This is a peer-reviewed, post-print (final draft post-refereeing) version of the following published document:


Published in Journal for Nature Conservation, and available online at:  
http://dx.doi.org/10.1016/j.jnc.2016.02.002

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

The URL for the published version is http://dx.doi.org/10.1016/j.jnc.2016.02.002

**Disclaimer**

The University of Gloucestershire has obtained warranties from all depositors as to their title in the material deposited and as to their right to deposit such material.

The University of Gloucestershire makes no representation or warranties of commercial utility, title, or fitness for a particular purpose or any other warranty, express or implied in respect of any material deposited.

The University of Gloucestershire makes no representation that the use of the materials will not infringe any patent, copyright, trademark or other property or proprietary rights.

The University of Gloucestershire accepts no liability for any infringement of intellectual property rights in any material deposited but will remove such material from public view pending investigation in the event of an allegation of any such infringement.

PLEASE SCROLL DOWN FOR TEXT
Dear Author,

Please, note that changes made to the HTML content will be added to the article before publication, but are not reflected in this PDF.

Note also that this file should not be used for submitting corrections.
Using palaeoecology to advise peatland conservation: An example from West Arkengarthdale, Yorkshire, UK

J. McCarroll\textsuperscript{a,}\textsuperscript{*}, F.M. Chambers\textsuperscript{a}, J.C. Webb\textsuperscript{a}, T. Thom\textsuperscript{b}

\textsuperscript{a} Centre for Environmental Change and Quaternary Research, School of Natural and Social Sciences, University of Gloucestershire, Francis Close Hall Campus, Swindon Road, Cheltenham GL50 4AZ, UK
\textsuperscript{b} Yorkshire Peat Partnership, Yorkshire Wildlife Trust, 1 St. George’s Place, York, North Yorkshire YO24 1GN, UK

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.

© 2016 Published by Elsevier GmbH.

1. Introduction

Global, peatlands are estimated to contain between 270 and 370 Tg of carbon (TgC; 1 Tg = 10\textsuperscript{12} g) as peat (Tolonen, Tomppo, Tolonen, & Reini, 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 net carbon sinks 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).

* Corresponding author.
E-mail addresses: jmc.carroll@glos.ac.uk (J. McCarroll), f.m.chambers@glos.ac.uk (F.M. Chambers), j.webb@glos.ac.uk (J.C. Webb), tim.thom@ywt.org.uk (T. Thom).

http://dx.doi.org/10.1016/j.jnc.2016.02.002
1617-1381/© 2016 Published by Elsevier GmbH.
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, Labatz, & 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 (SO₂, H₂SO₄ and SO₄²⁻) 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...
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...
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 (Rambunsh, 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; Froud & Willis, 2008; Davies & Bunting, 2010; Hjelle, Kaland, Kvamme, Ledøen, & 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, & Gall, 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.
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.
2. Methods

2.1. Field sampling strategy

The method used in the ACCROTEL Research Project (ACCROTEL, 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^2) 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, 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 acetylated using acetic anhydride and sulphuric acid (9:1). Hydrofluoric 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-
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 Sphagnum 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 TILIAGRAPH (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 Sphagnum 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 Shi (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, Blååw, 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 Bovre 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
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, 2008), error ±30 years at 1 σ. **Samples were dated using the fraction of plant material extracted from samples of peat by beta analytic.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Radiocarbon date (BP)</th>
<th>Lab number</th>
<th>Calibrated age (cal. BP)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>39.5</td>
<td>300 ± 30 BP</td>
<td>BETA-381604</td>
<td>485 (320.5) 156</td>
<td>plant macrofossils</td>
</tr>
<tr>
<td>38.5</td>
<td>310 ± 30 BP</td>
<td>BETA-385277</td>
<td>1822 (1696) 1570</td>
<td>plant macrofossils</td>
</tr>
<tr>
<td>38.5</td>
<td>3410 ± 30 BP*</td>
<td>BETA-379805</td>
<td>3828 (3695.5) 3563</td>
<td>wood</td>
</tr>
<tr>
<td>159.5</td>
<td>3640 ± 30 BP*</td>
<td>BETA-385278</td>
<td>4089 (3965) 3841</td>
<td>plant material**</td>
</tr>
<tr>
<td>182.5</td>
<td>3320 ± 30 BP</td>
<td>BETA-379806</td>
<td>3685 (3567.5) 3450</td>
<td>plant material**</td>
</tr>
<tr>
<td>260.5</td>
<td>4820 ± 30 BP</td>
<td>BETA-379807</td>
<td>5645 (5556.5) 5468</td>
<td>plant material**</td>
</tr>
<tr>
<td>289.5</td>
<td>5610 ± 30 BP</td>
<td>BETA-379808</td>
<td>6487 (6393.5) 6300</td>
<td>plant material**</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Pollen zone</th>
<th>Depth (cm)</th>
<th>Age 1 (cal. BP)</th>
<th>Age 2 (cal. BP)</th>
<th>Humification (wet/dry)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARK E</td>
<td>0–51</td>
<td>c. –60–700</td>
<td>c. –60–700</td>
<td>Wet</td>
<td>High concentration of Lycopodium spores, high percentage of Cyperaceae (up to 25%), Erica (up to 25%), Calluna (up to 50%), Rumex (c. 5%) and Poaceae (up to 60%). High number of Sphagnum spores (200) at 40 cm depth. Low percentages of Betula (&lt;5%) and all other tree pollen despite a slight rise in Pinus towards the surface. High numbers of charcoal fragments (up to 1000)</td>
</tr>
<tr>
<td>ARK D</td>
<td>51–150</td>
<td>c. 700–3700</td>
<td>c. 700–2800</td>
<td>Dry</td>
<td>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) 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</td>
</tr>
<tr>
<td>ARK C</td>
<td>150–185</td>
<td>c. 3700–4300</td>
<td>c. 2800–3500</td>
<td>Mainly dry. Some wet</td>
<td>High concentrations 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 &lt;5% at the bottom. Filiaceae and Polypodium increase in this zone and numbers of charcoal fragments and Sphagnum spores are low 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 (&lt;5%) and Calluna (&lt;10%) are low, as is the number of charcoal fragments (up to 200)</td>
</tr>
<tr>
<td>ARK B</td>
<td>185–260</td>
<td>c. 4300–5450</td>
<td>c. 3500–5450</td>
<td>Mainly dry</td>
<td>High concentrations 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 &lt;5% at the bottom. Filiaceae and Polypodium increase in this zone and numbers of charcoal fragments and Sphagnum spores are low 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 (&lt;5%) and Calluna (&lt;10%) are low, as is the number of charcoal fragments (up to 200)</td>
</tr>
<tr>
<td>ARK A</td>
<td>260–300</td>
<td>c. 5450–6700</td>
<td>c. 5450–6700</td>
<td>Wet</td>
<td>High concentrations 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 &lt;5% at the bottom. Filiaceae and Polypodium increase in this zone and numbers of charcoal fragments and Sphagnum spores are low 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 (&lt;5%) and Calluna (&lt;10%) are low, as is the number of charcoal fragments (up to 200)</td>
</tr>
</tbody>
</table>
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.
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).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Age (cal. BP)</th>
<th>Plant macrofossils</th>
<th>Pollen</th>
<th>Humification</th>
<th>DHI</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–50</td>
<td>500–200</td>
<td>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</td>
<td>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</td>
<td>High, reaching above 2. The wettest conditions in the profile</td>
<td>Mainly low (wet).</td>
<td>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 acroellem 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. Some of the most humified conditions on the mire</td>
</tr>
<tr>
<td>50–150</td>
<td>550–3700/2800</td>
<td>Low identified Sphagnum, low Trichophorum cespitosum, high Schoenus nigricans, high Equisetum fluviatile and Betula towards base, high Eriophorum vaginatum, high Monocots and occurrence of Erica tetralix</td>
<td>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</td>
<td>As low as 0.3, the driest conditions in the profile</td>
<td>Mainly high (dry)</td>
<td>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</td>
</tr>
<tr>
<td>150–210</td>
<td>3700/2800–5700/4300</td>
<td>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</td>
<td>High Lycopodium, high Quercus, Alnus and Corylus and high Sphagnum and Tilletia spargni until 165 cm depth. Lower Calluna, increase in Poaceae. Low charcoal. Presence of UImus, Tilia, Salix and Myrica. Filicales and Polyposidium increase</td>
<td>Mid-range and fluctuating; as low as 0.5 and as high as 1.2</td>
<td>Particularly low (wet) at 160 cm, then fluctuating around the trendline</td>
<td>Mire in wet state as indicated by presence of Sphagnum cuspidatum and Tilletia spargni, lower Calluna, low charcoal and low UOM. Increased woodland surrounding the mire as evidenced by increasing tree pollen and woodland indicators</td>
</tr>
<tr>
<td>210–250</td>
<td>5700/4300–5300/5350</td>
<td>No Sphagnum, high Equisetum fluviatile, Trichophorum cespitosum, Eriophorum vaginatum, UOM and a presence of E. angustifolium and Betula at 250 cm depth</td>
<td>High Betula, Quercus, Alnus and Corylus. Presence of UImus, Tilia, Salix, Myrica, Cyperaceae Polyposidium and Filicales. Low Sphagnum, Calluna, Poaceae and charcoal</td>
<td>Wetter, mid-range and fluctuating; as low as 0.8 and as high as 1.3</td>
<td>Fluctuating around the trendline.</td>
<td>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</td>
</tr>
<tr>
<td>250–300</td>
<td>5300/5350–6700</td>
<td>High percentage of UOM, Ericaceae, Monocot roots, Trichophorum cespitosum and Nymphaea leaves and seeds. High quartz grains at base of profile. No Sphagnum</td>
<td>High Betula, Potentilla, Quercus, Alnus and Corylus. Low Poaceae and Calluna, low charcoal</td>
<td>High, reaching above 2. Some of the wettest conditions in the profile</td>
<td>Fluctuating around the trendline</td>
<td>Very wet as evidenced by the presence of Nymphaea, high transmission values and low charcoal</td>
</tr>
</tbody>
</table>
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 100 years, demonstrating that comparable practices were taking place across the Yorkshire region, albeit on a slightly different timescale, highlighting the variance 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. 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 (Ejju, Mysterud, Austrheim, & Okland, 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 encouraging 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 F. 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 practices. 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


