Scheuchzeria palustris* reaches a maximum of 12% and remains relatively constant throughout. *Cennococcum* fungi are also present at 80 cm depth and monocot percentages increase to almost 40% at 100 cm depth. UOM decreases to a maximum of approximately 70% at 90 cm and 110 cm depth compared with a maximum of almost 90% in the previous zone (MDM2 – 2).

Eriophorum vaginatum leaves/stems fluctuate in zone MDM2-4, from a low of less than 10% at 55 cm depth to a high of 25% at 57.5 cm depth. *Sphagnum* appears, notably *Sphagnum.* section. *Acutifolia*, which is preceded by a presence of *Scheuchzeria palustris* at 65 cm depth. The percentage of total *Sphagnum* identified reaches 65% at approximately 30 cm depth with 80% of this being made up of *S. molle*. UOM is at its lowest, falling to approximately 10% at 25 cm depth and a maximum of 70% at 65 cm depth.

In zone MDM2-5, monocot roots reach a high of 50% at 7 cm depth and *Polytrichum commune* and *Vaccinium oxycoccus* are both present reaching their highest levels throughout the profile at 5%. UOM percentages are relatively low in comparison to the rest of the profile, reaching a maximum of 30%.

Table 2: Local mire vegetation at 20 cm intervals (after 10 cm depth), ages (cal. BP) and depth (cm).

Depth (cm)	Age (cal. BP)	Local Mire Vegetation
0–10	c. -60 – c. 17	*Calluna-Eriophorum vaginatum* mire with *Vaccinium oxycoccus* and *Polytrichum commune*
10–30	c. 17 – c. 500	*Sphagnum molle-Calluna-Eriophorum vaginatum* mire with *Polytrichum commune*
30–50	c. 500 – c. 800	*Sphagnum molle-Calluna-Eriophorum*-mire with *Polytrichum commune*
50–70	c. 800 – c. 900	*Calluna-Eriophorum vaginatum* mire with *Scheuchzeria palustris* and *Sphagnum molle*
70–90	c. 900 – c. 1300	*Eriophorum vaginatum-Calluna* mire with *Vaccinium oxycoccus* and *Scheuchzeria palustris*
90–110	c. 1300 – c. 1400	*Eriophorum vaginatum-Calluna* mire with *Scheuchzeria palustris* and *Equisetum fluviatile*
110–130	c. 1400 – c. 3100	*Eriophorum vaginatum-Sphagnum-Calluna* mire with *Vaccinium oxycoccus*, *Scheuchzeria palustris* and *Equisetum fluviatile*
130–150	c. 3100 – c. 6100	*Eriophorum vaginatum-Calluna-Sphagnum* mire with *Vaccinium oxycoccus*
150–170	c. >6100	*Eriophorum vaginatum-Myrica gale-Calluna* mire with *Alnus*

Table 2: Local mire vegetation at 20 cm intervals (after 10 cm depth), ages (cal. BP) and depth (cm).

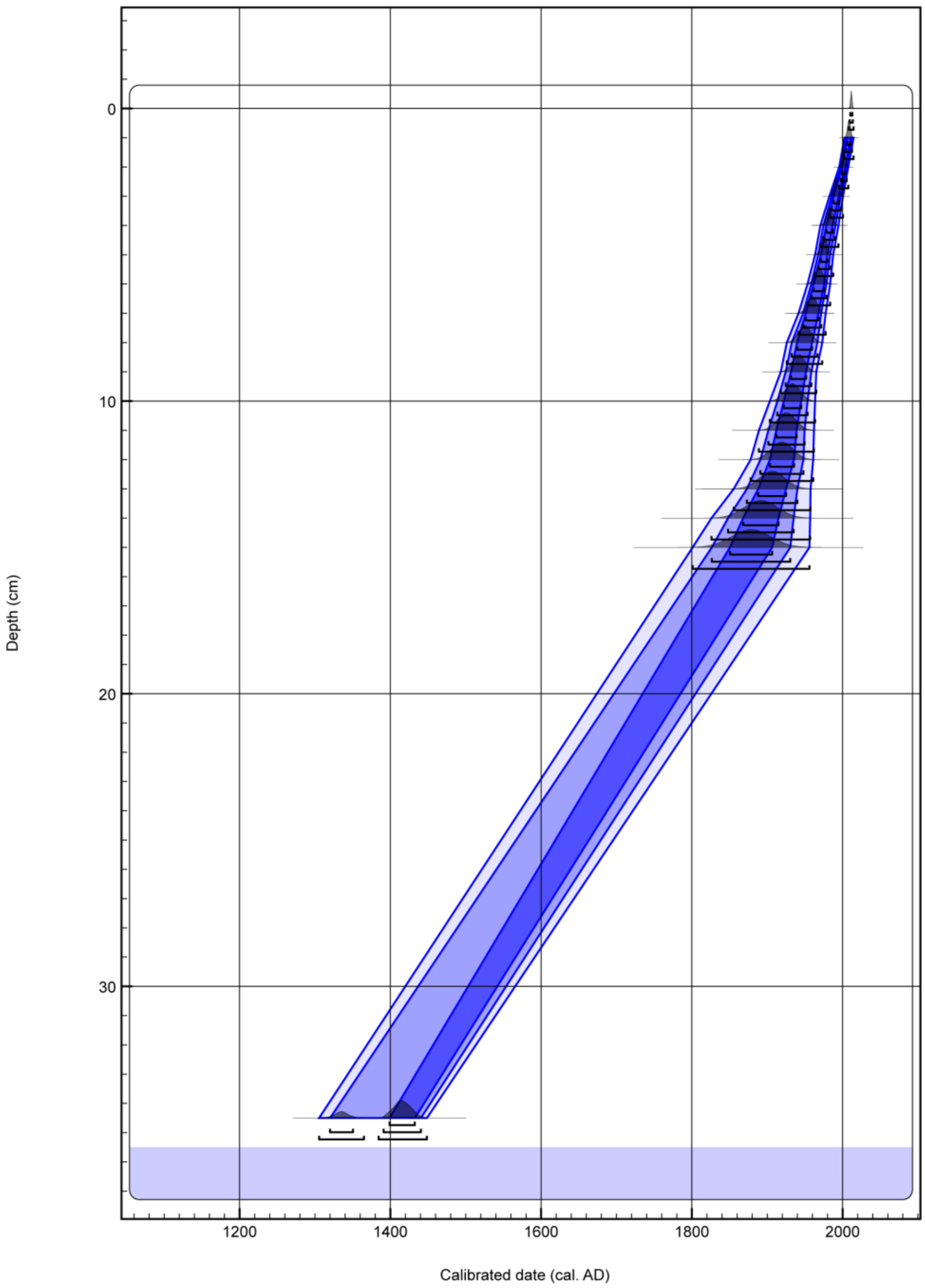

Figure 3: Bayesian (P_Sequence) age-depth model for Mossdale Moor constructed from a combination of 1 AMS Radiocarbon (34.5 cm depth) and 17 ^{210}Pb dates using OxCal version 4.2 software (Ramsey, 2009) and calibrated using INTCAL13 (Reimer et al., 2013).

4.3 Magnetic Susceptibility

Magnetic susceptibility fluctuates very little overall but drops between 130–120 cm depth and 20–0 cm depth. The increase in values towards the surface can be attributed to increasing pollution consistent with the introduction of SCPs (see Figure 5) and reflects the increased atmospheric deposition of magnetic minerals from industrial processes after the start of the industrial revolution.

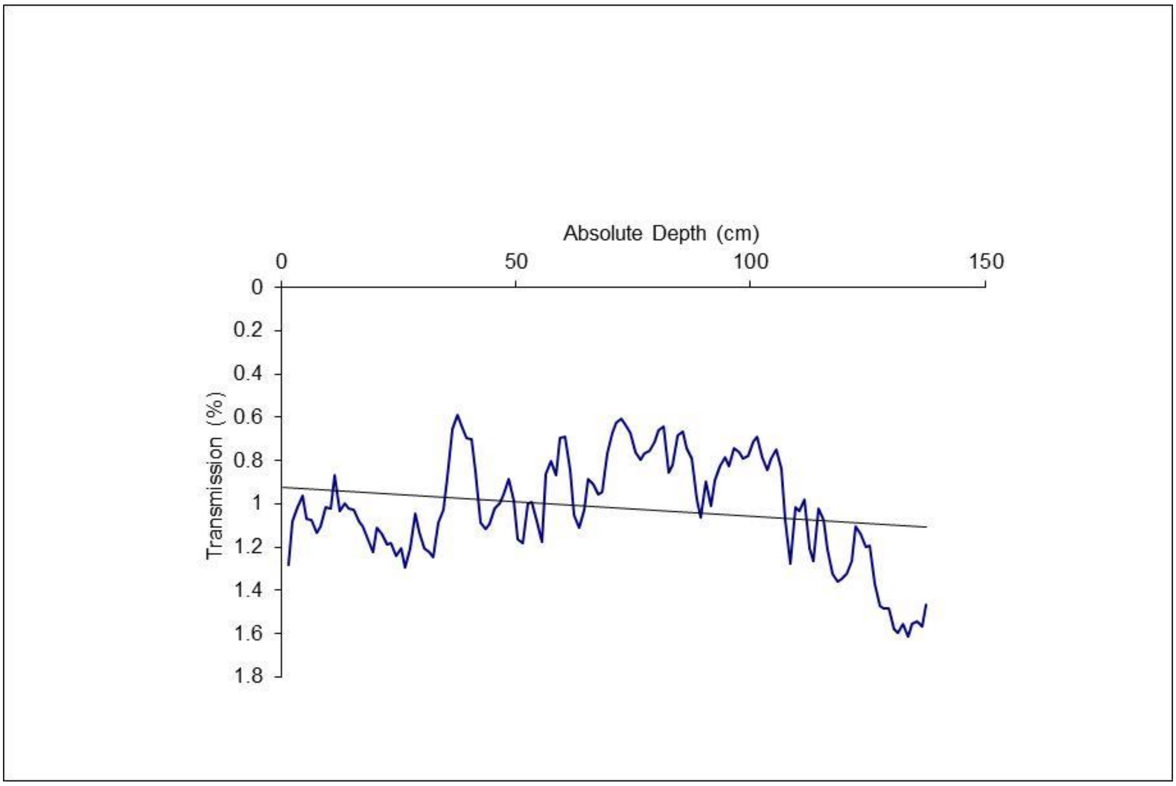

Figure 4: De-trended humification curve (%Transmission) plotted against depth (cm), Mossdale Moor.

4.4 Humification

The transmission percentage (%T) decreases in proportion to the amount of decomposition and to the fraction of mineral matter in peat (Blackford and Chambers, 1995). However, because the Mossdale Moor core contains negligible amounts of mineral sediment above the base, our results were not corrected. De-trended %T values for Mossdale Moor are plotted against depth (See Figure 4).

More highly decomposed peat produces a darker coloured alkali extract and therefore reduced light transmission (Chambers et al., 2011). Low transmission percentages represent drier conditions and the reverse represents wetter conditions. At the base of the profile, between 140–90 cm (c. 5300 to 1200 cal. BP) conditions are generally dry.

A rise in %T can be seen at approximately 90 cm depth (c. 1200 cal. BP), suggesting a brief transition to wetter conditions. It apparently becomes drier until approximately 70 cm (c. 1000 cal. BP), where %T can then be seen to increase to 26% at 64 cm (c. 950 cal. BP). Conditions then appear to become briefly drier at approximately 65 cm depth before becoming wetter again at 45 cm depth (approximately 700 cal. BP). %T then falls between 45–40 cm suggesting a shift back to drier conditions. From 40 cm onwards, conditions then become wetter again and remain relatively stable up to the surface.

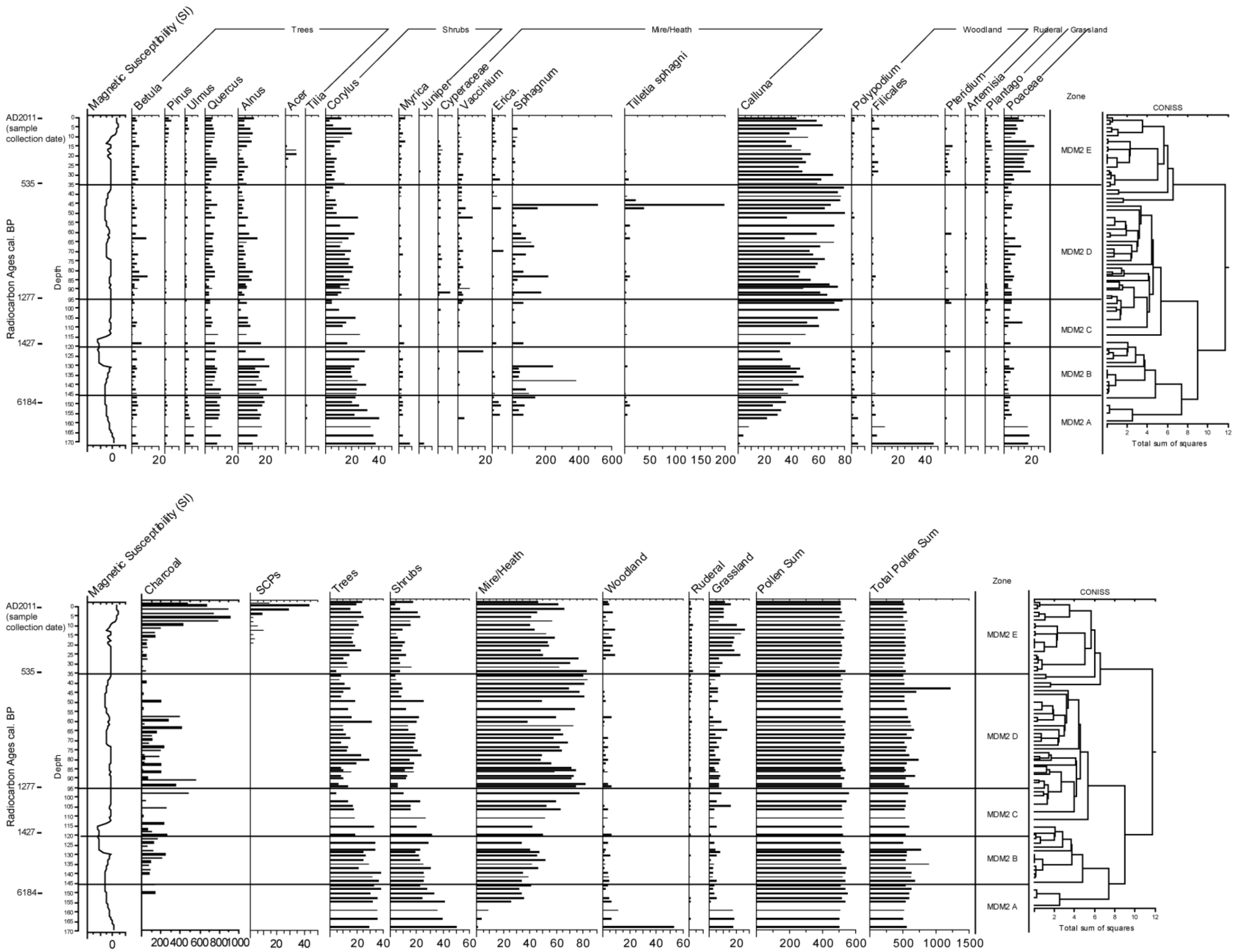

Figure 5: Percentage pollen, magnetic susceptibility (SI), charcoal (number of fragments per sample), SCPs (number) and radiocarbon ages diagram, Mossdale Moor.

4.5 Pollen

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

Table 3: Pollen zones, depths (cm), ages (cal. BP), charcoal (number of fragments per sample), humification (wet/dry) and pollen zone descriptions.

4.5.1 Pollen Zone Percentage Diagram

The pollen percentage diagram (Figure 5) was zoned using both CONISS within TILIA and by noting any substantial ecological changes 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.

Zone MDM2 – A is characterised by very low levels of *Calluna* pollen in comparison to the rest of the profile. There are high levels of *Filicales* and *Corylus* is at its highest percentage of almost 40% and *Poaceae* reaches approximately 18%.

In zone MDM2 – B, *Calluna* reaches higher levels when compared to MDM2 – A and steadily rises throughout. Charcoal also increases and remains throughout with small peaks in numbers of fragments counted per sample at 134 cm and 124 cm depths. *Corylus* declines with the increase in *Calluna* and *Sphagnum* is introduced and present throughout this zone with a peak in numbers at 127 cm depth, reaching 400 spores counted.

Corylus, *Alnus* and *Quercus* decrease in zone MDM2-C whilst *Calluna* rises steadily throughout before starting to descend at approximately 82 cm. There are two peaks in the number of charcoal fragments counted at 101 cm and 94 cm depth.

In zone MDM2 – D, *Calluna* rises following a slight decrease at 80-70 cm depth. At 42 cm depth, *Sphagnum* numbers reach their highest throughout the profile (at more than 500 spores counted) and numbers of *Tilletia sphagni* spores are consistent with this, reaching 200 spores counted. No charcoal fragments were counted at this depth. Towards the top of the zone, *Calluna* is dominant whilst numbers of charcoal and *Sphagnum* are both low. *Quercus, Alnus* and *Corylus* also decrease at this point.

In zone MDM2 – E, numbers of charcoal fragments and percentages of *Poaceae* and *Plantago* pollen reach much higher levels than throughout the profile. At 16 cm depth, *Calluna* slightly decreases whilst *Quercus, Alnus* and *Corylus* decrease to very low percentages and *Poaceae* and charcoal begin to increase. *Quercus, Alnus* and *Corylus* then rise slightly at 10cm depth before decreasing again at 2-3 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.

4.6 Radiocarbon and ^{210}Pb Ages

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

Table 4: Depth (cm), radiocarbon date (yr BP), Beta Analytic lab number, calibrated ages (yr BP) and material used to obtain date. *Rejected radiocarbon dates – both dates were rejected because they appear too young. **Radiocarbon dates were calibrated using OxCal 4.2 (Ramsey, 2009). The date from the base of the peat was obtained using charred material extracted at Beta Analytic from a bulk peat sample (149–151 cm) as no suitable plant macrofossils could be extracted at this depth. The age of this date implies a much slower accumulation rate between 118 cm and 150 cm depth. The sample at 34.5 cm depth was dated using Polytrichum commune. All other samples were dated using Eriophorum 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.

The radiocarbon date obtained from 34.5 cm (511–559 cal. BP) is in agreement with the ^{210}Pb dates and the relative age of the SCPs. However, this would suggest that the sediment accumulation rate has decreased since this time, which is unusual for a mire as accumulation rates normally increase towards the surface. Nevertheless, this may be explained by the degraded and dry nature of the mire in the last few hundred years and the erosions occurring at the site, leading to surface shrinkage.

The dating of the site is further supported by the detection of the post-glacial elm decline at 145 cm depth (c. 5400 cal. BP) that first occurs on British pollen diagrams in the centuries around 5800 cal. BP (Innes et al., 2013). Other chronological markers can also be used including the timing of establishment of pine plantations (Le Roux, 2011). A rise in *Pinus* can be seen from 15 cm upwards (c. cal. AD 1860 (±56) according to ^{210}Pb dates and approximately cal AD 1750 (±30) according to radiocarbon dates). An increase in *Pinus* associated with extensive reforestation usually predates the beginning of the 19th Century (Appleby et al., 1997).

There seems to be a discrepancy of almost 100 years between ^{14}C and ^{210}Pb dates at Mossdale Moor. The age estimates produced by both of these methods have been exposed to be prone to significant inaccuracy in some cases (van der Plicht et al., 2013). However, the SCPs support the ^{210}Pb dates and therefore the *Pinus* pollen rise may be several decades later than suggested by Appleby et al. (1997). Barber (1981) similarly suggests a date of AD 1800 ±25 years for the rise in pine pollen. When considering the error of 56 years for the ^{210}Pb date at 15 cm depth, there is a time overlap which covers the suggested age for the *Pinus* pollen rise. It may also take several decades before the *Pinus* pollen is incorporated into the peat record owing to long-distance transport before the forest reaches the site. Therefore, the rise in *Pinus* from 15 cm depth upwards is interpreted as anthropogenic reforestation.

5. Discussion

5.1 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.

5.2 Possible Climatic Changes Interpreted from Palaeoecology

5.2.1 Wetter Conditions (3800–2200 cal. BP).

Higher numbers of *Sphagnum* spores occur from 135 cm depth (c. 3800 cal. BP) upwards accompanied by high %T. 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* (see Tables 1 and 2) 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 3200 cal. BP and 2750-2350 cal. BP and Langdon et al. (2003) at 3850, 3400 and 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.

5.2.1 Drier Conditions (1400–1300 cal. BP).

A substantial dry shift is apparent between 107 and 95 cm depth (1400–1300 cal. BP). Evidence for this includes low %T, an absence of *Sphagnum* and high levels of UOM in the plant macrofossils (see Figures 2, and 4 and Tables 1 and 2). 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 (see Figure 5 and Table 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 However, 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 low %T 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.

5.2.2 Wetter Conditions (660–600 cal. BP).

At 45 cm depth (660 cal. BP) [AD 1280], there is evidence for wetter conditions regionally, indicated by high %T 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 (see Figure 2). 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 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 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 40cm depth, %T is beginning to decrease 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 %T and plant macrofossil record.

5.3 Increased Anthropogenic Activity (1300 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. 1300 cal. BP), where human clearance by fire is indicated by a charcoal fragment spike and an increase in *Calluna* pollen (see Figure 5). It is proposed that from 95 cm depth upwards, anthropogenic effects are more significant. At Mossdale Moor, %T is also low at this point, although it increases 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).

5.6 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. 1906AD) until a more substantial peak at 6 cm depth (c. cal. 1960AD) and a final peak at 3 cm depth (c. cal. 1990AD). Similar evidence has also been found in other projects. For example, Chambers et al (2007b) 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 (2007b) where the decline in SCPs was thought to post-date a Clean Air Act of 1968.

A huge 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., 2007b, 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 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. 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., 2007b). 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.

5.7 Implications for Conservation

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 95 cm depth (1300 cal. BP) with more tree coverage in the surrounding areas.

Feasible targets need to be financially reasonable; if expenditure was less of a concern, it might be recommended that more trees are planted in the areas surrounding Mossdale Moor if a more natural environment were being sought. 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 declined recently. This trend may accelerate when the monocots are replaced by plants such as *Sphagna* as opposed to *Calluna*. 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 and how these can be integrated.

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. 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. Carbon is sequestered in peatlands so long as formation of new peat exceeds decay losses of all peat accumulated previously (Clymo et al., 1998). 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. Suggestions for Future Work

A lack of *Sphagnum* remains observed in the plant macrofossil samples when *Sphagnum* spores are present 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). To investigate whether this is the case, it is possible to use biomarker analysis to see whether any traces of *Sphagnum* are present at these depths despite the absence of *Sphagnum* in the plant macrofossils. The use of biomarkers in peatland analysis is becoming more widespread and is recommended for use in climate studies and is therefore suggested as a future direction in this type of applied palaeoecological study (Swindles et al., 2013). *Sphagnum* cover on blanket bogs seems to be the most sufficient in terms of carbon storage (Bridgham et al., 2008, Harden et al., 1997) and therefore it is important to understand what the past *Sphagnum* consisted of, particularly down to species level as some are regarded as peat formers whereas others are not (Malmer et al., 1994).

Acknowledgements

We thank the Yorkshire Peat Partnership for their financial support; the Quaternary Research Association for additional financial support; John Daniell and Hongyan Zhao for assistance with fieldwork; Hongkai Li and Angus Mackenzie for assistance with the modelling of ^{210}Pb dates; Briony Eastabrook and Will Carpenter for laboratory assistance and Oliver Pritchard for proof reading.

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