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) Using palaeoecology to advise peatland conservation: An example from West Arkengarthdale, Yorkshire, UK. Journal for Nature Conservation, 30. pp. 90-102. doi:10.1016/j.jnc.2016.02.002

Official URL: http://dx.doi.org/10.1016/j.jnc.2016.02.002
DOI: http://dx.doi.org/10.1016/j.jnc.2016.02.002
EPrint URI: https://eprints.glos.ac.uk/id/eprint/3108

McCarroll, Julia and Chambers, Frank M and Webb, Julia C and Thom, T (2016). Using palaeoecology to advise peatland conservation: An example from West Arkengarthdale, Yorkshire, UK. Journal for Nature Conservation, 30, 90-102. ISSN 16171381

Journal for Nature Conservation xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.de/jnc

Using palaeoecology to advise peatland conservation: An example from West Arkengarthdale, Yorkshire, UK

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A R T I C L E I N F O

Article history:
Received 6 November 2015
Received in revised form 9 February 2016
Accepted 10 February 2016

Keywords:
Palaeoecology
Mire conservation
Peatlands
Bog ecology

A B S T R A C T

Globally, peatlands are regarded as important carbon stores and their conservation essential for ensuring continuation of terrestrial carbon storage. Numerous peatlands in particular regions of Europe have been degraded by drainage, burning, extraction, overgrazing and pollution in recent decades, often leading to erosion, loss of peat mass and a loss of a variety of flora. In the UK, some 90% of peatlands can be regarded as degraded. Implemented restoration schemes have been aimed at blocking drainage ditches, re-vegetating bare peat or changing the present vegetation assemblage to a more 'desirable' alternative. Here we use palaeoecological techniques to reconstruct the development of a blanket peatland through its entirety with a particular focus on recent land management practices and their impact on vegetation in order to determine and support restoration targets. Analysis at West Arkengarthdale, Yorkshire, UK, shows that the present vegetation is not characteristic and has only been present for c. 200 years. Peat has been developing at the site for approximately 6700 years with *Sphagnum* particularly abundant between 0–40 cm depth (present day—450 cal. BP) and 150–190 cm depth (c. 3200–3900 cal. BP) and seldom recorded elsewhere in the core. A very recent change in *Sphagnum* composition is seen towards the surface of the profile, with *Sphagnum papillosum* making up 100% of the identified *Sphagnum* in the last 50 years. Monocots, Poaceae, *Rumex* and *Polytrichum commune* increase with the beginning of the industrial revolution and an increase in charcoal fragments is indicative of increased pollution and managed burning to support grouse management. It is suggested that any intention to alter land management at the site to encourage a greater variety of *Sphagnum* species and a decrease in *Calluna* is in line with peatland development at the site over the past 450 years. This collaborative approach between research palaeoecologists and conservation agency staff has wider application elsewhere.

1. Introduction

Globally, peatlands are estimated to contain between 270 and 370 Tg of carbon (TgC; 1 Tg = 10^{12} g) as peat (Turunen, Tomppo, Tolonen, & Reinikainen, 2002) and comprise approximately 3% of the Earth's surface (Limpens et al., 2008). Peatland ecosystems are degraded by many factors including erosion, prescribed burning, climate change, over-grazing, drainage, afforestation and peat-cutting. Blanket peats form in hyper-oceanic regions with high rainfall and low summer temperatures and can cover vast landscapes. These ecosystems are anoxic with low pH and nutrient availability and therefore plant and microbial life are adapted to these conditions. Plant productivity exceeds soil organic matter decomposition, so carbon is sequestered over time (Gallego-Sala & Prentice, 2013). Blanket peats are found across the globe in the high-latitude, oceanic fringes of all continents and it is estimated that 10–15% of global blanket bog is located in the British Isles (Tallis, Meade, & Hulme, 1997). Blanket peatland covers 1.5 million hectares in the UK with approximately 14% of this in England (Jackson & McLeod, 2000). These areas act as a net carbon sink and are the largest terrestrial carbon reserves in the UK (Blundell & Holden, 2015). Not only are UK peatland ecosystems considered to be of national and international importance (Lindsay et al., 1988; Bain et al., 2011) because they provide such an important terrestrial carbon storage but also because they also provide maintenance of biodiversity and protection of water resources (Drew et al., 2013; Lindsay et al., 1988).

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http://dx.doi.org/10.1016/j.jnc.2016.02.002
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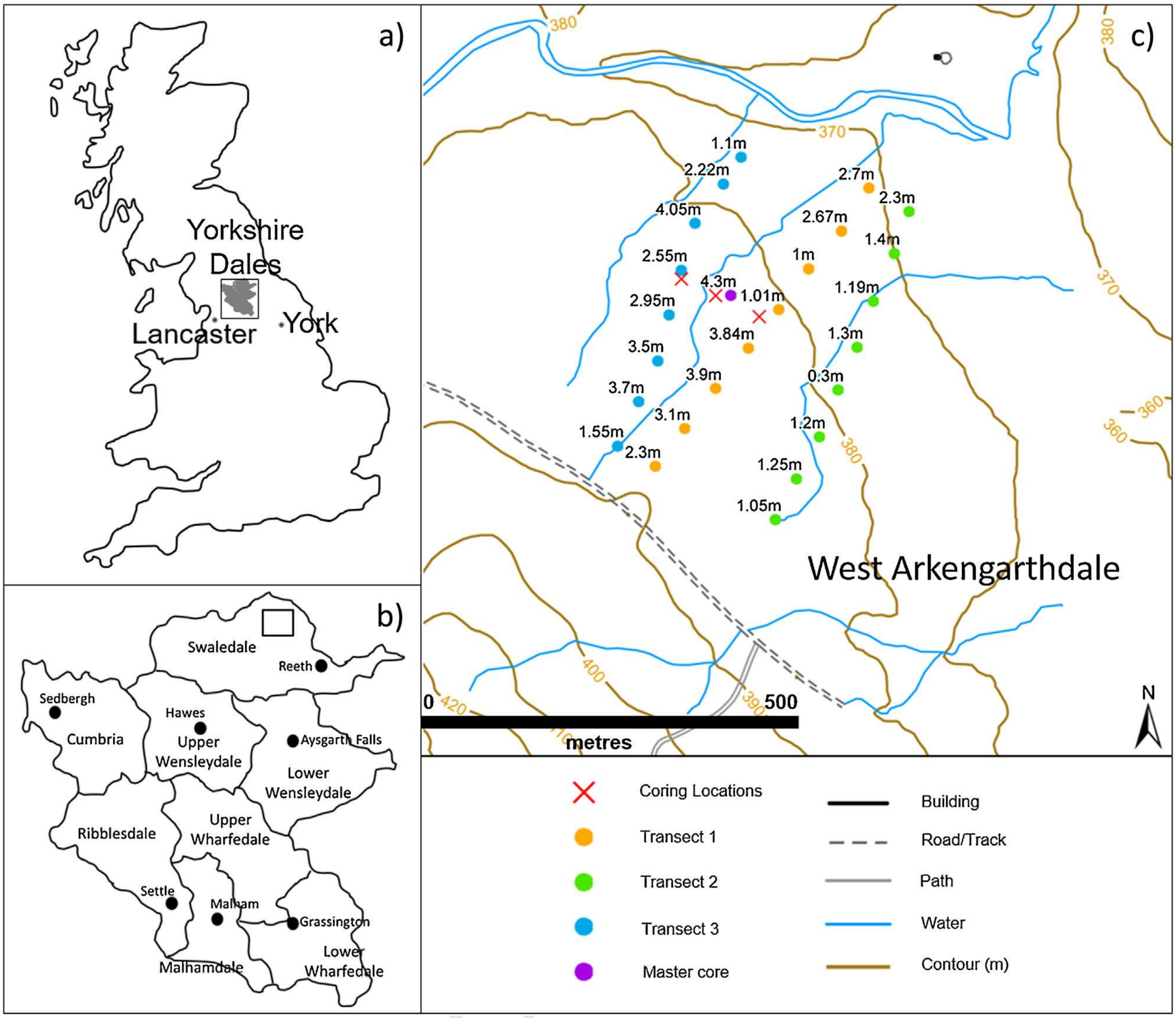

Fig. 1. (a) Map of United Kingdom showing location of the Yorkshire Dales in relation to the cities of Lancaster and York. (b) Map of the Yorkshire Dales showing location of Reeth, Swaledale and site location. (c) Map of West Arkengarthdale showing exact coring location at latitude: 54.458815N, longitude: −2.067067W.

1.1. Peatland degradation

Blanket mires are particularly vulnerable to degradation and this has become widespread in parts of the UK uplands. Degradation is caused by a number of factors including blanket peat erosion, which is a three-stage process beginning with a disruption of the vegetation cover, leaving peat exposed. This is followed by reduced cohesiveness of the exposed peat caused by frost action and drought, leaving the peat surface layer easily eroded by wind, water or oxidation (Yeloff , Labadz, & Hunt, 2006).

Tallis published a series of papers on peat erosion in the Pennines with extensive erosion being reported at Featherbed Moss (Tallis, 1985) and Holme Moss (Tallis, 1987) with the intention of informing management. Mackay and Tallis' (1996) have also focussed on erosion within the area with a study on the disappearance of *Sphagna* from sites on Fairsnape Fell, demonstrating the extent of the issue, specifically in the Pennines. Peat erosion can be worsened by over-grazing by sheep and studies have shown that on blanket mire, keeping more than one sheep per hectare increases the area of bare ground, carrying an increased risk of damage by erosion (Cooper, McCann, & Hamill, 2001). However, it is important to consider that the effect may vary depending on the breed and age of the sheep and the timing of grazing.

A contentious current issue in nature conservation in the UK is the prescribed burning of blanket bog, which has been used to manage vegetation growth in these ecosystems for centuries. However, its use has increased over approximately the last 200 years for both sheep and grouse management (Muller et al., 2012). Continued 'Global Warming' and the subsequent increase in evapotranspiration may well lead to lowered water tables in peatlands and an increase in wildfire frequency (Hogg, Lieffers, & Wein, 1992), particularly given that average daily temperatures are projected to increase by 1.8 °C by the 2050s for the South Pennines, Yorkshire Dales and North York Moors (Yorkshire-Futures et al., 2009). Furthermore, changes in precipitation patterns and warming are expected to affect peat bog vegetation composition and thereby its long-term carbon sequestration capacity.

Peatlands are naturally rich in organic acids but are also at risk from acid rain, particularly those in close proximity to industrial areas. Increases in sulphur (SO_2, H_2SO_4 and SO_{42}) deposition (Ferguson, Lee, & Bell, 1978) over 200 years of industrialisation have been linked with losses of bryophytes and a decrease in species diversity, particularly since the mid-19th century. Recent studies

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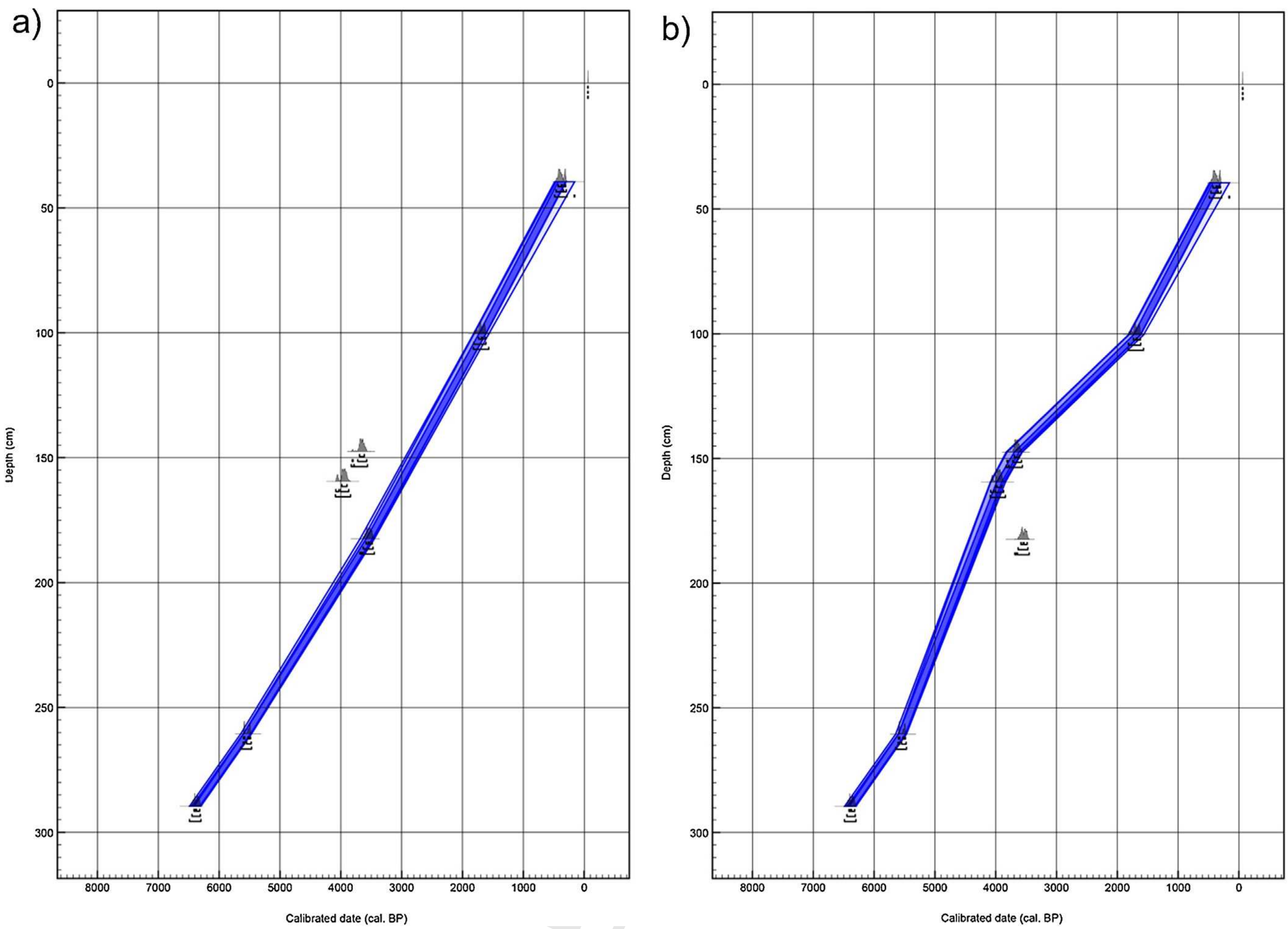

Q4 **Fig. 2.** (a) Bayesian (P_Sequence) age–depth model from five accepted and two rejected (excluded from blue line) AMS radiocarbon dates. (b) Bayesian (P_Sequence) age–depth model from six accepted and one rejected (excluded from blue line) AMS radiocarbon dates; both constructed using OxCal version 4.2 software (Ramsey, 2009) and calibrated using INTCAL13 (Reimer et al., 2013). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

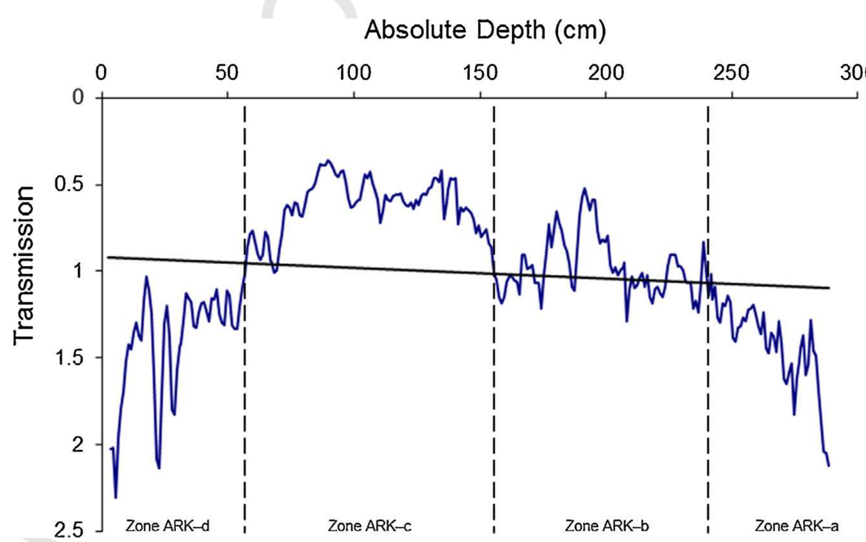

Fig. 3. Humification (transmission; raw percentage light transmission results were smoothed exponentially in MS Excel and de-trended using a linear regression model to remove any long-term trends; hence, transmission is no longer expressed as a percentage, but as a number) and absolute depth (cm).

have also shown that the degree of acid rain deposition onto peat bogs may be particularly important in regulating the production and emission of CH_4 from peat (Nedwell & Watson, 1995; Watson & Nedwell, 1998; Gauci, Dise, & Fowler, 2002). Peat is often cut to be used as fuel and the amount of peat cut from peatlands was much less until the introduction of tractor-powered peat-harvesters in the early 1980s in Northern Ireland. The effects of peat cutting using machinery include a reduction in canopy height, biomass

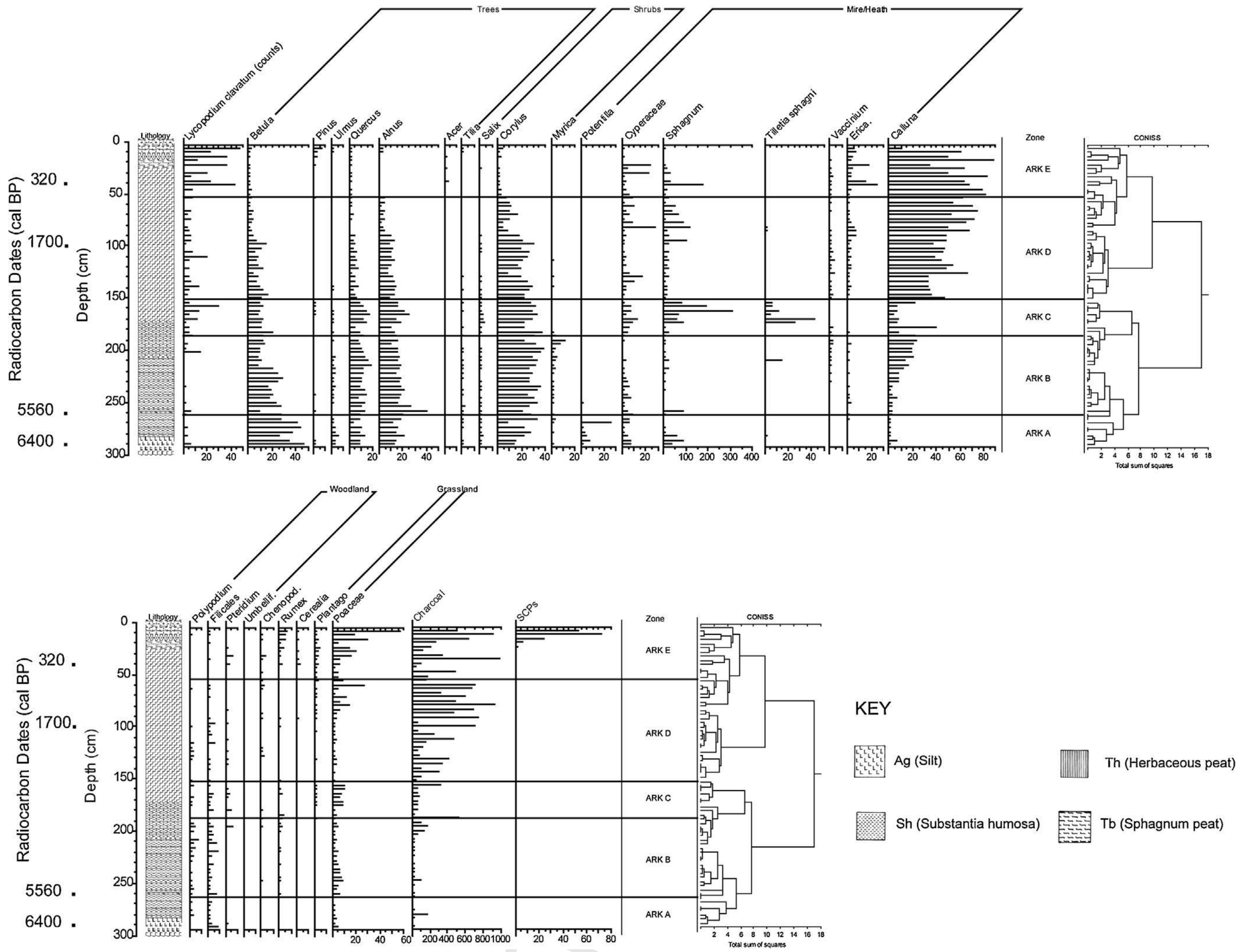

Fig. 4. Pollen percentages using: depth (cm), radiocarbon ages (cal. BP), lithology (Troels-Smith, 1955), number of charcoal fragments counted (per 500 counted terrestrial pollen grains), and number of SCPs counted (per 500 counted terrestrial pollen grains).

and species diversity. Few peatlands recover following such disturbance with many remaining barren of vegetation 10 years after harvesting ends (Cooper et al., 2001). Peatlands may also be subject to deliberate drainage, with one of the main aims being to benefit the growth of *Calluna vulgaris* to improve the habitat for grouse and sheep; however, any enhancements in the nutritional value of *C. vulgaris* can be counterbalanced by the decline in cover and the spread of unpalatable grasses. Investigations have also shown that plant species dependent on high water tables such as *Sphagnum* spp. have a lower abundance when closer to drains (Ramchunder, Brown, & Holden, 2009).

Many of the factors leading to the degradation of peatlands are interlinked, with drainage and over-grazing leading to erosion and wildfire. This in turn increases the rate of erosion, leading to increased carbon dioxide and methane entering the atmosphere and increased dissolved organic carbon (DOC) from peatlands entering water sources (Page et al., 2002). 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 (Davies & Bunting, 2010). Current restoration techniques include blocking drains and re-vegetating; however, how these areas are re-vegetated, to what end, and with which species is where palaeoecological studies can assist.

1.2. Using palaeoecology to advise conservation

It has been suggested that long-term datasets generated through palaeoecological techniques could be of use in nature conservation (Birks, 1996, 2012; Froyd & Willis, 2008; Davies & Bunting, 2010; Hjelle, Kaland, Kvamme, Lødøen, & Natlandsmyr, 2012; Muller et al., 2012; Willis, Bailey, Bhagwat, & Birks, 2010; Wilmshurst et al., 2014). Palaeoecology can provide the long-term ecological background to help answer questions covering the more recent time periods of principal interest to conservationists (Chambers, Mauquoy, & Todd, 1999; Chambers & Daniell, 2011; Seddon et al., 2014). Palaeoecological approaches can assist when considering the trajectories and driver of changes through time, can aid understanding of the nature of any departure from 'normal' conditions, and provide early warnings of future change (Finlayson, Clarke, Davidson, & Gell, 2015).

Early examples of palaeoecological studies to aid conservationists in the UK include research in the 1970s in Cumbria (Oldfield, 1970) and Upper Teesdale (Turner, Hewetson, Hibbert, Lowry, & Chambers, 1973) with a pause in such research during the 1980s before it resumes in the 1990s with a paper by Huntley (1991), followed by work on Exmoor (Chambers et al., 1999), in Wales

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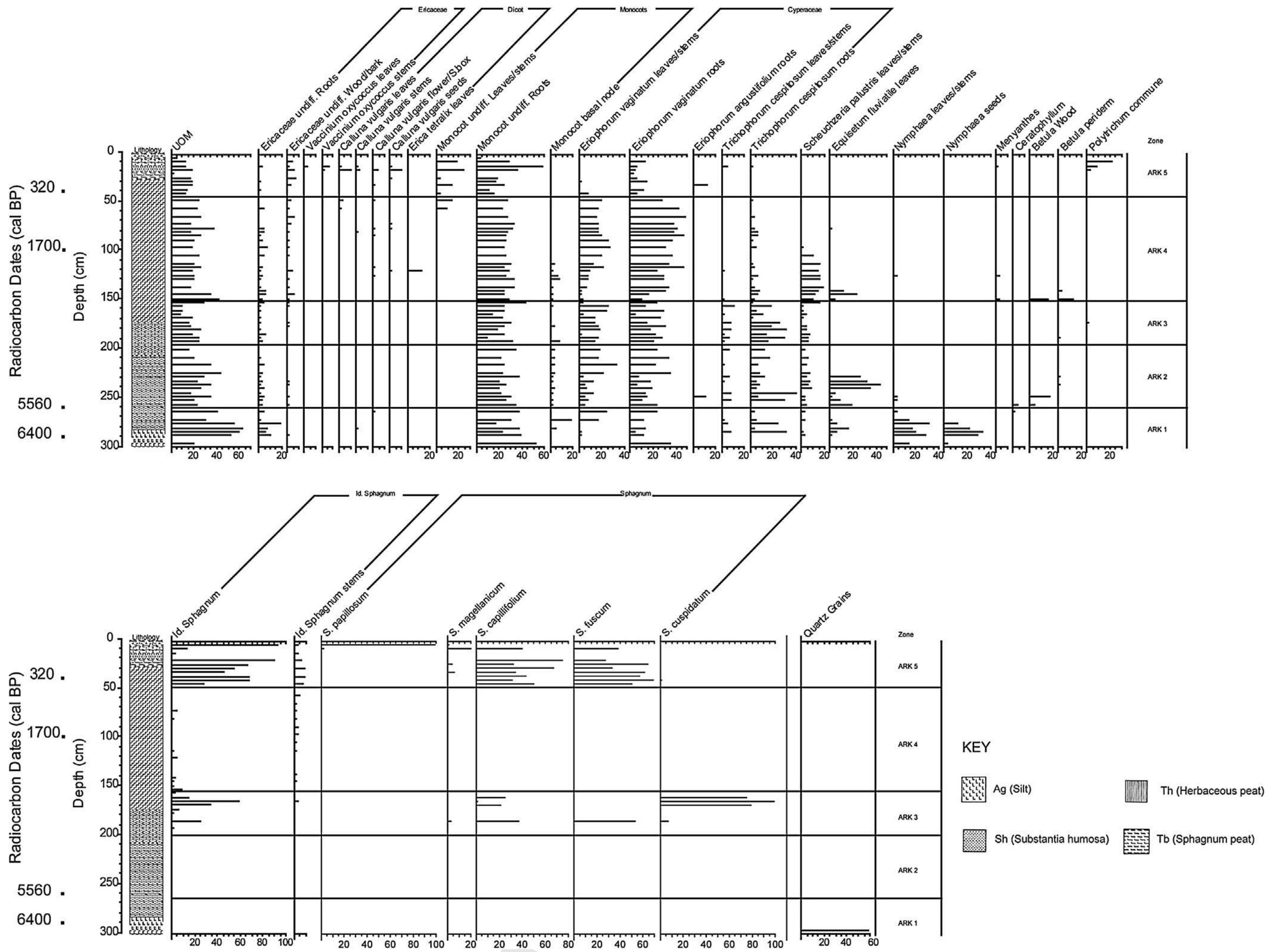

Fig. 5. Plant macrofossil percentages using: depth (cm), radiocarbon ages (cal. BP), and lithology (Troels-Smith, 1955).

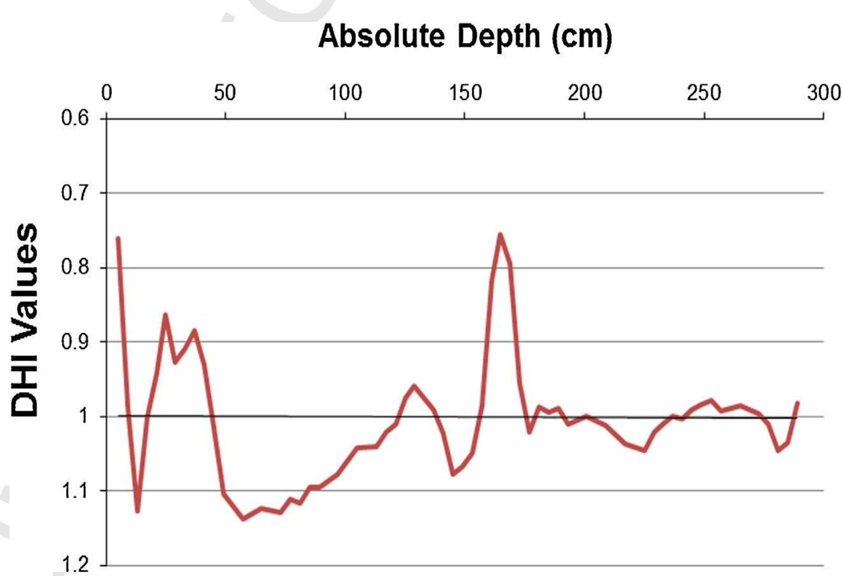

Fig. 6. Smoothed and De-trended DHI curve for plant macrofossils. Indices used were: UOM 8, Ericales rootlets 8, *Vaccinium oxycoccus* 5, *Calluna vulgaris* 8, Ericaceae undifferentiated 8, monocots undifferentiated 6, *Eriophorum vaginatum* 6, *Eriophorum angustifolium* 2, *Trichophorum cespitosum* 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 and Barber (2012) and Mauquoy et al. (2008) and knowledge of ecological tolerances and habitat preferences of each species.

(Chambers, Mauquoy, Cloutman, Daniell, & Jones, 2007; Chambers, Mauquoy, Gent et al., 2007), Scotland (Davies & Watson, 2007), Northern England (Chambers & Daniell, 2011) and the Pennines (Davies, 2015), with encouraging results. More recently, three further studies have been conducted in Yorkshire at Keighley Moor, by Blundell and Holden (2015); at Mossdale Moor, by McCarroll, Chambers, Webb, and Thom (2015); and at Oxenhope Moor by McCarroll (2015). The present vegetation at Keighley Moor has only been characteristic for the last c. 100 years (Blundell & Holden, 2015), whereas at Oxenhope Moor, human influence began 2100 cal. BP with the current vegetation being characteristic for 300 years (McCarroll, 2015) and at Mossdale Moor, a long history of human influence was observed with an intensification in human activity where a substantial charcoal increase is interpreted as recent (<450 years) management practices (McCarroll et al., 2015).

1.3. Site selection and description

The present study reports the results of palaeoecological reconstructions of West Arkengarthdale, Yorkshire, UK. This was conducted in collaboration with the Yorkshire Peat Partnership (YPP: 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.

The site was selected for palaeoecological analysis by the YPP based on the current judgement that it occupies a more desirable state when compared to other sites managed by the organisation. The site was also assessed by the authors to establish whether it was suitable for palaeoecological analysis. This study aims to aid understanding of vegetation changes throughout the peat profile, what might have caused these changes and how this information can aid conservation and restoration projects.

West Arkengarthdale is blanket mire at 380 m altitude located north-west of Reeth in North Yorkshire at latitude: 54°27′31.734″N, longitude: −2°4′1.4412″W (grid reference: 54.458815N, −2.067067W) (Fig. 1). A vegetation survey conducted during fieldwork identified that the modern-day peat supports vegetation characteristic of NVC type M20 (*Eriophorum vaginatum* blanket and raised mire) (Rodwell, 1998). Species identified include *E. vaginatum*, *Sphagnum* (including *S. cuspidatum* in pools), *C. vulgaris*, *Vaccinium oxycoccus*, *V. vitis-idaea*, *Polytrichum commune* and *Potentilla erecta*.

2. Methods

2.1. Field sampling strategy

The method used in the ACCROTELM Research Project (ACCROTELM, 2006; De Vleeschouwer, Hughes, Nichols, & Chambers, 2010) formed the basis of the field sampling strategy used in this project. Significant morphological differences can occur across blanket bogs and so to avoid this, transects of cores were extracted across the site and described using the Troels-Smith (1955) method, which in turn allowed the selection of the deepest point of the bog. The master core was taken in a lawn zone located by the multiple cores and adjacent, overlapping cores were extracted using a 5 cm diameter Russian corer, and also described using the Troels-Smith (1955) method. The samples were transferred to labelled plastic guttering, wrapped in airtight carbon-stable bags and stored in the laboratory fridges at 4 °C.

2.2. Laboratory methods

2.2.1. Radiocarbon dating and spheroidal carbonaceous particles (SCPs)

Two age-depth models have been produced in OxCal version 4.2 (Ramsey, 2009) based on calibrated radiocarbon dates obtained from plant macrofossils where possible (Fig. 2). Where this was not possible, peat samples (measuring approximately 4 cm^3) were sent to Beta Analytic Miami for analysis, where following pre-treatment, plant material (as opposed to bulk organic carbon) was selected for dating. Calibration of the radiocarbon ages to calendar years BP was conducted using INTCAL13 (Reimer et al., 2013) in OxCal version 4.2 (Ramsey, 2009). The depths selected for radiocarbon dating were chosen following pollen analysis and their positioning on boundaries selected by CONISS (an agglomerative cluster analysis technique which compares the total pollen assemblage of each sample with that of its stratigraphic neighbours) and by eye, or at particular areas of interest.

Spheroidal carbonaceous particles (SCPs) are small spheroidal particles of carbon produced from the incomplete combustion of fossil fuels (Parry, Charman, & Blake, 2013). They are emitted to the atmosphere and dispersed over wide geographical areas and as a consequence, they have been recorded in many areas of the world including those remote from sources. They are not produced by any natural processes and therefore are unambiguous indicators of atmospheric deposition from power generation and other industrial emissions (Rose & Appleby, 2005). SCPs are well preserved in peat sediments and have proved useful for reconstructing atmospheric pollution histories and as age-equivalent markers for dating stratigraphic sequences covering the last 150 years (Swindles, 2010). They 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 SCPs were counted alongside pollen (as the pollen preparation method used in this study does not degrade SCPs) and therefore the results are displayed on the pollen diagram (Fig. 4).

2.2.2. Humification analysis

A modified methodology based on that described by Chambers, Beilman, and Yu (2011) was used for the preparation and quantification of humification samples where 0.1 g of sediment is used as opposed to 0.2 g and therefore one phase of filtration has been removed. Humification was analysed contiguously at every centimetre and the data were then smoothed and de-trended in MS Excel and a horizontal trend line is displayed indicating the difference between wet and dry shifts (Fig. 3).

2.2.3. Pollen analysis

A modified methodology based on that of van Geel (1978) in Chambers, van Geel, and van der Linden (2011) was used in the preparation and quantification of pollen samples where *Lycopodium* tablets were added to the samples before they were boiled in 10% sodium hydroxide. The residue was then washed through a fine (180 μm) sieve and the samples were acetolysised using acetic anhyadride and sulphuric acid (9:1). Hydroflouric acid was used when the sediment sample contained clay or minerals. Pollen grains were identified using a reference collection of type slides at the University of Gloucestershire and Moore, Webb, and Collinson (1991). The pollen sum (500 grains) included pollen of trees, shrubs, ruderals and cultivated plants. The abundance data are represented on the pollen diagram prepared using TILIA v.1.7.16 and TILIA*GRAPH (Grimm, 1991) (Fig. 4) where the species were grouped by trees, shrubs, mire and heath, woodland and grassland. The diagram was zoned using the agglomerative clustering pro-

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gram CONISS and by noting any changes in pollen abundance by eye.

2.2.4. Plant macrofossil analysis

Sub-samples measuring approximately 4 cm^3 were taken at a 4 cm resolution through the total depth of the core and sieved through a 125 μm mesh with a standard 5 l volume of tap water. The samples were transferred to three glass petri dishes and spread out to form a monolayer and quantified using the quadrat and leaf count (QLC) method described by Barber, Chambers, Maddy, Stoneman, and Brew (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. Fifteen scans were completed for each sample to provide a representative estimate of vegetative macrofossil abundance. Seeds were counted as numbers rather than percentages and plant macrofossils were identified using type collections and with reference to modern plant material sampled from the study site. Daniels and Eddy (1985) was used to identify *Sphagna* and Smith (2004) was used for non-*Sphagnum* bryophytes. The abundance data are represented on the plant macrofossil diagram prepared using TILIA v.1.7.16 and TILIA*GRAPH (Grimm, 1991) (Fig. 5) and the plant macrofossil diagram has been sectioned into zones based on ecological changes identified by eye.

2.2.5. Dupont Hydroclimatic Index (DHI)

A revised version of the weighted average Dupont Hydroclimatic Index (DHI) (Dupont, 1986) was applied to the plant macrofossil data. This approach was used as in a test of detrended correspondence analysis (DCA) against the DHI, Daley and Barber (2012) found that DHI delivered a curve that correlated better with changes in independent proxy data from the same core, where the record incorporated data from both the upper and lower peat types, therefore demonstrating that DHI can produce a significant hydroclimatic result. Weights were assigned to species based on those used in Daley and Barber (2012) and Mauquoy, Yeloff, Van Geel, Charman, & Blundell (2008) with monocotyledonous remains allocated to explicit classes, including class 7 for *E. vaginatum* remains. The DHI scores were calculated in Excel using plant macrofossil percentages. The results were then smoothed and de-trended and are presented in Fig. 6.

3. Results and interpretation

3.1. Lithology

The lithology is shown in Figs. 4 and 5 alongside the pollen and charcoal and plant macrofossil results, following the Troels-Smith (1955) method.

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

3.2. Chronology

3.2.1. Radiocarbon dating

It is possible that the date obtained at 147.5 cm depth is too young, as the sample selected may have contained rootlets that contaminated the peat from a higher level (Table 1). However, if the date at 182.5 cm is correct, then both dates at 147.5 cm and 159 cm depth are too young. It is statistically more likely that one date is incorrect as opposed to two. The age-depth model produced excluding the two dates at 147.5 cm and 159.5 cm depth shows a steady accumulation rate (Fig. 2a) whereas the age–depth model produced including the two dates does not (Fig. 2b). The sample from 159.5 cm depth was obtained using plant material, likely to include *Sphagnum* leaves as approximately 20% of plant macrofossil samples at this depth contained *Sphagnum*. This is perhaps more reliable than dates obtained using wood or plant material from peat since *Sphagnum* macrofossils provide excellent material for ^{14}C sample selection. They can be easily selected and do not provide the same problems for dating such as *E. vaginatum*, where younger roots can penetrate deeper peat causing contamination (Piotrowska, Blaauw, Mauquoy, & Chambers, 2011).

It is also worth considering that although age generally increases with depth, this is not always the case. For example, Ashmore et al. (2000) theorised that an inverted age–depth model from Borve Valley, Barra, Outer Hebrides may have been caused by 'old' carbon being incorporated as a result of hypothesized ancient transporting events such as rapid mass-movement or fluvial activity. However, the lithological evidence does not suggest that this has taken place at West Arkengarthdale. Given that the reasoning behind the production of both age–depth models is valid and that they are in agreement on ages towards the surface (which is of primary concern given the conservation nature of this paper), both will be used in the interpretation of results.

3.2.2. SCPs

The introduction of SCPs can be seen at 20.5 cm depth (Fig. 4), dated to c. cal. AD 1815 using the radiocarbon age–depth models (Fig. 2). The SCP record usually starts in the mid-nineteenth century (Swindles, 2010) but given the error from the radiocarbon dates (±30 years at 1 σ) and varying times that the industrial revolution started across the UK, this could be accurate. The biggest peak can be seen at 8.5 cm depth, dated to cal. AD 1930 using the radiocarbon age–depth models (Fig. 2), yet, the biggest rise in SCPs normally correlates with the post second world war industrial boom (Swindles, 2010) and so again, this would appear to be slightly early according to radiocarbon dates. The discrepancy between the radiocarbon and SCP profiles could be attributed to possible vertical movement of SCPs (Garnett, Ineson, & Stevenson, 2000); however, the radiocarbon dates are calculated based on a uniform sediment accumulation rate of peat between 39.5 cm depth and the mire surface from the collection date (AD 2012). It is possible that the accumulation rate varied and so the relative dates inferred from the varying counts of SCPs are perhaps more reliable. This is also supported by an increase in *Pinus* (Fig. 4), usually dated to the beginning of the 19th century (Appleby, Shotyk, & Fankhauser, 1997) at 22 cm depth. The SCPs then decrease at 4.5 cm depth, which is interpreted as a decrease following the implementation of the first Clean Air Act in 1956, and stricter guidelines in 1968 and 1993. There was not sufficient peat available to analyse the surface sample.

3.3. Humification

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

Zone ARK–c is much drier in comparison to ARK–b with values rarely nearing the trend-line, with the exception of 70 cm depth, where values reach 1. Dry conditions are sustained between

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Table 1
Radiocarbon dates: depth (cm), radiocarbon date (BP), beta analytic lab number, calibrated ages (cal. BP) and material used. *Possible outliers. Radiocarbon dates were calibrated using OxCal version 4.2 (Ramsey, 2009), error ± 30 years at 1 σ. **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
39.5	300 ± 30 BP	BETA-381604	485 (320.5) 156	plant macrofossils
100.5	1780 ± 30 BP	BETA-385277	1822 (1696) 1570	plant macrofossils
147.5	3410 ± 30 BP*	BETA-379805	3828 (3695.5) 3563	wood
159.5	3640 ± 30 BP*	BETA-385278	4089 (3965) 3841	plant material**
182.5	3320 ± 30 BP*	BETA-379806	3685 (3567.5) 3450	plant material**
260.5	4820 ± 30 BP	BETA-379807	5645 (5556.5) 5468	plant material**
289.5	5610 ± 30 BP	BETA-379808	6487 (6393.5) 6300	plant material**

c. 3800/2800–650 cal. BP depending on which age model is used (Fig. 2).

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

3.4. 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 interpretations for both pollen and plant macrofossils are presented in Table 4.

3.5. DHI

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

Table 2
Pollen zone descriptions using: depth (cm), radiocarbon ages (cal. BP) and humification (wet/dry).

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

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

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

The data have been de-trended, therefore meaning they are now displayed as lower values than the scores attributed to the species (Fig. 6). Low values indicate wet conditions and these suggest that the mire was wet at 289 cm, 270–240 cm, 185–180 cm, 165 cm, 125 cm, 33–21 cm and 9–5 cm depths. Conversely, the mire was drier and/or warmer at 285–270 cm, 230–190 cm, 145 cm, 113–49 cm and 13 cm depths. The DHI curve shows similar results to the humification curve, with the exception of the apparent identified wet shift at 125 cm depth, caused by the presence of aquatic species *Nymphaea* and *Ceratophyllum*. However, both curves agree that the mire surface was wet at 289 cm (6400 cal. BP), 270–240 cm (5800–5100/5000 cal. BP), 185 cm (4300/3500 cal. BP), 165 cm (4000/3100 cal. BP) and generally wetter from 50–0 cm depths.

4. Discussion

4.1. *Peat formation —6400 cal. BP*

The DHI values are low between 6400–6300 cal. BP (289–285 cm depth) (Figs. 2 and 6) and the presence of aquatic species *Nymphaea* plant macrofossils at these depths (Fig. 5) suggests the presence of standing water. Furthermore, the presence of quartz grains in the plant macrofossils and silt identified in the sediment description at this depth suggest that peat has not yet begun to form and so the presence of an aquatic environment is identified. All proxies are in agreement and this is interpreted as the beginning of a natural vegetation succession and initiation of the peat growth. Generally, in Great Britain and Ireland, blanket bogs mainly appeared between 7500 and 5000 BP (uncalibrated dates) (Charman, 2002) and so this date is reasonable. Conversely, warmer conditions associated with the Holocene Thermal Maximum (c. 7000–6000 BP) may have prompted the peat growth, allowing some of the water to evaporate and the standing areas of water to accumulate plant remains and eventually lead to the growth of peat found overlying the silty sediments.

4.2. *Bronze-age woodland clearance*

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

Please cite this article in press as: McCarroll, J., et al. Using palaeoecology to advise peatland conservation: An example from West Arkengarthdale, Yorkshire, UK. *Journal for Nature Conservation* (2016), http://dx.doi.org/10.1016/j.jnc.2016.02.002

Table 4
Interpretation of mire surface conditions using: depth (cm), ages (cal. BP), plant macrofossil analysis and pollen analysis and hydrological changes (humification and DHI).

Depth (cm)	Age (cal. BP)	Plant macrofossils	Pollen	Humification	DHI	Interpretation
0–50	−60–550	High *Polytrichum commune*, low *Eriophorum vaginatum* and UOM, high Ericaceae and *Calluna vulgaris*. Highest identified *Sphagnum*. *S. papillosum* present at surface, *S. capillifolium* and *S. fuscum* between 20 cm and 45 cm depth. Presence of *Eriophorum angustifolium*	High *Lycopodium* spores, high Cyperaceae, *Erica*, *Calluna*, *Rumex* and Poaceae. High *Sphagnum* at 40 cm depth. Low tree pollen. Slight rise in *Pinus* towards surface. High charcoal	High, reaching above 2. The wettest conditions in the profile	Mainly low (wet).	Wet conditions on the mire as evidenced by high *T* values, low UOM, presence of *Eriophorum angustifolium* and high *Sphagnum*. The least humified conditions on the mire although the high preservation of the acrotelm may be responsible for an aspect of this. High MS values and SCPs towards the surface indicate anthropogenic influences, as does an increase in charcoal and presence of grasses and *Calluna vulgaris*
50–150	550–3700/2800	Low identified *Sphagnum*, low *Trichophorum cespitosum*, high *Scheuchzeria palustris*, high *Equisetum fluviatile* and *Betula* towards base, high *Eriophorum vaginatum*, high Monocots and occurrence of *Erica tetralix*	Increase in *Betula*, *Quercus*, *Alnus* and *Corylus* towards base. High Cyperaceae and *Calluna*. High *Sphagnum* at top of zone but decrease towards base. High charcoal	As low as 0.3, the driest conditions in the profile	Mainly high (dry)	Dry conditions on the mire as evidenced by low *Sphagnum*, high *Betula*, *Eriophorum vaginatum*, Monocots, *Erica tetralix* and high charcoal. Some of the most humified conditions on the mire
150–210	3700/2800–5700/4300	High *Trichophorum cespitosum*, low *Ericaceae*, low *Eriophorum vaginatum*, low UOM, high identified *Sphagnum*, mostly *S. cuspidatum* between 160 cm and 170 cm depth. No *Sphagnum* below 185 cm depth	High *Lycopodium*, high *Quercus*, *Alnus* and *Corylus* and high *Sphagnum* and *Tilletia sphagni* until 165 cm depth. Lower *Calluna*, increase in Poaceae. Low charcoal. Presence of *Ulmus*, *Tilia*, *Salix* and *Myrica*. *Filicales* and *Polypodium* increase	Mid-range and fluctuating; as low as 0.5 and as high as 1.2	Particularly low (wet) at 160 cm, then fluctuating around the trendline	Mire in wet state as indicated by presence of *Sphagnum cuspidatum* and *Tilletia sphagni*, lower *Calluna*, low charcoal and low UOM. Increased woodland surrounding the mire as evidenced by increasing tree pollen and woodland indicators
210–250	5700/4300–5300/5350	No *Sphagnum*, high *Equisetum fluviatile*, *Trichophorum cespitosum*, *Eriophorum vaginatum*, UOM and a presence of *E. angustifolium* and *Betula* at 250 cm depth	High *Betula*, *Quercus*, *Alnus* and *Corylus*. Presence of *Ulmus*, *Tilia*, *Salix*, *Myrica*, *Cyperaceae* *Polypodium* and *Filicales*. Low *Sphagnum*, *Calluna*, Poaceae and charcoal	Wetter, mid-range and fluctuating; as low as 0.8 and as high as 1.3	Fluctuating around the trendline.	Relatively dry as indicated by *Betula* growing on the bog, high UOM and low charcoal. Area surrounding bog likely to be wooded as indicated by the presence of tree pollen and woodland indicators
250–300	5300/5350–6700	High percentage of UOM, *Ericaceae*, Monocot roots, *Trichophorum cespitosum* and *Nymphaea* leaves and seeds. High quartz grains at base of profile. No *Sphagnum*	High *Betula*, *Potentilla*, *Quercus*, *Alnus* and *Corylus*. Low Poaceae and *Calluna*, low charcoal	High, reaching above 2. Some of the wettest conditions in the profile	Fluctuating around the trendline	Very wet as evidenced by the presence of *Nymphaea*, high transmission values and low charcoal

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4.3. Increased anthropogenic activity

It is likely that humans were affecting the landscape during Mesolithic times, as can be seen by occasional decreases in tree pollen consistent with increases in charcoal and shrub and heath pollen. A gradual reduction in tree pollen is noted throughout the profile but a marked reduction is evident at 150 cm depth (3700/2800 cal. BP) consistent with an increase in charcoal, Ericaceae and *Calluna* pollen (Fig. 4, Table 2) and is likely indicative of increased anthropogenic activity. Before this, *Calluna* is less prevalent and *Myrica* is present, likely to be growing on the mire. There were many more trees growing in the areas surrounding the mire, with tree pollen reaching between 40 and 60% of the total pollen. At the same time, *Sphagnum* (mainly *S. cuspidatum*) disappears before *Sphagnum* section *Acutifolia* species re-appear at c. 450 cal. BP. This disappearance is also likely attributed to an increase in burning and drier surface conditions.

4.4. Recent (<500 years) management

4.4.1. Changes in Sphagnum composition

The re-introduction of *Sphagnum* 450 years ago may have been caused by changes towards a wetter climate as evidenced by low humification, low UOM and low DHI values. However, conditions were not wet enough to form pools as the recorded species *S. capillifolium* and *S. fuscum* would usually be found forming hummocks. However, as only one master core was analysed, it cannot be ruled out that pools may have been present elsewhere across the bog. Having said this, all the evidence does suggest a climatic deterioration, which coincides with the Little Ice Age (c. 600–150 cal. BP) (Swindles, Morris, Baird, Blaauw, & Plunkett, 2012) and is also identified by Langdon, Barber, and Hughes (2003) from Temple Hill Moss, southeast Scotland and Barber et al. (2004) in northern Germany and Denmark and is found in many other proxy records from the UK and Europe.

There is a very recent (<50 years) initiation of *Sphagnum papillosum* coincident with an increase in charcoal towards the surface (Fig. 5, Table 3), a species which occurs in communities with high N deposition and which has increased from the 1950s and peaked around 1990 (Payne, 2014). This can be compared to changes in *Sphagnum* cover identified at Mossdale Moor with a disappearance of *Sphagnum* at c. 100 years ago (McCarroll et al., 2015) and Keighley Moor (Blundell & Holden, 2015), where the present *Sphagnum* cover has only been characteristic for the last c. 100 years, demonstrating that comparable practices were taking place across the Yorkshire region, albeit on a slightly different timescale, highlighting the variances between sites.

4.4.2. Other vegetation changes

There is also an increase in Ericaceae, *Calluna* and Poaceae pollen consistent with high charcoal from 50 cm depth (500 cal. BP) towards the surface. The increase in charcoal is indicative of burning, which has increased in the last few hundred years with the introduction of rotational burning for the management of grouse (Lee et al., 2013). Grazing of sheep has also taken place at the site, which is also known to encourage the growth of grasses (Wilson, Wilson, & Johnstone, 2011). *Pinus* plantations in the area surrounding West Arkengarthdale from 22 cm depth (c. cal. AD 1800) are also indicative of recent management. The increasing occurrence of monocots from 30 cm depth (200 cal. BP) is associated with degraded blanket mire (Chambers, Cloutman, Daniell, Mauquoy, & Jones, 2013) and an increase in *P. commune* at the same depth is indicative of heath and the increase in *Rumex* from 35 cm depth (250 cal. BP) towards the surface is associated with increased grazing pressure (Evju, Mysterud, Austrheim, & Økland, 2006).

4.5. Applications of palaeoecological data

The palaeoecological data suggest that West Arkengarthdale has been affected by a multitude of pressures including grazing and burning; therefore, it seems unlikely that the site could be restored to a previous state unless these anthropogenic pressures are reduced. Given the tolerance of *S. papillosum* to such management practices and pollution, if *Sphagnum* cover is desired, it might be recommended that this species is encouraged. However, the spread of *S. papillosum* is a recent phenomenon and so perhaps this trend should be discouraged. *S. cuspidatum* has been identified as part of the present-day vegetation in some areas at the site as well as being present at the site for approximately 200 years between 170–160 cm depths (4100/3250–3900/3000 cal. BP) and so could be encouraged with the re-wetting of the bog.

Realistic targets for conservation management need to be economically rational. Although it might be recommended that drainage ditches continue to be filled to re-wet the surface of the mire and thus provide a more suitable environment for species adapted for water-logged conditions, there is a need to consider changes in management in relation to potential carbon storage, grouse management, farming, water quality and water storage for flooding management. It is important to consider how and whether these factors can be integrated and whether species such as *S. cuspidatum* would be able to thrive if management practices do not change.

Considering the predicted heightened sensitivity of such sites to climate change and increasing erosion, it is important that an understanding of processes occurring at site level is gained. Carbon is sequestered in peatlands so long as formation of new peat exceeds decay losses of all peat accumulated previously (Clymo, Turunen, & Tolonen, 1998). With many sites being described as degraded and dominated by graminoids with reduced levels of *Sphagna*, it is likely that more carbon will be released than sequestered. In understanding past vegetation and encouraging the return to environments rich in *Sphagna* with a variety of peat-forming species, such sites may be capable of becoming carbon sinks as opposed to carbon sources. However, the site should be restored depending on its intended use, with a view to encourage the return to more biodiverse environments.

5. Conclusions

Research questions developed with the YPP have allowed palaeoecological data to provide evidence for the previous vegetation, its development, past changes and approximate timing of the changes at a degraded peatland site in Yorkshire. This has supported understanding of the causes of vegetation degradation in an area where palaeoecological knowledge was previously lacking. It is intended that these findings be used to aid understanding of the previous habitat and whether and how it can be restored. At West Arkengarthdale, it has been demonstrated that:

1) The present vegetation state is not typical and is most likely a result of increased anthropogenic pressures including increased grazing pressures, an increase in pollution and managed burning, particularly over the last 200 years.
2) An increase in charcoal from 150 cm depth is consistent with a change in species composition including the disappearance of *Sphagnum* and an increase in *Calluna*.
3) Species composition changes in the last 500 years including a further increase in *Calluna*, an increase in *Erica* spp., an almost disappearance of tree pollen, a decrease in *E. vaginatum* and *Trichophorum cespitosum* and the re-introduction of *Sphagnum*

capillifolium and *S. fuscum* in greater abundance than existed previously.

4) Species composition alters consistently with the beginning of the industrial revolution to include a rise in *Rumex*, *Pinus*, *Poaceae*, monocots and *P. commune*.
5) A very recent rise in dominance of *S. papillosum* occurred during the last 50 years.
6) Attempting to 'restore' *T. cespitosum*, *S. capillifolium*, *S. fuscum* and *S. cuspidatum* and reduce *Calluna* is a goal that would fit in with past developments at the site.

Benefits in biodiversity, carbon sequestration, flood water storage and water quality can be expected to be seen if attempts are made to return such grass and shrub dominated peatland sites towards a mix including more sedges and mosses.

5.1. Wider application

This collaborative approach between research palaeoecologists and practical site managers is relatively novel. It means that conservation management goals, including safeguarding carbon storage, are informed by site history, past vegetation development and dominant plant association between past and present cultural practice. In terms of practically using the palaeoecological evidence in restoration and conservation at West Arkengarthdale, conservationists can use the micropropagation technique, which enables small samples of selected *Sphagnum* species such as *S. fuscum* to be increased into greater volumes for practical use. In this instance, the evidence provided by this project is particularly useful as the YPP and other UK restoration projects are currently mainly using *Sphagnum fallax*, *S. capillifolium*, S. *palustre* and *S. papillosum*.

There are practical difficulties in attempting to restore *T. cespitosum* as conservationists are aiming to increase the wetness of the bog in order to achieve greater *Sphagnum* growth. The YPP are currently working towards this using various methods including blocking any drains that may have been previously cut into the bog. Ideally, this would then lead to a natural decrease in *Calluna* and an increase in species of wetter communities such as *Erica tetralix*. As *T. cespitosum* is a species of wet heath, the YPP would not necessarily endeavour to increase its growth at the site, however; it may occur in small numbers in drier areas around the bog.

Acknowledgements

We thank the Yorkshire Peat Partnership for their financial support; Will Carpenter, Bryony Overs, Rachel Leven and Briony Eastabrook for assistance with fieldwork; and Richard Lindsay for his advice.

References

ACCROTELM, 2006. *ACCROTELM: Abrupt Climate Changes Recorded Over The European Land Mass* [Online]. http://www2.glos.ac.uk/accrotelm/index.html Accessed 13.01.12.
Appleby, P. G., Shotyk, W., & Fankhauser, A. (1997). Lead-210 age dating of three peat cores in the Jura Mountains, Switzerland. *Water, Air and Soil Pollution*, *100*, 223–231.
Ashmore, P., Brayshay, B., Edwards, K. J., Gilbertson, D., Grattan, J., Kent, M., et al. (2000). Allochthonous and autochthonous mire deposits slope instability and palaeoenvironmental investigations in the Borve Valley, Barra, Outer Hebrides, Scotland. *The Holocene*, *10*, 97–108.
Bain, C., Bonn, A., Stoneman, R., Chapman, S., Coupar, A., Evans, M. et al. (2011). IUCN UK Commission of Inquiry on Peatlands. *IUCN UK Peatland Programme, Edinburgh*.
Barber, K., Chambers, F., Maddy, D., Stoneman, R., & Brew, J. (1994). A sensitive high-resolution record of late Holocene climatic change from a raised bog in northern England. *The Holocene*, *4*, 198–205.
Barber, K. E., Chambers, F. M., & Maddy, D. (2004). Late Holocene climatic history of northern Germany and Denmark: peat macrofossil investigations at Dosenmoor, Schleswig-Holstein, and Svanemose, Jutland. *Boreas*, *33*, 132–144.
Birks, H. J. B. (1996). Contributions of quaternary palaeoecology to nature conservation. *Journal of Vegetation Science*, *7*, 89–98.
Birks, H. J. B. (2012). Ecological palaeoecology and conservation biology: controversies, challenges, and compromises. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*, 292–304.
Blundell, A., & Holden, J. (2015). Using palaeoecology to support blanket peatland management. *Ecological Indicators*, *49*, 110–120.
Chambers, F. M., Mauquoy, D., Cloutman, E. W., Daniell, J. R. G., & Jones, P. S. (2007). Recent vegetation history of Drygarn Fawr (Elenydd SSSI), Cambrian Mountains, Wales: implications for conservation management of degraded blanket mires. *Biodiversity and Conservation*, *16*, 2821–2846.
Chambers, F. M., Mauquoy, D., Gent, A., Pearson, F., Daniell, J. R. G., & Jones, P. S. (2007). Palaeoecology of degraded blanket mire in South Wales: data to inform conservation management. *Biological Conservation*, *137*, 197–209.
Chambers, F. M., Mauquoy, D., & Todd, P. A. (1999). Recent rise to dominance of *Molinia caerulea* in environmentally sensitive areas: new perspectives from palaeoecological data. *Journal of Applied Ecology*, *36*, 719–733.
Chambers, F., Cloutman, E., Daniell, J., Mauquoy, D., & Jones, P. (2013). Long-term ecological study (palaeoecology) to chronicle habitat degradation and inform conservation ecology: an exemplar from the Brecon Beacons, South Wales. *Biodiversity and Conservation*, *22*, 719–736.
Chambers, F. M., Beilman, D. W., & Yu, Z. (2011). Methods for determining peat humification and for quantifying peat bulk density: organic matter and carbon content for palaeostudies of climate and peatland carbon dynamics. *Mires and Peat*, *7*, 1–10.
Chambers, F. M., van Geel, B., & van der Linden, M. (2011). Considerations for the preparation of peat samples for palynology: and for the counting of pollen and non-pollen palynomorphs. *Mires and Peat*, *7*, 1–14.
Chambers, F. M., & Daniell, J. R. G. (2011). Conservation and habitat restoration of moorland and bog in the UK uplands: a regional: paleoecological perspective. *PAGES Newsletter*, *19*, 45–47.
Charman, D. (2002). *Peatlands and environmental change*. John Wiley & Sons Ltd.
Clymo, R., Turunen, J., & Tolonen, K. (1998). Carbon accumulation in peatland. *Oikos*, 368–388.
Cooper, A., McCann, T. P., & Hamill, B. (2001). Vegetation regeneration on blanket mire after mechanized peat-cutting. *Global Ecology and Biogeography*, *10*, 275–289.
Daley, T., & Barber, K. (2012). Multi-proxy Holocene palaeoclimate records from Walton Moss, northern England and Dosenmoor, northern Germany, assessed using three statistical approaches. *Quaternary International*, *268*, 111–127.
Daniels, R. E., & Eddy, A. (1985). *Handbook of European Sphagna*. Instiute of Terrestrial Ecology.
Davies, A. L. (2015). Late Holocene regime shifts in moorland ecosystems: high resolution data from the Pennines, UK. *Vegetation History and Archaeobotany*, 1–13.
Davies, A. L., & Bunting, J. M. (2010). Applications of palaeoecology in conservation. *The Open Ecology Journal*, *3*, 54–67.
Davies, A. L., & Watson, F. (2007). Understanding the changing value of natural resources: an integrated palaeoecological–historical investigation into grazing–woodland interactions by Loch Awe, Western Highlands of Scotland. *Journal of Biogeography*, *34*, 1777–1791.
De Vleeschouwer, F., Hughes, P. D. M., Nichols, J. E., & Chambers, F. M. (2010). A review of protocols in peat palaeoenvironmental studies. *Mires and Peat*, *7*.
Drew, S., Waldron, S., Gilvear, D., Grieve, I., Armstrong, A., Bragg, O., et al. (2013). The price of knowledge in the knowledge economy: should development of peatland in the UK support a research levy? *Land Use Policy*, *32*, 50–60.
Dupont, L. M. (1986). Temperature and rainfall variation in the Holocene based on comparative palaeoecology and isotope geology of a hummock and a hollow (Bourtangerveen, The Netherlands). *Review of Palaeobotany and Palynology*, *48*, 71–159.
Evju, M., Mysterud, A., Austrheim, G., & Økland, R. H. (2006). Selecting herb species and traits as indicators of sheep grazing pressure in a Norwegian alpine habitat. *Ecoscience*, *13*, 459–468.
Ferguson, P., Lee, J., & Bell, J. (1978). Effects of sulphur pollutants on the growth of *Sphagnum* species. *Environmental Pollution (1970)*, *16*, 151–162.
Finlayson, C. M., Clarke, S. J., Davidson, N. C., & Gell, P. (2015). Role of palaeoecology in describing the ecological character of wetlands. *Marine and Freshwater Research*,
Froyd, C. A., & Willis, K. J. (2008). Emerging issues in biodiversity & conservation management: The need for a palaeoecological perspective. *Quaternary Science Reviews*, *27*, 1723–1732.
Gallego-Sala, A. V., & Prentice, I. C. (2013). Blanket peat biome endangered by climate change. *Nature Climate Change*, *3*, 152–155.
Garnett, M. H., Ineson, P., & Stevenson, A. C. (2000). Effects of burning and grazing on carbon sequestration in a Pennine blanket bog, UK. *Holocene*, *10*, 729–736.
Gauci, V., Dise, N., & Fowler, D. (2002). Controls on suppression of methane flux from a peat bog subjected to simulated acid rain sulfate deposition. *Global Biogeochemical Cycles*, *16*, 1–12.
Gearey, B. R., Marshall, P., & Hamilton, D. (2009). Correlating archaeological and palaeoenvironmental records using a Bayesian approach: a case study from Sutton Common South Yorkshire, England. *Journal of Archaeological Science*, *36*, 1477–1487.
Grimm, E. (1991). TILIA 1.7.16, TILIA*Graph 1.7.16. Springfield, IL.: Illinois State Museum, Research and Collection Centre.
Hjelle, K. L., Kaland, S., Kvamme, M., Lødøen, T. K., & Natlandsmyr, B. (2012). Ecology and long-term land-use, palaeoecology and archaeology–the

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usefulness of interdisciplinary studies for knowledge-based conservation and management of cultural landscapes. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*, 321–337.
Hogg, E. H., Lieffers, V. J., & Wein, R. W. (1992). Potential carbon losses from peat profiles: effects of temperature, drought cycles, and fire. *Ecological Applications*, *2*, 298–306.
Huntley, B. (1991). Historical lessons for the future. *The Scientific Management of Temperate Communities for Conservation*, 473–503.
Jackson, D., & McLeod, C. (2000). *Handbook on the UK status of EC Habitats Directive interest features: provisional data on the UK distribution and extent of Annex I habitats and the UK distribution and population size of Annex II species Version 1*. REPORT-JOINT NATURE CONSERVATION COMMITTEE.
Langdon, P. G., Barber, K. E., & Hughes, P. D. M. (2003). A 7500-year peat-based palaeoclimatic reconstruction and evidence for an 1100-year cyclicity in bog surface wetness from Temple Hill Moss, Pentland Hills, southeast Scotland. *Quaternary Science Reviews*, *22*, 259–274.
Lee, H., Alday, J. G., Rose, R. J., O'Reilly, J., Marrs, R. H., & Wilsey, B. (2013). Long-term effects of rotational prescribed burning and low-intensity sheep grazing on blanket-bog plant communities. *Journal of Applied Ecology*, *50*, 625–635.
Limpens, J., Berendse, F., Blodau, C., Canadell, J., Freeman, C., Holden, J., et al. (2008). Peatlands and the carbon cycle: from local processes to global implications—a synthesis. *Biogeosciences*, *5*, 1475–1491.
Lindsay, R., Charman, D., Everingham, F., O'reilly, R., Palmer, M., Rowell, T., et al. (1988). *The flow country: the peatlands of Caithness and Sutherland*. Nature Conservancy Council.
Mackay, A. W., & Tallis, J. H. (1996). Summit-type blanket mire erosion in the Forest of Bowland, Lancashire, UK: predisposing factors and implications for conservation. *Biological Conservation*, *76*, 31–44.
Mauquoy, D., Yeloff, D., Van Geel, B., Charman, D. J., & Blundell, A. (2008). Two decadally resolved records from north-west European peat bogs show rapid climate changes associated with solar variability during the mid-late Holocene. *Journal of Quaternary Science*, *23*, 745–763.
McCarroll, J. (2015). *Application of palaeoecological techniques to inform blanket mire conservation in Yorkshire, UK. Unpublished PhD Thesis*. University of Gloucestershire.
McCarroll, J., Chambers, F., Webb, J., & Thom, T. (2015). Application of palaeoecology for peatland conservation at Mossdale Moor, UK. *Quaternary International*.
Moore, P. D., Webb, J. A., & Collinson, M. E. (1991). *Pollen analysis*. Oxford: Blackwell.
Muller, S. D., Miramont, C., Bruneton, H., Carré, M., Sottocornola, M., Court-Picon, M., et al. (2012). A palaeoecological perspective for the conservation and restoration of wetland plant communities in the central French Alps, with particular emphasis on alder carr vegetation. *Review of Palaeobotany and Palynology*, *171*, 124–139.
Nedwell, D. B., & Watson, A. (1995). CH4 production: oxidation and emission in a U.K. ombrotrophic peat bog: Influence of SO42- from acid rain. *Soil Biology and Biochemistry*, *27*, 893–903.
Oldfield, F. (1970). The ecological history of Blelham Bog National Nature Reserve. In *Studies of the vegetational history of the British Isles*. pp. 141–157. Cambridge: Cambridge University Press.
Page, S. E., Siegert, F., Rieley, J. O., Boehm, H.-D. V., Jaya, A., & Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, *420*, 61–65.
Parry, L. E., Charman, D. J., & Blake, W. H. (2013). Comparative dating of recent peat deposits using natural and anthropogenic fallout radionuclides and Spheroidal Carbonaceous Particles (SCPs) at a local and landscape scale. *Quaternary Geochronology*, *15*, 11–19.
Payne, R. (2014). The exposure of British peatlands to nitrogen deposition, 1900–2030.
Piotrowska, N., Blaauw, M., Mauquoy, D., & Chambers, F. (2011). Constructing deposition chronologies for peat deposits using radiocarbon dating. *Mires and Peat*, *7*, 1–14.
Ramchunder, S. J., Brown, L. E., & Holden, J. (2009). Environmental effects of drainage: drain-blocking and prescribed vegetation burning in UK upland peatlands. *Progress in Physical Geography*, *33*, 49–79.
Ramsey, C. B. (2009). *Bayesian Analysis of Radiocarbon Dates*.
Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., et al. (2013). IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon*, *55*, 1869–1887.
Rodwell, J. S. (1998). *British plant communities*. Cambridge University Press.
Rose, N. L., & Appleby, P. G. (2005). Regional applications of lake sediment dating by spheroidal carbonaceous particle analysis I: United Kingdom. *Journal of Paleolimnology*, *34*, 349–361.
Seddon, A. W. R., Mackay, A. W., Baker, A. G., Birks, H. J. B., Breman, E., Buck, C. E., et al. (2014). Looking forward through the past: identification of 50 priority research questions in palaeoecology. *Journal of Ecology*, *102*, 256–267.
Smith, A. J. E. (2004). *The moss flora of Britain and Ireland*. Cambridge University Press.
Swindles, G. T. (2010). Dating recent peat profiles using spheroidal carbonaceous particles (SCPs). *Mires and Peat*, *7*, 1–5.
Swindles, G. T., Morris, P. J., Baird, A. J., Blaauw, M., & Plunkett, G. (2012). Ecohydrological feedbacks confound peat-based climate reconstructions. *Geophysical Research Letters*, 39.
Tallis, J. H. (1985). Mass movement and erosion of a southern Pennine blanket peat. *The Journal of Ecology*, 283–315.
Tallis, J. H. (1987). Fire and flood at Holme Moss: erosion processes in an upland blanket mire. *The Journal of Ecology*, 1099–1129.
Tallis, J. H., Meade, R., & Hulme, P. D. (1997). *Blanket mire degradation: causes, consequences and challenges*. Manchester Mires Research Group.
Troels-Smith, 1955. Characterisation of unconsolidated sediments, *Danmarks Geologiske Undersøgelse 4 Række*, 3, 1–73.
Turner, J., Hewetson, V. P., Hibbert, F., Lowry, K. H., & Chambers, C. (1973). The history of the vegetation and flora of Widdybank Fell and the Cow Green reservoir basin, Upper Teesdale. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *265*, 327–408.
Turunen, J., Tomppo, E., Tolonen, K., & Reinikainen, A. (2002). Estimating carbon accumulation rates of undrained mires in Finland—application to boreal and subarctic regions. *The Holocene*, *12*, 69–80.
van Geel, B. (1978). A palaeoecological study of holocene peat bog sections in Germany and The Netherlands, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals. *Review of Palaeobotany and Palynology*, *25*, 1–120.
Watson, A., & Nedwell, D. B. (1998). Methane production and emission from peat: the influence of anions (sulphate: nitrate) from acid rain. *Atmospheric Environment*, *32*, 3239–3245.
Willis, K. J., Bailey, R. M., Bhagwat, S. A., & Birks, H. J. B. (2010). Biodiversity baselines: thresholds and resilience: testing predictions and assumptions using palaeoecological data. *Trends in Ecology and Evolution*, *25*, 583–591.
Wilmshurst, J. M., Moar, N. T., Wood, J. R., Bellingham, P. J., Findlater, A. M., Robinson, J. J., et al. (2014). Use of pollen and ancient DNA as conservation baselines for offshore islands in New Zealand. *Conservation Biology*, *28*, 202–212.
Wilson, L., Wilson, J. M., & Johnstone, I. (2011). The effect of blanket bog drainage on habitat condition and on sheep grazing: evidence from a Welsh upland bog. *Biological Conservation*, *144*, 193–201.
Yeloff, D. E., Labadz, J. C., & Hunt, C. O. (2006). Causes of degradation and erosion of a blanket mire in the southern Pennines, UK. *Mires and Peat*, *1*, 1–18.
Yeo, M. (1997). Blanket mire degradation in Wales. In J. H. Tallis, R. Meade, & P. D. Hulme (Eds.), *Blanket mire degradation: causes, consequences and challenges*. Aberdeen: Macaulay Land Use Research Institute.
Yorkshire-Futures, Assembly, T. Y. A. H., Agency, T. E., Forward, Y., England, N., Commission, T. F. et al. (2009). Weathering the Storm. Leeds: Yorkshire Futures.

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