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, T (2016) Informing innovative peatland conservation in light of palaeoecological evidence for the demise of Sphagnum imbricatum: the case of Oxenhope Moor, Yorkshire, UK. Mires and Peat, 18 (N/A). pp. 1-24. doi:10.19189/MaP.2015.OMB.206

Official URL: http://mires-and-peat.net/pages/volumes/map18/map1808.php
DOI: 10.19189/MaP.2015.OMB.206
EPrint URI: https://eprints.glos.ac.uk/id/eprint/3184

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McCarroll, Julia and Chambers, Frank M and Webb, Julia C and Thom, T (2016). ***Informing innovative peatland conservation in light of palaeoecological evidence for the demise of Sphagnum imbricatum: the case of Oxenhope Moor, Yorkshire, UK.*** **Mires and Peat, 18. ISSN 1819-754X**

Published in Mires and Peat, and available online at:

http://mires-and-peat.net/pages/volumes/map18/map1808.php

We recommend you cite the published (post-print) version.

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Informing innovative peatland conservation in light of palaeoecological evidence for the demise of *Sphagnum imbricatum*: the case of Oxenhope Moor, Yorkshire, UK

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SUMMARY

Actively growing mires have high conservation value and the potential to sequester carbon. However, drainage, burning, overgrazing and atmospheric pollution have led to depauperation of native flora and loss of peat at many peatland sites. In order to counteract such degradation, palaeoecological techniques can be applied and the data then used to inform nature conservation practice. The present study exemplifies this approach and was conducted on 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 Oxenhope Moor were used to reconstruct Holocene vegetation changes spanning approximately the last 7000 years. Humification, pollen, plant macrofossil and charcoal analyses show distinct changes in species composition and indicate their potential causes. Human-induced changes identified at 2100 cal. BP are most likely to reflect deliberate clearance by fire. *Sphagnum imbricatum* disappears and is subsequently replaced by *S. papillosum* at *ca*. 1000 cal. BP, possibly due to drier conditions and competition between the two species. Increased human activity is identified since the Industrial Revolution where monocots and *Eriophorum vaginatum* increase, interpreted as a result of managed burning. It is intended that the long-term ecological history of the site, derived using palaeoecological techniques, will be used to inform conservation practice and can help set feasible targets for restoration and conservation. Specifically, encouraging a species mix that has pre-19th century longevity is suggested, including the specific recommendation that translocation of *S. imbricatum* be explored experimentally at this site, with a view to ascertaining likely success elsewhere.

KEY WORDS: bog ecology, conservation management, mire conservation, palaeoecology, peatlands

INTRODUCTION

Globally, peatlands comprise approximately 3 % of the Earth's surface (Limpens *et al.* 2008) and are estimated to contain between 270 and 370 teragrams of carbon (TgC; 1 Tg = 10^{12} g) as peat (Turunen *et al*. 2002). The carbon balance of northern peatlands alone plays a significant role in the global carbon cycle as, despite relatively low gross primary production rates within these ecosystems, they contain up to 30 % of total terrestrial carbon (Gorham 1991). In the UK, peatland ecosystems are considered to be of national and international importance (Lindsay *et al.* 1988, Bain *et al.* 2011) because they provide terrestrial carbon storage, as well as for maintenance of biodiversity and protection of water resources (Drew *et al.* 2013). However, this importance is threatened by widespread evidence of degradation.

Peatland degradation can be caused by many factors including erosion (Yeloff *et al.* 2006), overgrazing (Worrall & Clay 2012), prescribed burning (Worrall *et al.* 2007, Muller *et al.* 2012), climate change (Hogg *et al.* 1992, Heijmans *et al.* 2013), acid rain (Nedwell & Watson 1995, Watson & Nedwell 1998, Gauci *et al.* 2002), peat cutting (Cooper *et al.* 2001, Charman & Pollard 1995) and drainage (Ramchunder *et al.* 2009). 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 reduction of biodiversity (Yeo 1997). It is predicted that they will show heightened sensitivity to disturbance as a result of climatic change and increasing erosion over the coming decades (House *et al.* 2010, Gallego-Sala & Prentice 2013).

The vegetation considered typical of undisturbed peatlands is under threat across much of the UK, as is evident from blanket mire communities following observed changes in vegetation composition with reductions in ericaceous species and *Sphagna*. Many areas are now dominated by graminaceous species such as *Molinia caerulea* and *Eriophorum vaginatum*

(Grant *et al.* 1996, Chambers 2001, Davies & Bunting 2010).

Many of the problems peatlands face are interlinked, with drainage and overgrazing leading to erosion and wildfire. This exacerbates the problem of erosion, in turn leading to increased dissolved organic carbon (DOC) from peatlands entering water sources and increased methane and carbon dioxide entering the atmosphere (Page *et al.* 2002). Drain blocking and assisted re-vegetation are generally undertaken as the first stage of restoration to repair damage and reduce the risk of further deterioration (Brooks *et al.* 2014). However, with which species these areas are re-vegetated, what changes are made to management actions (e.g. burning and grazing) and to what end, is where palaeoecological studies might assist.

Using palaeoecology to advise conservation

Palaeoecologists have recognised that the long-term datasets generated through palaeoecological techniques could be of use in nature conservation (Birks 1996, Froyd & Willis 2008, Davies & Bunting 2010, Willis *et al.* 2010, Birks 2012, Hjelle *et al.* 2012, Muller *et al.* 2012, Wilmshurst *et al.* 2014, McCarroll *et al.* 2015). 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 *et al.* 1999, Chambers & Daniell 2011, Seddon *et al.* 2014).

Palaeoecological studies to aid conservationists in the British Isles were first carried out on Exmoor (Chambers *et al.* 1999) followed soon after by studies in Wales (Chambers *et al.* 2007a, Chambers *et al.* 2007b), Scotland (Davies & Watson 2007), northern England (Chambers & Daniell 2011), the Pennine Hills (Davies 2015), Ireland (Stevenson & Thompson 1993) and other locations (Stevenson & Rhodes 2000). Studies have also been conducted in the county of Yorkshire, at Keighley Moor by Blundell & Holden (2015) and at Mossdale Moor by McCarroll *et al.* (2015). At Keighley Moor it was found that the present vegetation at the site has only been characteristic for the last *ca.* 100 years (Blundell & Holden 2015), whereas at Mossdale Moor a long history of human influence was observed with an intensification in human activity between 20 and 0 cm where a substantial charcoal increase is interpreted as recent (< 300 years) management practices using burning to encourage browse on the moor (McCarroll *et al.* 2015).

The present study reports the results of palaeoecological reconstructions from Oxenhope Moor, Yorkshire. It was conducted in collaboration with the Yorkshire Peat Partnership (YPP), which is an organisation run by the Yorkshire Wildlife Trust that restores and conserves 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 this degraded peatland.

This study aims to build an understanding of vegetation changes throughout the history of the peat profile; to determine what might have caused these changes and how these findings compare regionally with analyses conducted by the authors and other researchers; and to consider how this information can support the development of innovative methods for conservation and restoration projects. Specific recommendations are made, including experimental translocation of species, which have implications for bog conservation elsewhere.

SITE SELECTION AND DESCRIPTION

Oxenhope Moor was selected for palaeoecological analysis by the YPP based on the current judgement that it is one of the most degraded of the sites managed by the agency. The site was also assessed by the authors to establish whether it was suitable for palaeoecological analysis. The YPP manage other peatland sites in Yorkshire including Mossdale Moor (McCarroll *et al.* 2015) and West Arkengarthdale (McCarroll 2015), which also underwent palaeoecological analysis conducted by the same authors.

Oxenhope Moor is located at 430 m altitude, approximately 14 km west of Bradford at latitude 53.793759 ºN, longitude 1.977952 ºW (Figure 1). The modern-day peat supports species characteristic of National Vegetation Classification (NVC) types M20 (*Eriophorum vaginatum* blanket and raised mire) and M25 (*Molinia caerulea* - *Potentilla erecta* mire) (Rodwell 1998) as surveyed by Natural England in 2008. Although a variety of species have been identified at the site, including *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*, some of these

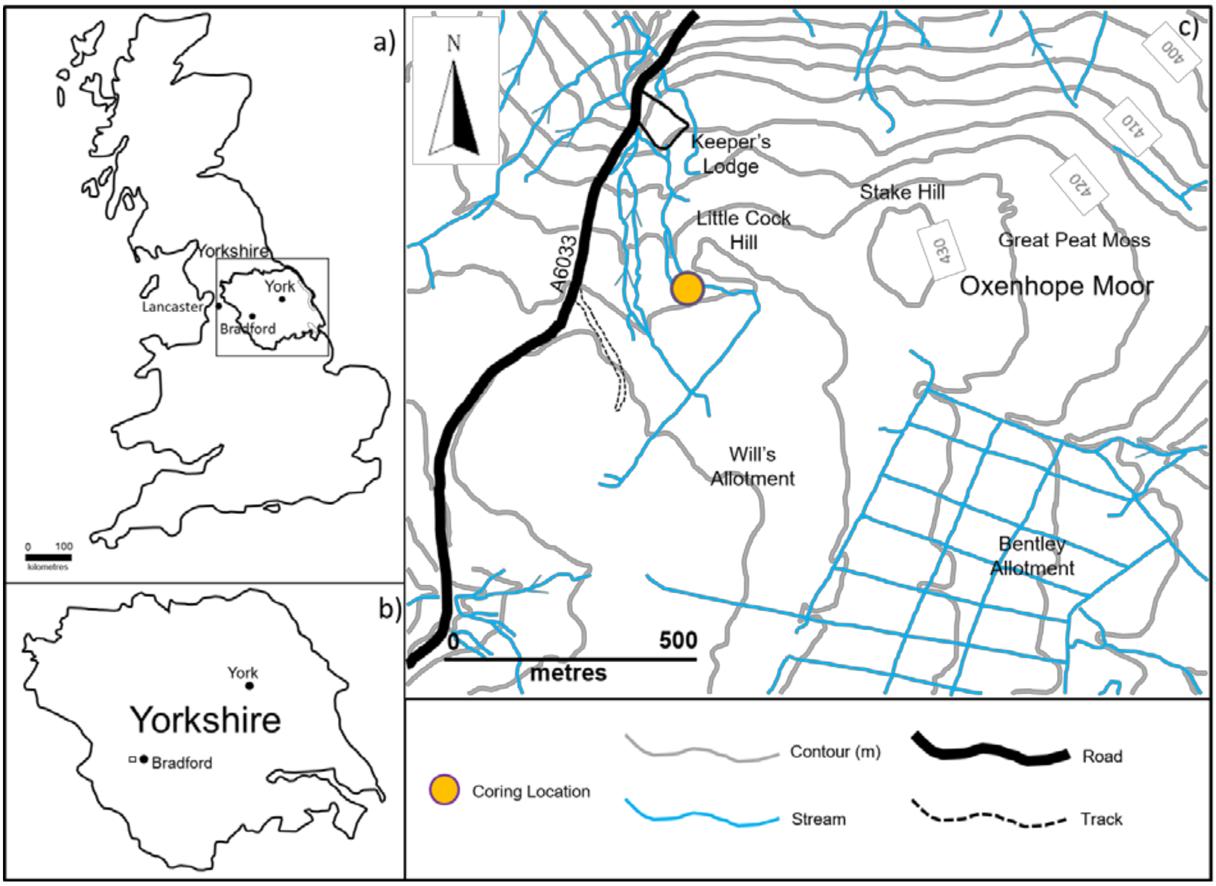

Figure 1. a) Map of United Kingdom showing the locations of Yorkshire (a county) and the cities of Lancaster, Bradford and York. b) Map of Yorkshire; the small square west of Bradford indicates the extent of Map c), i.e. the location of Oxenhope Moor. c) Map of Oxenhope Moor showing the exact coring location at Latitude: 53.793759 ºN, Longitude: 1.977952 ºW.

species are present in low numbers, the site is dominated by *Eriophorum* spp. and there are large areas of exposed peat. Though higher ground is dominated by *Eriophorum* spp., to the east the ground slopes down towards a reservoir where *Molinia* becomes dominant.

Field sampling strategy

The field sampling strategy was based on the method used in the ACCROTELM Research Project (ACCROTELM 2006, De Vleeschouwer *et al*. 2010) whereby the site morphology was established, firstly, by measuring peat depths across Oxenhope Moor in order to find the deepest ombrotrophic zone closest to the highest point of the bog. The gross site stratigraphy was then determined by describing multiple cores using the Troels-Smith (1955) method. This enabled the identification and selection of the master core, which was taken in a lawn zone located by the multiple cores, selecting the one with the most variable stratigraphy. Overlapping adjacent cores were extracted using a 5 cm diameter Russian corer, photographed and placed in labelled plastic guttering, wrapped in airtight carbon-stable bags and transported to the laboratory where they were stored at 4 °C.

Laboratory methods

Radiocarbon dating and spheroidal carbonaceous particles (SCPs)

The seven depths selected for radiocarbon dating were chosen following pollen analysis and their positioning at particular points of interest or on boundaries selected using the agglomerative clustering program CONISS (Grimm 1991) and by eye. An age-depth model has been produced based on calibrated radiocarbon dates obtained from plant macrofossils where possible and relative dates from SCPs. Where plant macrofossils were unavailable, peat samples were sent for analysis to Beta Analytic Miami where, following pre-treatment, plant remains were selected for dating. Calibration of the radiocarbon ages to calendar years BP was conducted using INTCAL13 (Reimer *et al.* 2013) and the age-depth model produced in OxCal version 4.2 (Ramsey 2009).

Spheroidal carbonaceous particles (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 easy and inexpensive 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 in the 1960s (Rose & Appleby 2005, Parry *et al.* 2013). The pollen preparation method used in this study does not degrade SCPs and, therefore, SCPs were counted alongside pollen.

Humification analysis

The preparation and quantification of contiguous humification samples followed a modified methodology based on that described by Chambers *et al.* (2011a). The protocol differed in that 0.1 g of sediment was used as opposed to 0.2 g and therefore one phase of filtration was removed. Humification was analysed contiguously at every centimetre and determined colorimetrically using a NaOH extract, where samples were measured in a spectrophotometer set at a wavelength of 540 nm. 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.

Pollen analysis

The preparation and quantification of pollen samples at an 8 cm resolution followed a modified methodology based on that of van Geel (1978) in Chambers *et al.* (2011b). *Lycopodium* tablets were added to the samples. 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 were represented on the pollen diagram prepared using TILIA v.1.7.16 and TILIA*GRAPH (Grimm 1991). The species were grouped by trees, shrubs, mire and heath, woodland and grassland (for woodland and grassland, these are spores and herbs, respectively). The diagram was zoned using CONISS and by noting by eye any changes in pollen abundance.

Plant macrofossil analysis

At an 8 cm resolution, 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 three 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 10 × 10 grid graticule mounted in a stereo dissecting microscope at ×10 magnification. A representative estimate of vegetative macrofossil abundance was completed using 15 replicate scans for each sample and seeds were counted as numbers rather than percentages. Plant macrofossils were identified using type collections, with reference to modern plant material sampled from the study site and using Daniels & Eddy (1985) to identify *Sphagna* and Smith (2004) to identify non-*Sphagnum* bryophytes. The abundance data were represented on a plant macrofossil diagram prepared using TILIA v.1.7.16 and TILIA*GRAPH (Grimm 1991). Zonation was based on ecological changes noted by eye.

Dupont Hydroclimatic Index (DHI)

A modified version of the weighted average Dupont Hydroclimatic Index (DHI) (Dupont 1986) was applied to the macrofossil data. In a detrended correspondence analysis (DCA) test against the DHI, Daley & 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 acrotelm and catotelm, thus indicating that DHI may yield a more meaningful result. Weights were assigned to species based on those used in Daley & Barber (2012) and Mauquoy *et al.* (2008) with allocation of monocotyledonous remains to specific classes including Class 7 for *Eriophorum vaginatum*. The DHI scores were calculated in Excel using plant macrofossil percentages, then smoothed and de-trended.

RESULTS AND INTERPRETATION

Chronology

Radiocarbon dating

The radiocarbon dates show an increasing sediment accumulation rate throughout the profile, with the exception of a slower accumulation rate towards the base of the profile between 479.5 cm and 436.5 cm (34.5 years *per* cm of peat accumulated) and a decreasing rate towards the surface (14.2 years *per* cm between 28.5 cm and 0 cm). All radiocarbon dates are in agreement and have, therefore, been accepted (Table 1).

Table 1. Details of radiocarbon dating (depth, radiocarbon date, Beta Analytic Lab. Number, calibrated ages and material used). The 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.

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

Spheroidal Carbonaceous Particles (SCPs)

The first introduction of SCPs is at 24 cm (Figure 2), where the number counted per 500 terrestrial pollen grains counted reaches 18. According to the sediment accumulation rates calculated between the radiocarbon date obtained at 28.5 cm (405 cal. BP) and the sample collection date (AD 2012), the approximate date would be *ca*. cal. AD 1700 (see above). Swindles (2010) states that an SCP rise might be expected in the mid-19th century as a result of the Industrial Revolution, but earlier SCPs are possible if local industry contributed to SCP deposition. The apparent discrepancy between the radiocarbon and SCP profiles might be attributed to possible vertical movement of SCPs (Garnett *et al.* 2000) or to the statistical error associated with the radiocarbon date obtained from 28.5 cm, although this is only ± 30 years at 1 σ. However, it is possible that the sediment accumulation rate between 28.5 cm and the mire surface from the collection date (AD 2012) was not uniform, perhaps owing to peat shrinkage or a slowing in accumulation. According to van der Plicht *et al.* (2013), ages of near-surface horizons might be estimated by extrapolating a deposition rate derived from ^{14}C dating of lower peat layers to the surface. However, this does not take into account possible changes in peat accumulation rates towards the surface which may be related to the likely lack of auto-compaction or, in drained bogs, the countervailing effect of peat shrinkage. Therefore, more reliable dating methods are required to improve the accuracy and precision of age estimates of recent peat and so the relative dates inferred from the varying counts of SCPs are perhaps more reliable (Figure 3). A second peak in SCPs (14 counted) can be seen at 8 cm, and would usually signify 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. However, the rate of accumulation has slowed between 28.5 cm depth and the surface. This can perhaps be attributed to unfavourable conditions for the accumulation of peat consistent with increasing human influence such as management practices including the grazing of sheep and burning.

Lithology

Although some vegetative remains (mainly *Sphagna* and sedges) could be identified in the field, most of the peat horizons were moderately well humified. Layers of *Sphagnum* peat (Tb) were observed between 250–243, 150–140 and 133–130 cm; *Sphagnum* was also identified from plant macrofossil analysis at these depths (Figure 4). The rest of the peat consisted mainly of 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.

Humification

The raw percentage transmission results were smoothed exponentially in MS Excel and then de-trended using a linear regression model to remove any long-term trends; hence, transmission (T) is no longer expressed as a percentage, but as a number (Figure 5).

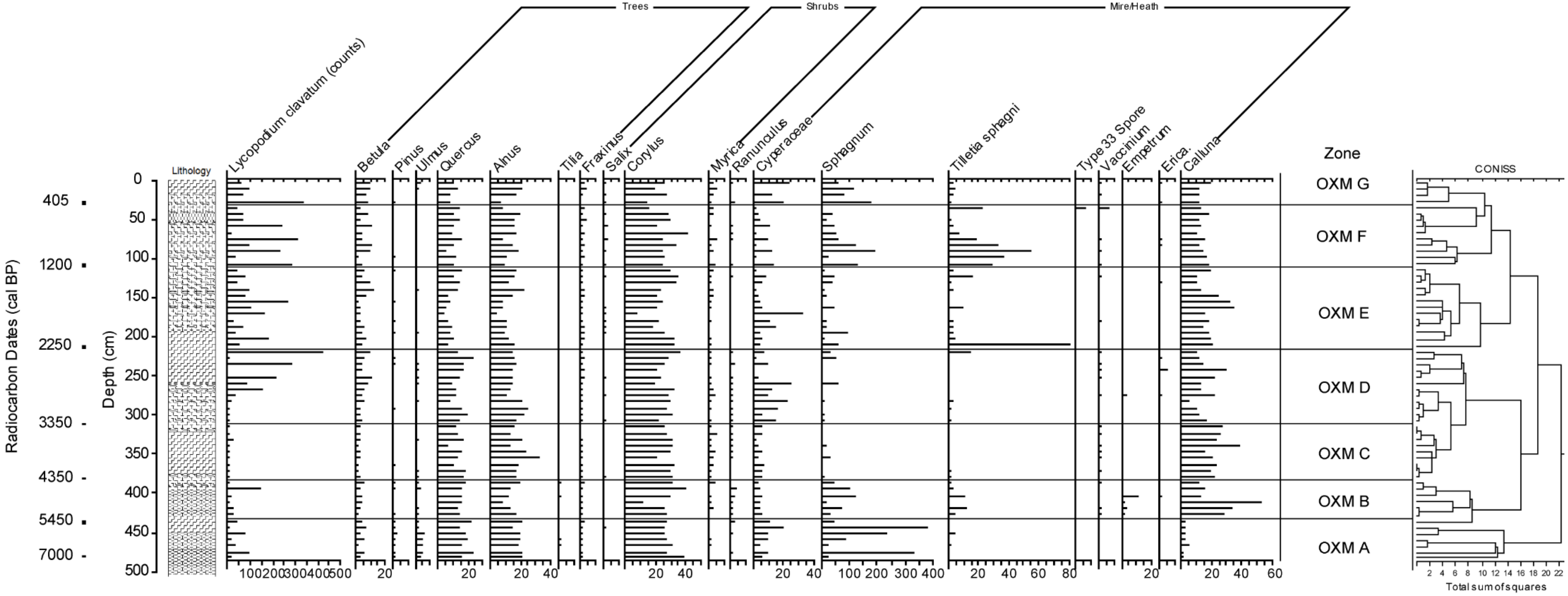

Figure 2 (part). Pollen percentages using depth (cm), radiocarbon ages (cal. BP), lithology (Troels-Smith 1955), number of charcoal fragments counted (*per* 500 counted terrestrial pollen grains), and number of SCPs counted (*per* 500 counted terrestrial pollen grains). Continued overleaf.

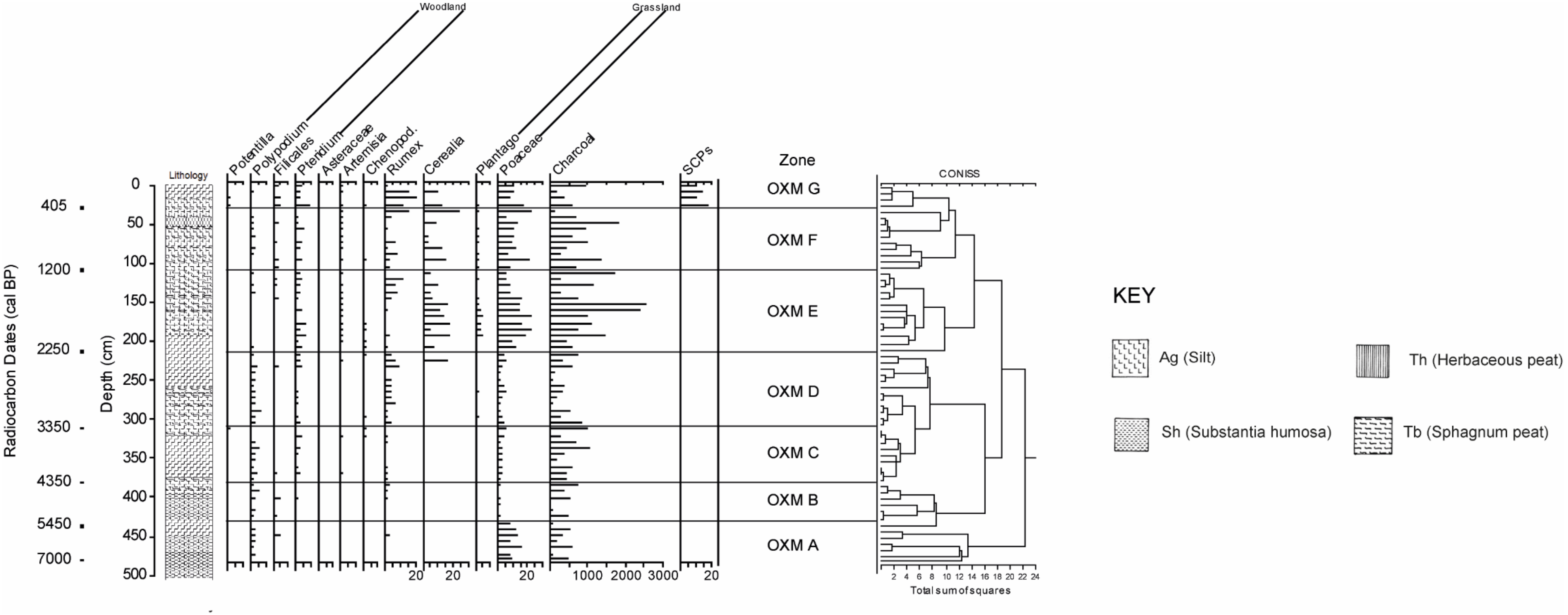

Figure 2 (continued). Pollen percentages using depth (cm), radiocarbon ages (cal. BP), lithology (Troels-Smith 1955), number of charcoal fragments counted (*per* 500 counted terrestrial pollen grains), and number of SCPs counted (*per* 500 counted terrestrial pollen grains).

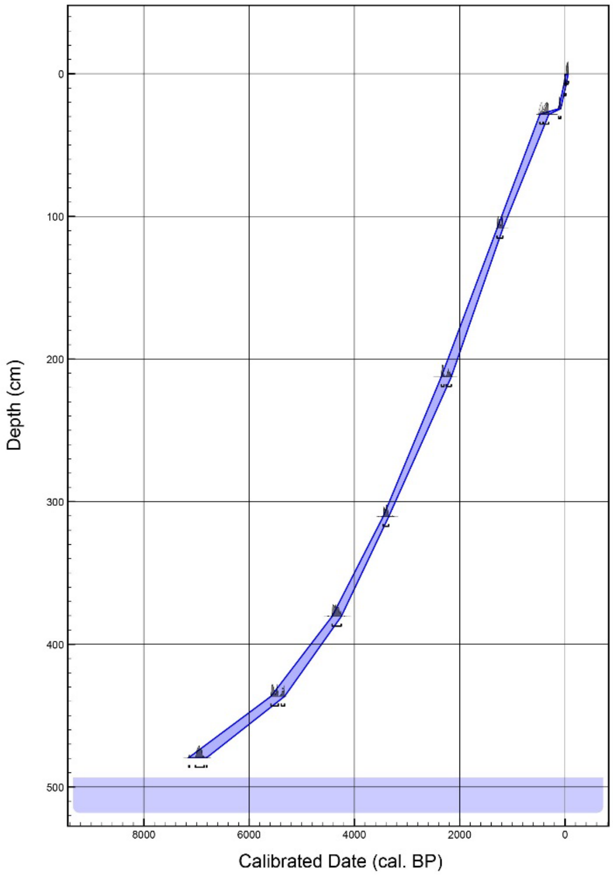

Figure 3. Bayesian (P_Sequence) age-depth model from seven accepted AMS radiocarbon dates and relative dates from SCPs constructed using OxCal version 4.2 software (Ramsey 2009) and calibrated using INTCAL13 (Reimer *et al.* 2013).

In the first zone, OXM-a, conditions appear to be generally wet in comparison to the rest of the profile, with notably wet conditions at 470 cm (6700 cal. BP), 383.5 cm (4400 cal. BP) and 410.5 cm (5900 cal. BP). Between 366 and 277 cm, Zone OXM–b (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 (2600 cal. BP) can be seen to represent dry/warm conditions. The fall in T at 139.5 cm (1400 cal. BP) represents the driest conditions in the profile and a sustained particularly dry shift can be seen in Zone OXM–d (2400–1800 cal. BP). There are three episodes of wetter conditions within Zone OXM–f (700 to -60 cal. BP/ cal. AD 1250–2012), with particularly wet conditions at 116.5 cm (1200 cal. BP) and at 28.5 cm (400 cal. BP/cal. AD 1550) consistent with the Little Ice Age.

Vegetation changes from pollen and charcoal and plant macrofossil analysis

A summary of the principal features of the pollen zonation is presented in Table 2, the principal features of the macrofossil data are summarised in Table 3, and the interpretation for both pollen and plant macrofossils is presented in Table 4.

DHI

A modified version of DHI (Dupont 1986) has been applied to the plant macrofossil data to provide a qualitative indication of changes in water table (Figure 6).

The data have been de-trended, meaning they are now displayed as lower values than the scores attributed to the species. Species indicating wet conditions are given a lower score when calculating DHI and, therefore, low values indicate wet conditions. The results suggest 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 (250 cal. BP/cal. AD 1700) (Figure 6). DHI values are particularly low between 270 and 200 cm, indicating the wettest conditions on the mire. However, this may have been exaggerated as UOM (Unidentified Organic Matter, indicative of dry conditions and therefore having a high score) is very low at this point, resulting in a much lower DHI score. Conversely, at 465 cm, 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 (1600 cal. BP–600 cal. BP/cal. AD 1350) as indicated by high values.

DISCUSSION

A summary of on-site and off-site vegetation changes and hydrological changes is presented in Table 4. Particular points for discussion are considered below.

Main ecological shifts and inferred drivers of change

At 5400 cal. BP (430 cm), the introduction of *Sphagnum* section *Acutifolia* and a decrease in *Eriophorum vaginatum* and monocots can be seen from the plant macrofossil record. Consistent with

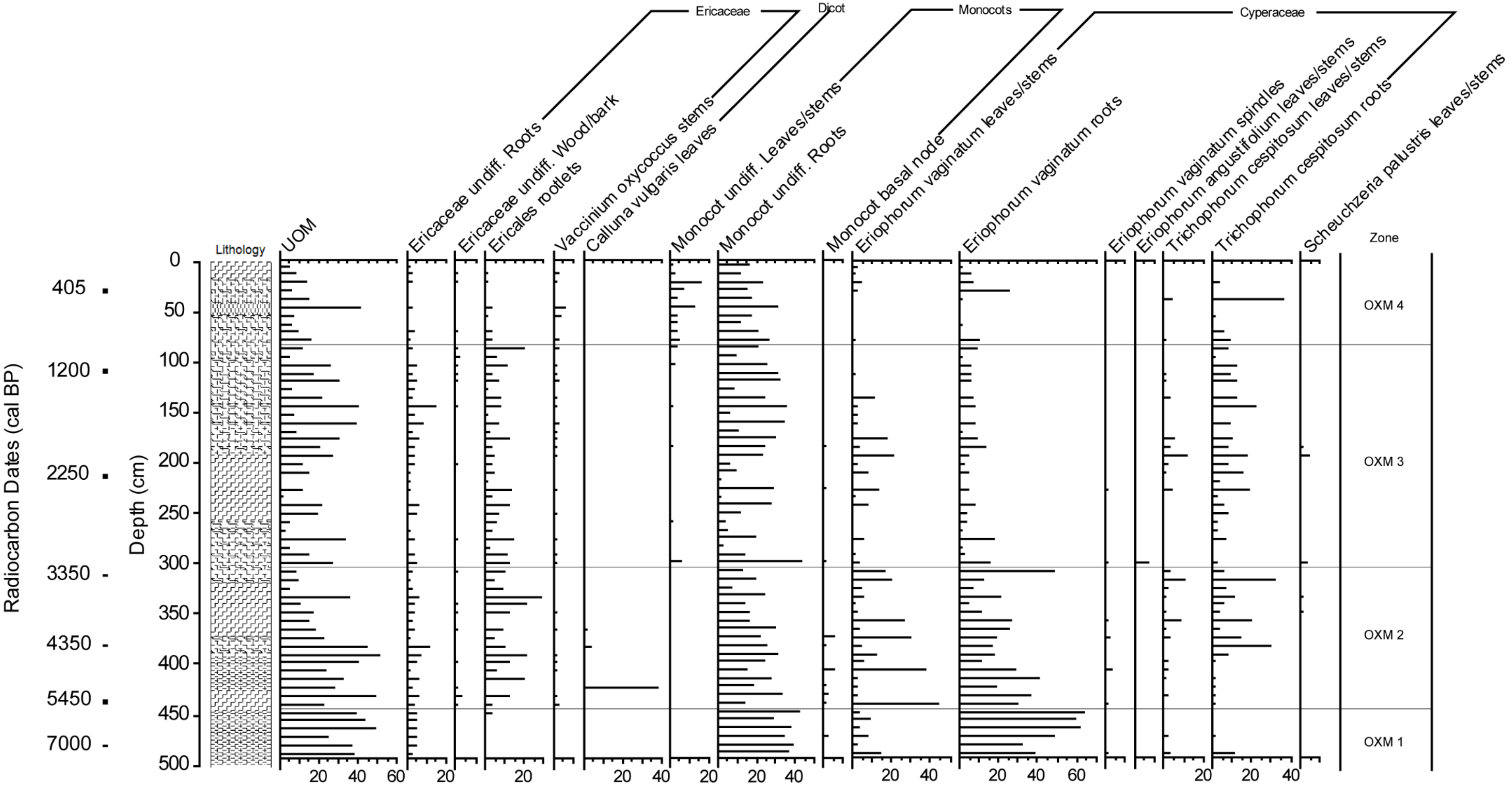

Figure 4 (part). Plant macrofossil percentages using: depth (cm), radiocarbon ages (cal. BP), and lithology (Troels-Smith 1955). Continued overleaf.

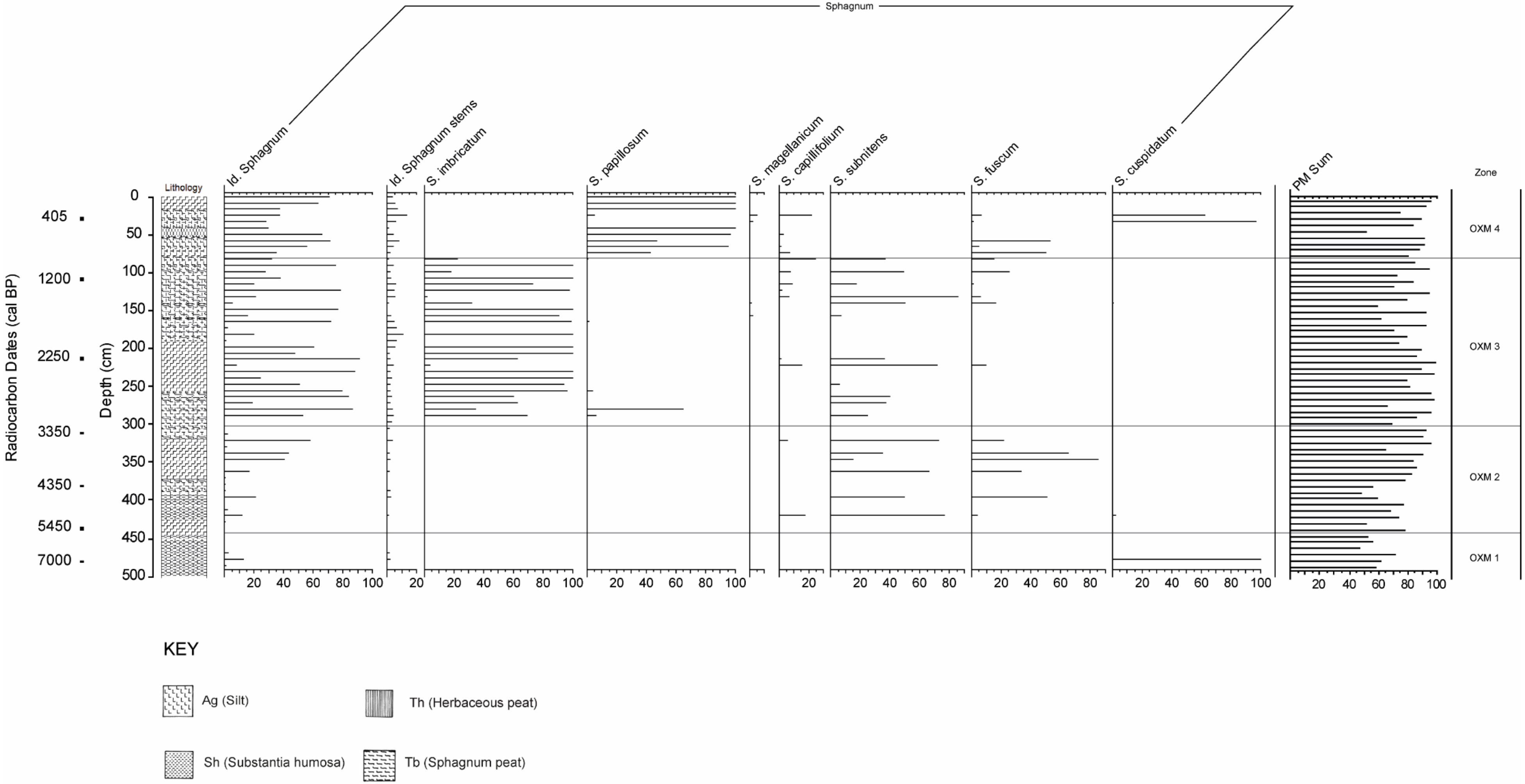

Figure 4 (continued). Plant macrofossil percentages using: depth (cm), radiocarbon ages (cal. BP), and lithology (Troels-Smith 1955).

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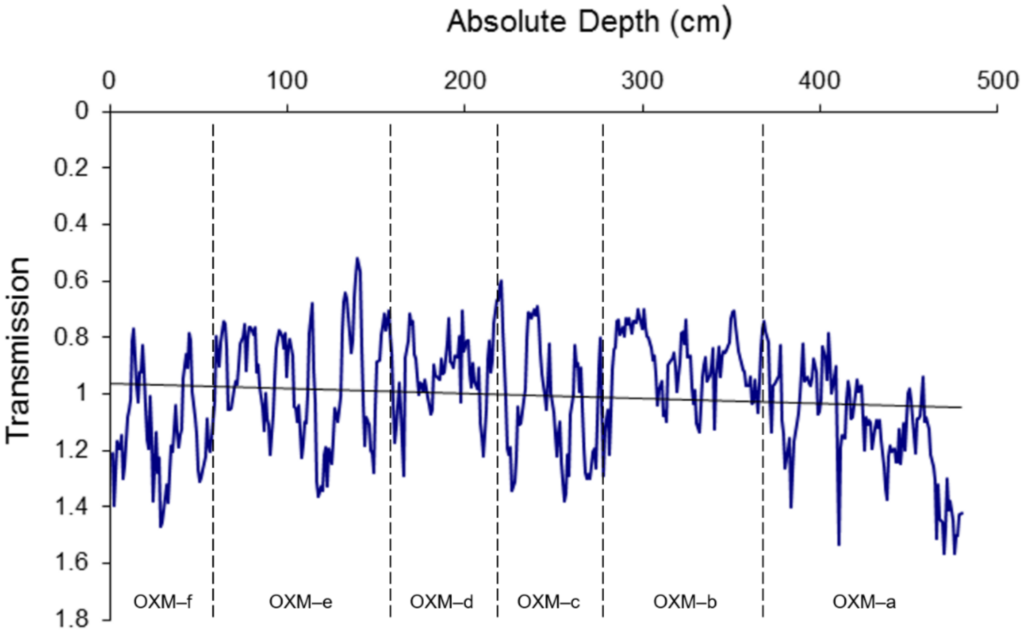

Figure 5. Humification (transmission; raw percentage light transmission results were smoothed exponentially in MS Excel and de-trended using a linear regression model to remove any long-term trends; hence, transmission is no longer expressed as a percentage, but as a number) and depth (cm).

this is the introduction of *Calluna* identified from the pollen record. Conditions prior to this are wet, as indicated by the presence of *S. cuspidatum*, low DHI values and low humification. The presence of *Calluna* indicates that the site is becoming slightly drier; this is likely to be the result of natural fluctuations as the peatland ecosystem becomes established and less waterlogged as more plant material accumulates. From *ca*. 3000 cal. BP (300 cm) *Sphagnum imbricatum* contributes to the record. Today this species is absent from most of Wales and England. Where it survives, it occupies dry hummocks, but in the past it is considered to have inhabited the wettest areas (Green 1968), and this may be the case at Oxenhope Moor. DHI values and humification are also low, consistent with a change to wetter conditions. An increase in Poaceae and charcoal, the introduction of Cerealia and a decrease in trees can be seen at 2250 cal. BP (210 cm), most probably caused by an increase in human activity with the clearing of trees for agricultural purposes. At *ca*. 1000 cal. BP (80 cm), the disappearance of *Sphagnum imbricatum* and simultaneous introduction of *S. papillosum* occurs, perhaps owing to drying of the blanket peat and resultant competition between the two species. An increase in *Rumex* pollen and the introduction of SCPs occurs at *ca*. 350 cal. BP (30 cm) and is attributed to increasing human activity with the beginning of the Industrial Revolution and increasing levels of pollutants.

The demise of *Sphagnum imbricatum*

Sphagnum imbricatum began growing at the site at *ca*. 3000 cal. BP, when conditions were somewhat wet, as indicated by low charcoal and low humification. These conditions began to change from *ca*. 2000 cal. BP, as indicated by a rapid change from low to high DHI values and a general increase in humification values. *S. imbricatum* survived these environmental changes for *ca*. 1000 years before disappearing (at *ca*. 1000 cal. BP / cal. 950 AD) and this may be owing to a delayed vegetation response and some level of resilience from *S. imbricatum* before the drying became too severe to be endured and *S. papillosum* took a competitive advantage. Conversely, the disappearance of *S. imbricatum* has been found to coincide with rising water tables in some studies (Mauquoy & Barber 1999, McClymont *et al*. 2008, McClymont *et al*. 2009), and several other studies in Britain and Europe have identified a climatic deterioration at *ca*. 1000 BP (Hughes *et al.* 2000, Barber *et al*. 2003, Langdon *et al*. 2003), suggesting increasing wetness as a cause in those particular examples.

Other research suggests that *S. imbricatum* may have disappeared as a result of increased dryness (Green 1968), which seems more likely in the case of Oxenhope Moor, given that the palaeoenvironmental evidence at the time of its demise is suggestive of dry conditions. The decline of *S. imbricatum* from two ombrotrophic mires (Bolton Fell Moss and Walton

Table 2. Pollen zone descriptions using depth (cm), radiocarbon ages (cal. BP) and humification (Wet/Dry).

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

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’ (Mauquoy & Barber 1999). It is probable that the demise of *S. imbricatum* at Oxenhope Moor was caused by similar circumstances (such as environmental stress) to those identified by Mauquoy & Barber (1999) as *S. imbricatum* is out-competed by *S. papillosum*, which can grow the same amount as *S. imbricatum* in 20 days less time (Mauquoy & Barber 1999), thus giving it a competitive advantage. *S. papillosum* is also known to occur in communities with high N deposition (Payne 2014), which may have contributed to its ability to thrive at the site, particularly since the beginning of the Industrial Revolution, when its dominance increased.

There is, however, a complicating issue. *S. imbricatum* is considered to exist in two forms or subspecies in Britain, namely a lax form in lawns and minerotrophic habitats (*S. imbricatum* ssp. *affine*; syn. *S. affine*) and a more compact form (*S. imbricatum* ssp. *austinii* syn. *S. austinii*) which is typically hummock-forming on raised and blanket mires (Hill 1988); although Andrus (1987) claimed

Table 3. Plant macrofossil zone descriptions using depth (cm), radiocarbon ages (cal. BP) and humification (Wet/Dry).

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

four forms internationally. It is likely that *S. imbricatum* ssp. *austinii* dominated at Oxenhope, although it is conceivable there may also have been *S. imbricatum* ssp. *affine*, whereas remains recorded at Walton Moss and Bolton Fell Moss were all of *S. imbricatum* ssp. *austinii*. The latter was present at Fallahoghy Bog in Northern Ireland, the decline of which Swindles *et al.* (2015) attributed to a combination of fire and soil-derived dust during agricultural intensification.

Increased anthropogenic influences

Anthropogenic influences increase from 200 cm (2100 cal. BP) as indicated by a rise in charcoal, a decrease in tree pollen, an increase in *Calluna* which dominates well-drained heaths (Clapham *et al*. 1962), and the presence of Cerealia pollen. Cerealia pollen is indicative of agriculture, the rise in charcoal is suggestive of burning (perhaps used for woodland clearance), and the rise in *Calluna* pollen is likely to have been a response to this (Atherton 2010).

A particularly marked event occurs at 150 cm (1600 cal. BP), 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

Table 4. On-site and off-site vegetation changes using age (cal. BP), pollen zones, depth (cm), interpretation using pollen, charcoal and plant macrofossil analysis and hydrological changes (DHI and humification).

		Vegetation Changes Interpreted from Pollen and Plant Macrofossil Analysis	**Hydrological Changes**	
Age (cal. BP)	**Off site**	**On site**	**DHI (Wet/Dry)**	**Humifi-cation (Wet/Dry)**
-60–350	Highest percentage of *Rumex* (~20 %) indicative of anthropogenic influence.	High number of *Sphagnum* spores (~200) and low charcoal (<1000 fragments) suggest wetter conditions, which is unusual given the prescribed burning that takes place. High percentages of *S. papillosum*, *Eriophorum vaginatum* and *Trichophorum cespitosum* from plant macrofossils suggest presence of hummocks. UOM is at its lowest throughout the profile, perhaps owing to ideal preservation conditions of the acrotelm.	Wet	Wet
350–1200	Indicators of human activity (*Rumex* and Cerealia) are relatively high, indicating anthropogenic influence on the landscape.	High numbers of *Sphagnum* and *Tilletia sphagni* spores suggest wet conditions and presence of pools (van Geel 1978), particularly at ~80 cm depth. *Sphagnum imbricatum* disappears at this depth and is replaced by *S. papillosum*. A high percentage of Poaceae pollen (~20 %) and high number of charcoal fragments suggest that grass species have benefited owing to managed burning (Yeloff *et al*. 2006, Ramchunder *et al*. 2009). *S. cuspidatum* is present briefly at ~40 cm depth (500 cal. BP), synchronous with the Little Ice Age (LIA). A return to dominance by *S. papillosum* follows the end of the LIA.	Mainly Wet	Wet
1200–2250	Cerealia and *Plantago* pollen are at their highest levels, indicative of human activity.	Poaceae pollen rises between 210 and 105 cm depth, reaching the highest concentration in the profile at ~25 % and may have been encouraged by an increase in burning. At 150 cm depth, charcoal reaches the highest level in the profile with >2500 fragments counted, synchronous with an absence of *Sphagnum* spores, which is thought to be fire sensitive (Worrall *et al*. 2007, Muller *et al*. 2012). However, *Sphagnum imbricatum* is present in the plant macrofossils.	Mainly Dry	Dry

		Vegetation Changes Interpreted from Pollen and Plant Macrofossil Analysis	**Hydrological Changes**	
Age (cal. BP)	**Off site**	**On site**	**DHI (Wet/Dry)**	**Humification (Wet/Dry)**
2250–3350	The highest levels of *Quercus*, *Alnus* and *Corylus* pollen and the lowest levels of charcoal could represent a time of generally lower levels of human activity between 290 and 201 cm depth. However, 220 cm depth sees the introduction of Cerealia pollen, which indicates the beginning of intensification in human activity.	Presence of hummock-forming species *S. capillifolium*, *S. subnitens* and *S. fuscum* can be seen. *Trichophorum cespitosum* and Ericales rootlets are also present, indicating that the water table was low enough to support the development of slightly drier hummocks and species that do not thrive when submerged below the water table. For instance, *Trichophorum cespitosum* is associated with drier areas, and with drained and grazed areas (Wilson *et al*. 2011).	Wet	Dry
3350–4350	*Alnus* reaches its highest percentage (~35 %) throughout the profile, suggesting damp conditions surrounding the mire. A possible *Ulmus* decline is also identified at 370 cm depth (4100 cal. BP).	Absence of *Sphagnum* spores, high percentages of *Calluna* pollen (~30 %), high charcoal and high UOM from plant macrofossils suggest dry conditions and perhaps wildfire. Abundance of Cyperaceae also much lower, suggesting that conditions were too dry to sustain them. Species typical of dry heath including *Empetrum* pollen and hummock-forming species of *Sphagnum* (*S. subnitens* and *S. fuscum* from plant macrofossils) are present, and *Eriophorum vaginatum* and *Trichophorum cespitosum* thrive.	Mainly Wet	Dry
4350–5450	High percentages of *Corylus* growing in the surroundings of the mire but lower *Alnus*, *Quercus* and *Betula* pollen than OXM C and OXM A.	Species typical of dry heath present including *Empetrum*, *Sphagnum* (~100 spores counted) and *Tilletia sphagni* (~10 spores counted). At 410 cm depth, the highest percentage of *Calluna* pollen (up to ~55 %) throughout the profile can be seen and is consistent with 40 % *Calluna vulgaris* remains at 405 cm depth from the plant macrofossils, which is dominant on well-drained heaths (Clapham *et al*. 1962) and dry moorland.	Dry	Dry
5450–7000	*Ulmus* pollen is present at its highest percentage, suggesting a period of low human activity, as clearance is one theory for the reduction seen in *Ulmus* from *ca*. 5700 cal. BP onwards (Peglar & Birks 1993).	From the base of the profile to ~430 cm depth, wetter conditions are suggested by the highest number of *Sphagnum* spores as well as a presence of *Sphagnum cuspidatum* from the plant macrofossils. Poaceae pollen is present at (~20 %), indicating initial colonisation before *Calluna* becomes dominant higher in the profile. High UOM in the plant macrofossils could be attributed to the less favourable conditions for preservation in the catotelm.	Wet	Wet

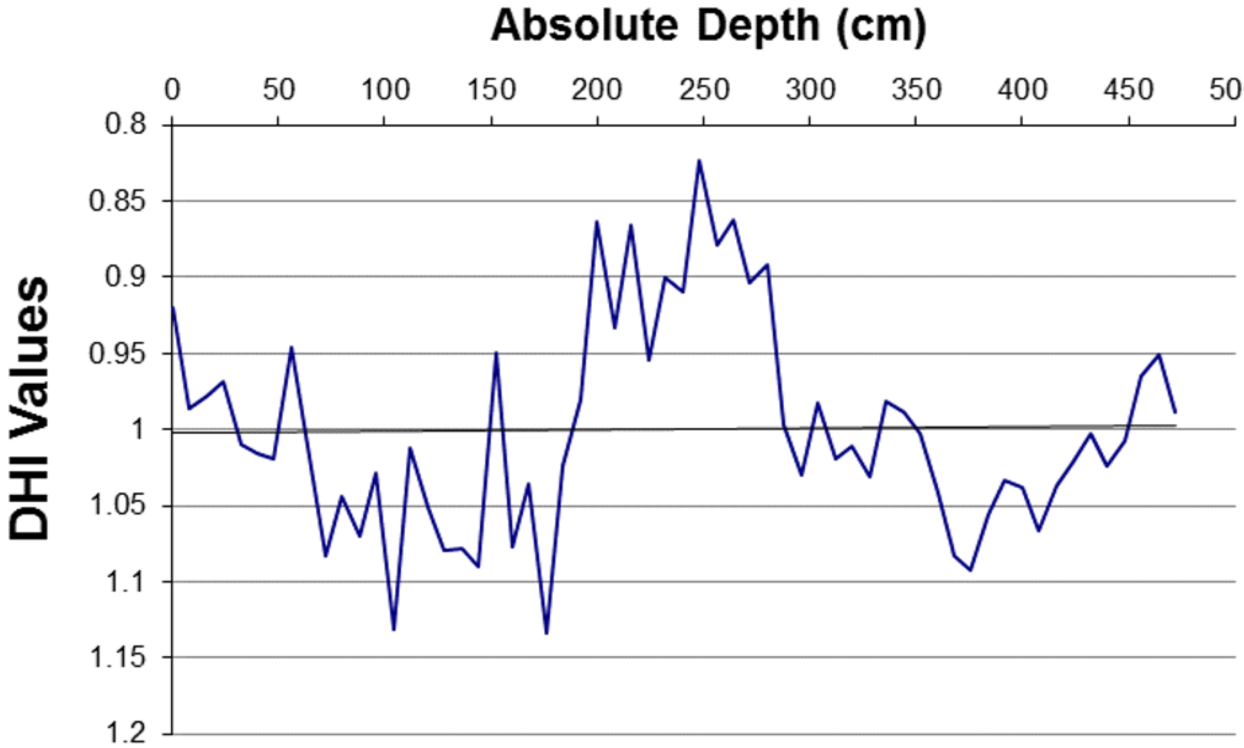

Figure 6. Smoothed and de-trended DHI curve for plant macrofossils. Indices used were: UOM 8, Ericales rootlets 8, *Vaccinium oxycoccus* 5, *Calluna vulgaris* 8, Ericaceae undifferentiated 8, monocots undifferentiated 6, *Eriophorum vaginatum* 6, *Eriophorum angustifolium* 2, *Trichophorum cespitosum* 6, *Scheuchzeria palustris* 2, *Sphagnum imbricatum* 4, *Sphagnum papillosum* 4, *Sphagnum magellanicum* 3, *Sphagnum* section *Acutifolia* 5, *Sphagnum cuspidatum* 1; based upon weights used in Daley & Barber (2012) and Mauquoy *et al.* (2008) together with knowledge of ecological tolerances and habitat preferences of each species.

at Rishworth, West Yorkshire by Bartley (1975), where a considerable change in the pollen dated to 1920 ± 80 BP is noticeable with a significant rise in Poaeceae, Cyperaceae, *Plantago lanceolata* and *Rumex acetosella* and the appearance of cereal type pollen.

Burning and draining of peat encourage species such as *Calluna vulgaris* to thrive (Worrall *et al.* 2007); 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. On the other hand, species such as *Trichophorum cespitosum* and *Eriophorum vaginatum* increase, 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 frequent drained areas on a Welsh upland bog (Wilson *et al.* 2011).

Recent (< 300 years) management

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

Despite a general reduction in charcoal in the last 300 years and an overall decreasing trend in *Calluna* throughout the Oxenhope Moor profile, recent 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.* 2007a, Chambers *et al.* 2007b).

A rise in *Rumex*, which is known to resist increasing grazing pressures (Evju *et al.* 2006), also reflective of an intensification in management practices, is evident within the last 500 years. However, the presence and increase in *Sphagnum* within the last 500 years may indicate some sort of 'recovery'. Having said this, *S. papillosum* is the dominant species and is more resilient than other species of *Sphagnum* (Mauquoy & 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.

Regional context

Studies focusing on land clearance and the use of fire in northern England provide similar findings to the present study, where increases in charcoal are consistent with decreases in tree pollen and increases in Poaceae pollen, indicating that fire during the mid-Holocene was a highly significant source of woodland disturbance. For example, 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.

Innes & 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.

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*. Research suggests that possible intensification of arable activity took place in *ca*. 2100–1800 cal. BP (Gearey *et al.* 2009). Similarly, at Oxenhope Moor, an increase in *Plantago lanceolata* can be seen from *ca*. 2000 cal. BP, in line with a possible intensification of arable activity on a wider scale during this time.

A climatic study on humification from Harold's Bog, North Yorkshire, shows evidence of a climatic deterioration at 1400 cal. BP, also identified across other sites in Europe (Blackford & Chambers 1991). Conversely, evidence from Mossdale Moor (McCarroll *et al.* 2015) 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.

Vegetation changes in Yorkshire and the surrounding areas also include responses to increasing pollution. Pollution from surrounding industrial areas is likely to have influenced Oxenhope Moor as the peat in the upper levels of the core was much darker in colour than the rest of the profile, possibly from pollutants. From 25 cm upwards, the introduction of SCPs can be seen, resultant from the increase in atmospheric pollutants. There are high levels of *Rumex* (indicative of anthropogenic influence) and Cyperaceae pollen and an increase in *Eriophorum vaginatum*, a species which frequently dominates degraded blanket mire (Chambers *et al.* 2007b). Comparisons can be made with Astley Moss and Danes Moss, north-west England, where Davis & 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 Oxenhope Moor as well as Astley Moss and Danes Moss suggests that recent changes in vegetation and testate amoebae assemblages are likely to have been influenced by increases in pollutants from the surrounding region.

Declines in *Sphagna* reported in the southern Pennines (Tallis 1985, Tallis 1987) have also been attributed to the onset of the Industrial Revolution and associated increased levels of pollutants. Bryophytes are very susceptible to atmospheric pollution, as they possess no cuticle and their growth is easily inhibited by increased levels of pollution (Rao 1982). Mackay & Tallis (1996) also state that past pollution levels may have had an ecological impact on the species composition of the Bowland blanket mires because, in the southern Pennines during the 1990s when the study was conducted, *Sphagnum* species were somewhat rare, with only *S. recurvum* described as being widespread.

These and other studies have also focused on erosion within the area. For example, it was thought unlikely that pollution was a cause for the disappearance of *Sphagna* from sites on Fairsnape Fell (Mackay & Tallis 1996). This is because *Sphagnum* did not decline across all sites in the study and the concentrations of heavy metals in the uppermost peat layers at Bowland sites that retain *Sphagnum* were not distinctly unlike those at southern Pennines sites where *Sphagna* had disappeared (Mackay & Tallis 1996). Extensive erosion was reported at Featherbed Moss (Tallis 1985) and Holme Moss (Tallis 1987) in the neighbouring Pennines; however, palaeoecological analyses in the present study have not found this to be an issue at Oxenhope Moor.

The apparent replacement of *S. imbricatum* with *S. papillosum* at 1000 cal. BP at Oxenhope Moor is much earlier than the extreme reduction in general *Sphagnum* cover found by other studies within the area, such as at Keighley Moor in northern England (Blundell & Holden 2015). The study focuses on changes in vegetation and has shown that the present vegetation at the site has only been characteristic for the last *ca*. 100 years. 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. Similarly, at Mossdale Moor, *Sphagnum* is seen to disappear from *ca*. 100 cal. BP, also attributed to management practices and an increase in charcoal fragments from the pollen record (McCarroll *et al.* 2015), thus highlighting the differences in timing that can occur between sites.

Management implications

According to the palaeoenvironmental reconstructions, trees formed a significant landscape component in the areas surrounding Oxenhope Moor in previous millennia. However, planting trees in the present day is not necessarily a functional approach to ecosystem restoration as this may increase evapotranspiration and lead to drying of the landscape. Perhaps of more importance would be continuation of filling drainage ditches to re-wet the surface of the mire and thus provide a more suitable environment for species adapted for waterlogged conditions. Additionally, *Eriophorum* species and other monocots appear to have increased recently, which is symptomatic of drying, and the spread of *Sphagnum papillosum* has only occurred during the last 1000 years. Ideally, these trends should be discouraged and, alternatively, other wet-loving species (such as *S. cuspidatum*) should be encouraged in conjunction with the re-wetting of the bog. However, if *Sphagnum* cover is desired, the palaeoecological evidence shows that *S. papillosum* and *S. fuscum* are well adapted to the environmental conditions currently prevailing at the site and are perhaps better suited for Oxenhope Moor than other *Sphagnum* species. Furthermore, it is unclear whether species such as *S. cuspidatum* would be able to thrive under current management practices and prevalent ecological conditions.

Given the changes that have occurred at this 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 better assess the ecological condition of the site in both a continuing and long-term manner. How the site is managed in terms of its intended use in the present day and the future needs to be considered. The above suggestions may be appropriate for Oxenhope Moor as it is currently being managed; however, future management strategies may focus on farming, carbon storage, water quality and water storage for flooding management, necessitating adjustment of conservation and restoration targets.

As *Sphagnum imbricatum* was present at Oxenhope Moor for two millennia, consideration could be given to translocating this species (*S. austinii*) to the site as an experiment in mire restoration. *S. imbricatum* was, for millennia in Britain and Ireland, a major peat-former (Tallis 1964, Green 1968, Mauquoy & Barber 1999, Hughes *et al.* 2008); with its demise being attributed to a variety of causes (McClymont *et al.* 2008) including increased bog surface wetness, competition, changes in nutrient and other atmospheric inputs, anthropogenic disturbance and genetic erosion (Swindles *et al.* 2015). Translocation of *S. austinii* has previously been suggested by Chambers & Daniell (2011) for south Wales and northern England where palaeodata show that it became regionally extinct as a result of human activity. They also state that, given its peat-forming ability in raised bogs in England and Wales for thousands of years in the mid to late Holocene, inter-regional translocation of this species could be justified as part of future habitat restoration.

However, Hughes *et al.* (2008) showed that *S. austinii* is only present where nitrogen loading lies below a critical threshold of 10 kg ha^{-1} yr^{-1}. They also found that the species had re-established itself during phases of reduced human activity. Furthermore, Ferguson & Lee (1983) transplanted *S. austinii* at a polluted blanket bog site in the southern Pennines and, although there was some good growth in the first year, there was none in the second. These results were compared with the outcome of transplanting at a relatively unpolluted site in the Berwyn Mountains, North Wales, where there was good growth in both years. Despite the results, Ferguson & Lee (1983) concluded that concentrations of sulphur pollutants at the time may not have entirely accounted for the failure of the transplants.

It is currently unknown whether *S. austinii* could survive prevailing conditions at Oxenhope Moor and in other areas, particularly given that its demise has been attributed to a variety of causes at different sites across the UK. At Oxenhope Moor, the palaeoenvironmental evidence suggests that its disappearance is most likely to have been caused by an increase in drying and related enhanced competition from *S. papillosum*. However, pollution may also have played a role. Having said this, several decades have passed since the experiment conducted by Ferguson & Lee (1983) and there is a possibility that the aerial deposition of pollutants has reduced following amendments to the UK Clean Air Act in 1993. Therefore, we suggest that the experimental translocation of *S. austinii* to Oxenhope Moor should be trialled on the basis that its success or failure could determine whether this species should be translocated to other blanket bog sites across the UK.

The YPP is currently restoring degraded blanket bogs using a range of techniques to restore hydrology, repair erosion features and revegetate areas of bare peat. The YPP is also investigating methods for re-establishing *Sphagnum* on large areas of blanket bog which are currently vegetated with species such as *Eriophorum vaginatum* and *Calluna vulgaris* but lack any form of functioning acrotelm and are, therefore, unlikely to be forming new peat.

A key element of this approach is to introduce *Sphagnum* species. A number of techniques are currently used including the harvesting and spreading of capitulum fragments, planting whole *Sphagnum* plants and the use of *Sphagnum* grown through micropropagation techniques, which are then planted out in various beads, gels and solutions. Micropropagation techniques enable small samples of selected or rarer *Sphagnum* species to be ‘bulked up’ into larger volumes for use in restoration projects. However, the YPP and other UK restoration projects are currently using *Sphagnum* species that are present today (mainly *S. fallax*, *S. capillifolium*, *S. palustre* and *S. papillosum*) and not the peat-forming species *S. imbricatum*. The YPP is now using the palaeoecological evidence from this and other similar projects conducted by the same authors to identify funding in order to develop a programme of research and experimental translocations. This will determine the conditions needed to enable the successful reintroduction of *S. austinii* (*S. imbricatum* ssp. *austinii*) and other *Sphagnum* species to the sites managed by the YPP.

CONCLUDING REMARKS

This palaeoecological study has allowed the reconstruction of ecological processes on a much longer timescale than is possible from monitoring studies. Human activity has been identified with an increase in intensity recognised from 2100 cal. BP, evidenced by decreasing tree pollen and increasing charcoal fragments. In particular, vegetation changes in the form of increased levels of monocots and Poaceae and reduced biodiversity have occurred over the last 1000 years, as has a change in the complement of *Sphagnum* species, specifically a change in the dominant species of *Sphagnum* from *S. imbricatum* to *S. papillosum*. Therefore, it appears that the current structure of the vegetation is determined largely by past management practices. Human influence became particularly intense following the beginning of the Industrial Revolution, when there was expansion of monocots and the graminaceous species *Eriophorum vaginatum*, as found in other similar studies (Chambers 2001, Chambers & Daniell 2011), and an intensification of burning evidenced by increasing charcoal perhaps in conjunction with draining for management purposes and grazing of sheep. The formation of *Calluna*-dominated communities emerges as part of a relatively recent shift in other studies (Chambers *et al.* 1999, Chambers *et al.* 2007a, Chambers *et al.* 2007b); however, at Oxenhope Moor, *Calluna* has apparently decreased over time.

Ecologically, the purpose of restoration has often been to return the site back to its ‘original’ state (before human intervention) (Davis & Wilkinson 2004). Rather, the site should be restored according to its intended use, with a view to encouraging the return of plant communities rich in *Sphagnum* and other wet-loving species, thus allowing it to become more biodiverse. Specifically, at Oxenhope Moor, *Sphagnum fuscum* has been present throughout the majority of the profile, as have *Eriophorum vaginatum*, *Trichophorum cespitosum* and various types of Ericaceae; and *S. papillosum* appears well adapted to current environmental conditions. Thus, perhaps restoring the site with a combination of these species might be appropriate.

Furthermore, the palaeoecological evidence has highlighted the previous importance of *Sphagnum imbricatum* as a major peat former for two millennia at the site. The authors suggest that the experimental translocation of *S. austinii* should be trialled at Oxenhope Moor using the micropropagation technique. If successful, this innovative approach has potential to initiate the formation of new peat and could, in turn, be used elsewhere.

Research questions formulated in conjunction with the YPP have enabled palaeoecological data to provide evidence for the previous vegetation, its development, past changes and timing of the changes at a degraded peatland site in Yorkshire. This research project has identified various changes in vegetation composition throughout the profile, has determined, where possible, the causes of these changes and placed this within a regional context. 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.

ACKNOWLEDGEMENTS

We thank the Yorkshire Peat Partnership for their financial support; Oliver Pritchard, James Dracott and Briony Eastabrook for assistance with fieldwork; Will Carpenter for laboratory assistance; and Richard Lindsay for his advice.

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Submitted 30 Sep 2015, final revision 12 Mar 2016
Editor: Olivia Bragg

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