Holocene fire history: can evidence of peat burning be found in the palaeo-archive?

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SUMMARY

Smouldering wildfires in peatlands have the potential to release substantial amounts of the carbon currently sequestered in these ecosystems. However, past studies of Holocene fire history in peatlands have given little consideration to the identification of evidence left behind after peat burning, or to charring of the peat matrix. In this study, modern peat samples from peatlands across the globe were charred in order to assess the identifiable characteristics of charred peat. On this basis we believe that charred aggregates of partially decayed organics which can be identified in cores provide clear evidence that the peat matrix itself burned. A range of charred morphotypes could be found throughout a 2 m peat core from All Saints Bog in County Offaly, Ireland, and we are able to identify charred partially decayed aggregates that appeared to correspond with peaks in fire activity on the bog. These may reflect periods when surface fires ignited the peat surface below, or when the radiant heat from surface fires was sufficient to pyrolyse the surface peat. We conclude that it is possible to find evidence of peat burning in the palaeo-archive, and that future studies should begin to document the occurrence of charred particles so that the discipline can begin to build a picture of possible past peat fire activity.

KEY WORDS: charcoal, charred aggregates, peat matrix, smouldering wildfire

INTRODUCTION

Covering 3 % of the globe's surface, peatlands contain approximately one-third of the terrestrial carbon (C) on Earth (Gorham 1991, Limpens *et al.* 2008, Strack 2008, Weissert & Disney 2013). The Northern Hemisphere contains the majority (80 %) of the globe's peatlands and stores approximately 455 Pg of C, or ~90 % of the peatland C pool (Gorham 1991, Limpens *et al.* 2008, Wieder *et al.* 2009, Yu 2011).

Peatlands face an uncertain future as a result of climate and land use change (Joosten 2009) because, under the right conditions, they are deemed to be amongst the most flammable ecosystems on the globe (Rein 2013). Peatland fires are increasing in frequency and severity (Joosten 2009, Waddington *et al.* 2014). The particularly large fires recorded in relatively recent years, e.g. the 1997 mega-fires in Indonesia and the major fires of 2010 in Russia, have led to an increase of research interest in the topic (Page *et al.* 2002, Ballhorn *et al.* 2009, Witte *et al.* 2011, Krol *et al.* 2013, Waddington *et al.* 2014). As the severity of these fires increases the deeper layers of peat may become increasingly vulnerable to burning (Flannigan *et al.* 2009). Approximately 98.5 % of total peatland ecosystem C is made up of peat (Gorham 1991) and C density increases with peat depth (Flannigan *et al.* 2009). Therefore, the burning of deep peat soils could potentially result in large amounts of older C being released. Owing to this the future of the globe's peatlands and their increasing vulnerability to fire has become an important topic with some authors suggesting that fires in peatlands may mean that they have already become a source of carbon, rather than a sink, when considered globally (Turetsky *et al.* 2004, Joosten 2009).

Smouldering is a flameless form of combustion which can occur on and beneath the peat surface and, therefore, continue undetected for several months (Davies *et al.* 2013, Hadden *et al.* 2013, Rein 2013). Smouldering fires are the main type of fire that occurs in peat (Rein 2013). The fact that smouldering fires propagate not only laterally, but also vertically through the peat profile, means that C stored in deeper layers is vulnerable to burning and can thus be released into the atmosphere (Rein 2013). Therefore, any future increase in smouldering combustion of peat could result in significant contributions to global C emissions (Flannigan *et al.* 2009, Joosten 2009).

'As one of fire's most eminent legacies' (Kurth *et al.* 2006) charcoal has been at the forefront of palaeo-reconstructions of fire activity (Umbanhowar & McGrath 1998, Kurth *et al.* 2006, Conedera *et al.* 2009, Mooney & Tinner 2011, Kasin *et al.* 2013).

Most Holocene fire records derived from peat cores focus on charcoal abundance but do not identify the nature of the charcoal itself. This means that the source of the charcoal could be surface fires from which charcoal is later incorporated into the peat record; or, as Patterson *et al*. (1987) suggest, that peat may be a source of charcoal and, therefore, the charcoal reflects burning of the peat itself. However, to date, little attention has been paid to the notion of charred or burnt peat being found in the palaeo-record; and the question of how charred peat may be distinguished from charred plant parts appears to have been overlooked. This means that there are no clear records of the role of peat fire activity in the history of peatlands.

It is likely that most reconstructions of fire activity based on charcoal preserved in peat record burning of surface vegetation rather than peat. Charred peat will only remain once a smouldering fire front reaches a barrier to its spread (e.g. Prat-Guitart *et al.* 2016a, 2016b), but must also be taken into account when conducting palaeo-fire reconstructions (Zaccone *et al.* 2014). Searching for charred peat in the palaeo-archive is not expected to be simple as smouldering fires not only create their own charcoal but also consume it; therefore, there may be little charcoal left after a smouldering fire (Rein 2013, Zaccone *et al.* 2014). However, there is a need to search for this evidence of peat burning, as it is critical to any future consideration of the long-term C balance and C-storage capacity of peatlands.

All Saints Bog (53° 09′ N, 07° 59′ W) in County Offaly, Ireland offers an excellent opportunity for study of the nature of charcoal generated by fires in peatland settings. It is located at 40–45 m a.s.l., average annual rainfall (1979–2008) is approximately 810 mm, and mean daily temperatures are in the range 4.6–14.9 °C (Cole & Mitchell 2003). It is an ombrotrophic raised bog dominated by *Sphagnum* moss (Cole & Mitchell 2003) and contains the largest (14.34 ha) stand of moor birch (*Betula pubescens*) bog woodland in Ireland (close to site 14 shown in Figure 2 of Hudspith *et al.* 2014). Consequently, this site has been designated a European Special Area of Conservation (SAC) (Cross & Lynn 2013).

A recent assessment by the Irish National Parks and Wildlife Service described All Saints Bog as being in ‘unfavourable-inadequate’ conservation condition, due to drying-out evidenced by an increase in bracken (*Pteridium aquilinum*) (Fernandez *et al.* 2005, Fernandez *et al.* 2012, Cross & Lynn 2013). This is attributed primarily to drainage associated with historical turf-cutting, which removed 29 % of the bog (Cole & Mitchell 2003, Fernandez *et al.* 2005, Cross & Lynn 2013). The bog has continued to dry out since turf-cutting and associated activities ceased, making peat fires a pervasive threat (Hudspith *et al.* 2014). Indeed, it is known that both surface and sub-surface burning have occurred regularly (Fernandez *et al.* 2005). Most recently, in 2013 (precipitation < 25 mm, average temperature for July 22.6 °C), a fire that broke out during a warm and dry summer period resulted in approximately 10 % of the bog being burnt (Westmeath Independent 2013, Hudspith *et al.* 2014). An earlier fire in 2003 affected 42 % of the bog (Fernandez *et al.* 2005).

In the study described here, different peats from fourteen bogs across the globe were charred and the visual nature of the charred particles that resulted was described, in order to provide a means to identify smouldering wildfires in the peatland palaeo-archive. A peat core taken from All Saints Bog was then examined for evidence of these charred morphologies as evidence of historical smouldering fires and to provide a basis for assessing the overall fire history of this peatland.

METHODS

Experimental production of charred peats

Twenty-six peat samples from fourteen peatlands in northern Europe, North America and south-east Asia (Table 1) were experimentally burned in order to determine the range of morphologies that can be observed in charred peat. These samples included peat from the acrotelm and catotelm, but surface vegetation was not included. All samples were dried at 45 °C for 48 hours before charring. For each sample, three replicate sub-samples of ~ 1cm^3 and equal (dry) weight were charred. Each replicate was placed in the centre of a 7.5 cm square sheet of aluminium foil of known weight, then the foil was folded around the peat and the top twisted leaving a space for vapours generated during charring to escape, in order to prevent the formation of tar particles as described by Franzén & Malmgren (2012). Each wrapped peat was placed in a stainless steel crucible with clean mineral sand in the bottom, then entirely covered (to restrict the oxygen supply) by pouring more sand into the crucible (Crawford & Belcher 2014). This method is designed to maximise char production by limiting oxygen supply to the fuel, so that all morphologies which may result from charring of the peat can be observed. It is not designed to replicate the smouldering process, which includes both pyrolysis and oxidation. The filled crucibles were placed in a Carbolite GLM3 furnace and heated for one hour at 500 °C in order to pyrolyse

Table 1. Detailed list of the peat samples analysed. The coring locations and the depths in the cores and monoliths from which the samples were taken are provided, along with the main vegetation constituent of each peat.

Site name	Country	Latitude	Longitude	Depth (cm)	Main constituent	Description
All Saints Bog	Ireland	53° 09′ N	07° 59′ W	10–20	*Sphagnum*	Ombrotrophic lowland raised bog, 29 % of the area has been cut away, the rest of the bog is relatively intact (Cole & Mitchell 2003). Peat samples: C. Belcher and V. Hudspith, University of Exeter, pers. comm. 2014.
Crater Pool	Sweden	68° 19′ N	19° 51′ E	0–5 8–13 16–21	*Sphagnum* *Sphagnum* *Sphagnum*	Palsa peatland in northern Sweden (A. Gallego-Sala pers. comm. 2014; Swindles *et al*. 2015). Peat samples: A. Gallego-Sala, University of Exeter, pers. comm. 2014.
Dosenmoor	Germany	54° 07′ N	10° 01′ E	465–470	*Sphagnum*	Ombrotrophic raised bog, mineral content is very low, centre of bog dominated by raised bog peat (6.3 m), 1.2 m of the bog is classified as fen peat (van den Bogaard *et al*. 1994). Peat samples: M. Amesbury, University of Exeter, pers. comm. 2014.
Electric Bog	Sweden	67° 51′ N	19° 22′ E	0–3 20–23	*Sphagnum* *Sphagnum*	Palsa and fen peatland in northern Sweden (A. Gallego-Sala pers. comm. 2014; Swindles *et al*. 2015). Peat samples: A. Gallego-Sala, University of Exeter, pers. comm. 2014.
Fagelmossen	Sweden	59° 32′ N	12° 11′ E	150–155	*Sphagnum*	Ombrotrophic raised bog unaffected by human activities; *Rubus chamaemorus*, *Andromeda polifolia* and *Calluna vulgaris* present (Amesbury *et al*. 2012). Peat samples: M. Amesbury, University of Exeter, pers. comm. 2014.
Fallahogy Bog	Northern Ireland	54° 45′ N	06° 36′ W	0–5 400–405	*Sphagnum* *Sphagnum*	Ombrotrophic raised bog, turf-cutting has almost completely removed southern section, mosses dominate, reeds and wood fragments also present (Smith 1958, Barber *et al*. 2000). Peat samples: M. Amesbury, University of Exeter, pers. comm. 2014.
Instrument Bog	Sweden	68° 11′ N	19° 45′ E	0–3 24–27	*Sphagnum* *Sphagnum*	Ombrotrophic bog in northern Sweden (A. Gallego-Sala pers. comm. 2014, Swindles *et al*. 2015). Peat samples: M. Amesbury, University of Exeter, pers. comm. 2014.
Manacrin Moor	England	50° 32′ N	04° 37′ W	55–60	unknown	Minerotrophic peatland close to Bodmin Moor, *Corylus* and *Betula* macrofossils are present through the peat (M. Grosvenor pers. comm. 2014). Peat samples: M. Grosvenor, University of Exeter, pers. comm. 2014.
North Uist	Scotland	57° 34′ N	07° 18′ W	30–35	*Sphagnum*	Ombrotrophic blanket bog in the Outer Hebrides, Scotland. Peat samples: L. Orne, University of Exeter, pers. comm. 2014.
Plaine Bog	Canada	50° 17′ N	63° 32′ W	23–28	*Sphagnum*	A maritime ombrotrophic raised bog, peat depth 356 cm (Magnan *et al*. 2014). Peat samples: N. Sanderson, University of Exeter, pers. comm. 2014.
Railway Bog	Sweden	68° 05′ N	19° 49′ E	0–4 20–26 38–43	*Sphagnum* *Sphagnum* *Sphagnum*	A palsa and fen peatland with *Sphagnum fuscum* and *Rubus chamaemorus* (A. Gallego-Sala pers. comm. 2014, Swindles *et al.* 2015). Peat samples: A. Gallego-Sala, University of Exeter, pers. comm. 2014.
Walton Moss	England	54° 59′ N	02° 46′ W	370–375	*Sphagnum*	Lowland ombrotrophic raised bog, largely flat, dominated by *Sphagnum* with *Betula* present where there has been no/little human activity (Hughes *et al*. 2000). Peat samples: M. Amesbury, University of Exeter, pers. comm. 2014.
Western Svalbard	Norway	78° 56′ N	11° 29′ E	16–21	unknown	Minerotrophic peatland in an isolation basin on a raised shoreline, clay was found beneath the peat layer (M. Grosvenor pers. comm. 2014). Peat samples: M. Grosvenor, University of Exeter, pers. comm. 2014.
Sebangau Swamp Site 1a	Indonesia	00° 32′ S	113° 04′ E	0–3 27–30	peat swamp forest	The peat is formed from woody plant debris, this results in high soil permeability and porosity (Posa *et al*. 2011). Peat samples: A. Gallego-Sala, University of Exeter, pers. comm. 2014.
Sebangau Swamp Site 4a	Indonesia	00° 32′ S	113° 04′ E	0–3 27–30	peat swamp forest	Peat samples: A. Gallego-Sala, University of Exeter, pers. comm. 2014.
Sebangau Swamp Site 5b	Indonesia	00° 32′ S	113° 04′ E	0–3 27–30	peat swamp forest	Peat samples: A. Gallego-Sala, University of Exeter, pers. comm. 2014.

the peats, which were then unwrapped carefully (to avoid breaking the charred material) and emptied into separate petri dishes. Dry samples of *Calluna vulgaris* and *Sphagnum* moss were also charred, using the same method, in order to aid charcoal identification when assessing the All Saints peat core.

The resulting charcoal morphologies of each of the 26 peat samples were visually analysed using a low power Zeiss optical microscope with a digital camera attached, noting the differing morphologies. This captured images of all the resulting charred peat aggregates and charred organic material (e.g. *Calluna vulgaris* and *Sphagnum* moss).

Sampling at All Saints Bog

A 2 m core was taken on All Saints Bog in November 2013 using a Russian peat corer (Belokoptyov & Beresnevich 1955). The sampling location was next to 'Site 2' indicated in Figure 2 of Hudspith *et al*. (2014). On extraction, the core sections were so highly waterlogged that they could not be transported whole to the laboratory for careful division into 2 cm sections. The best resolution that could be achieved by dividing in the field was 10 cm, which is adequate for the remit of the study - the search for charred peat. *Calluna vulgaris* flowers, twigs and leaves and *Sphagnum* moss were also collected from All Saints Bog, to assist with identification of charred surface fuels and charred constituents of peat.

Hydrogen peroxide (H_2O_2) digestion

H_2O_2 was used to disaggregate the peat and extract the subfossil charcoals. Unlike non-charred organic material, charcoal particles are not bleached or digested by H_2O_2 (Rhodes 1998, Schlachter & Horn 2010). Therefore, this processing method eases identification of charcoal particles in the sample (Rhodes 1998, Schlachter & Horn 2010). The whole of each 10 cm section of fresh peat sample was placed in a 250 ml glass beaker, covered with 75 ml of 30 % H_2O_2, and 125 ml of deionised water was added to dilute the H_2O_2. The beakers were then agitated very gently on an orbital shaker for 48 hours, to ensure good contact between oxidant and particles without disaggregation or alteration of the particle shapes. Similar protocols that were previously employed by researchers such as Rhodes (1998) and Schlachter & Horn (2010) used H_2O_2 at slightly lower concentrations (~6 %) than in our study (~ 10 %). Each sample was individually passed through a 125 µm mesh sieve to separate the macrofossil charcoal from the supernatant liquid. The material left in the sieve, which included the macrofossil charcoal, was decanted into a sample pot using deionised water to wash the particles from the sieve.

Charcoal quantification and charred peat identification

Each of the macrofossil samples from All Saints Bog was emptied, a small amount at a time, into a petri dish where water was gently added to cover the entire surface. The 'lustre' of the charcoal particles increased, and this helped the observer to distinguish charcoal from the bleached non-charred organic material (Rhodes 1998). The particles included in quantification were those that were entirely black in colour and had reflective properties (i.e. silvery sheen under the light; see Scott 2010). Those that could not be categorically identified as charcoal, e.g. because they were too small to positively identify, were omitted from the count (Blackford 2000). The petri dish was left uncovered, allowing researchers to press the charcoal particles with a needle and observe fracturing, which further aided identification of the charred material (Rhodes 1998, Scott 2010). Charcoal particles were quantified by counting the number of particles visible under the microscope until the entire area of the petri dish had been traversed (Rhodes 1998). At times, a small soft brush was used to separate the charcoal from the non-charred organic material. The charcoals were imaged and the different morphotypes noted and compared to those created in the laboratory.

RESULTS

Charred peat characteristics

The peat charring experiments yielded a broad range of charcoal morphologies including charred botanically identifiable constituents of the peats such as heather flowers, woody clasts and mossy fragments (Figure 1). These are similar in appearance to the charred samples of recognisable vegetation from the All Saints Bog core (Figure 2). Thus, charred botanically identifiable clasts cannot be used as evidence of peat burning as they could either be derived from dead and decaying clasts within the peat or have been deposited in the peat following charring in fires on the peatland surface. However, it was also possible to identify relatively small (< 5mm) charred aggregates of organics, black in colour (Figure 3), of which some were more or less spherical and others more irregular in shape (Figure 3). The morphology of the aggregates contrasts with the typically angular shapes of the charred but clearly identifiable botanical particles. Seeds and their casings were also present; although spherical, these were easily identifiable as their surfaces were relatively smooth and they tended not to fragment when pressed with a needle. The morphology of the charred aggregates could be regarded as similar to that of the black spherical tar spherules which can be produced by the combustion of peat (Franzén & Malmgren 2012). However, there are clear differences between the morphologies of tar particles and the charred aggregates. Unlike the majority of tar spherules, the charred peat aggregates are not glossy under the microscope nor do they have a hollow, bubble-like surface texture. Thus, their identification as tar spherules can be ruled out.

Identification of charred peat

Of the 14 peatlands and 26 peat samples that were charred (Table 1), 12 peatlands and 24 samples contained charred peat aggregates after experimental burning, and these aggregates could be identified by comparison with other charred organic material such as *Sphagnum* moss, and *Calluna vulgaris* roots, wood and leaves (Figure 1). The peatlands which did not appear to produce charred peat aggregates were Plaine Bog in Canada and an unnamed bog in Western Svalbard, Norway. The peat aggregates found in the 24 samples provide clear evidence of peat burning as they represent partially decayed aggregates of organics combined as peat matrix. Whilst the other botanically identifiable clasts found in the peat also reflect peat burning in this case, it would be impossible to use them as indicators because similar morphologies could also be produced in surface peatland fires (compare Figures 1 and 2). Therefore, the only plant remains in the palaeo-archive that can be used to assess burning of peat are the charred partially decomposed organic aggregates. Whilst the peat aggregates are often small (< 5mm), their morphology contrasts clearly with the typically more angular shapes of the charred plant material found in each of the peat samples. Figure 3 shows a range of charred peat aggregates.

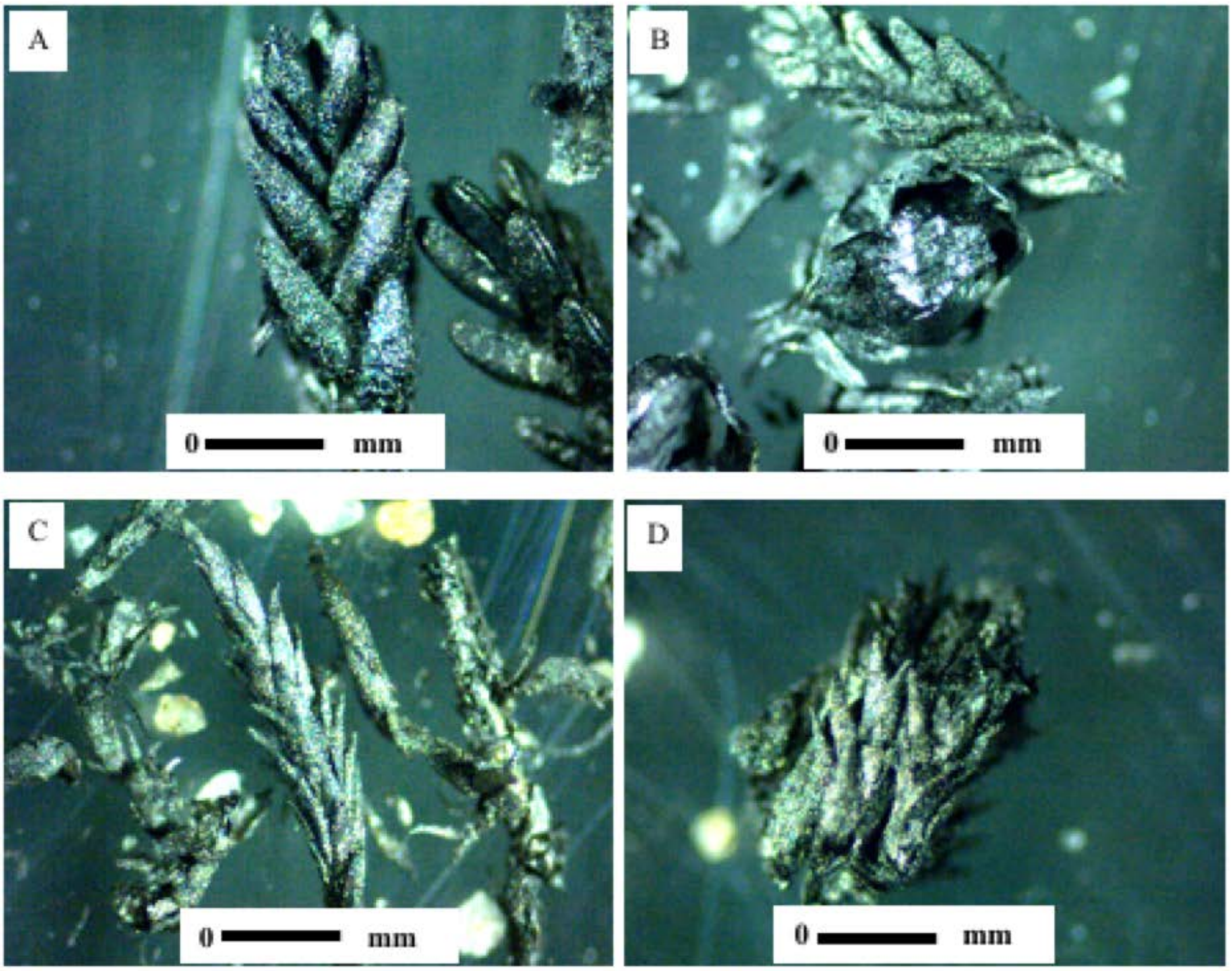

Figure 1. Charcoal produced by charring All Saints Bog peat. A and B: charred *Calluna vulgaris*; C and D: charred *Sphagnum* moss fragments.

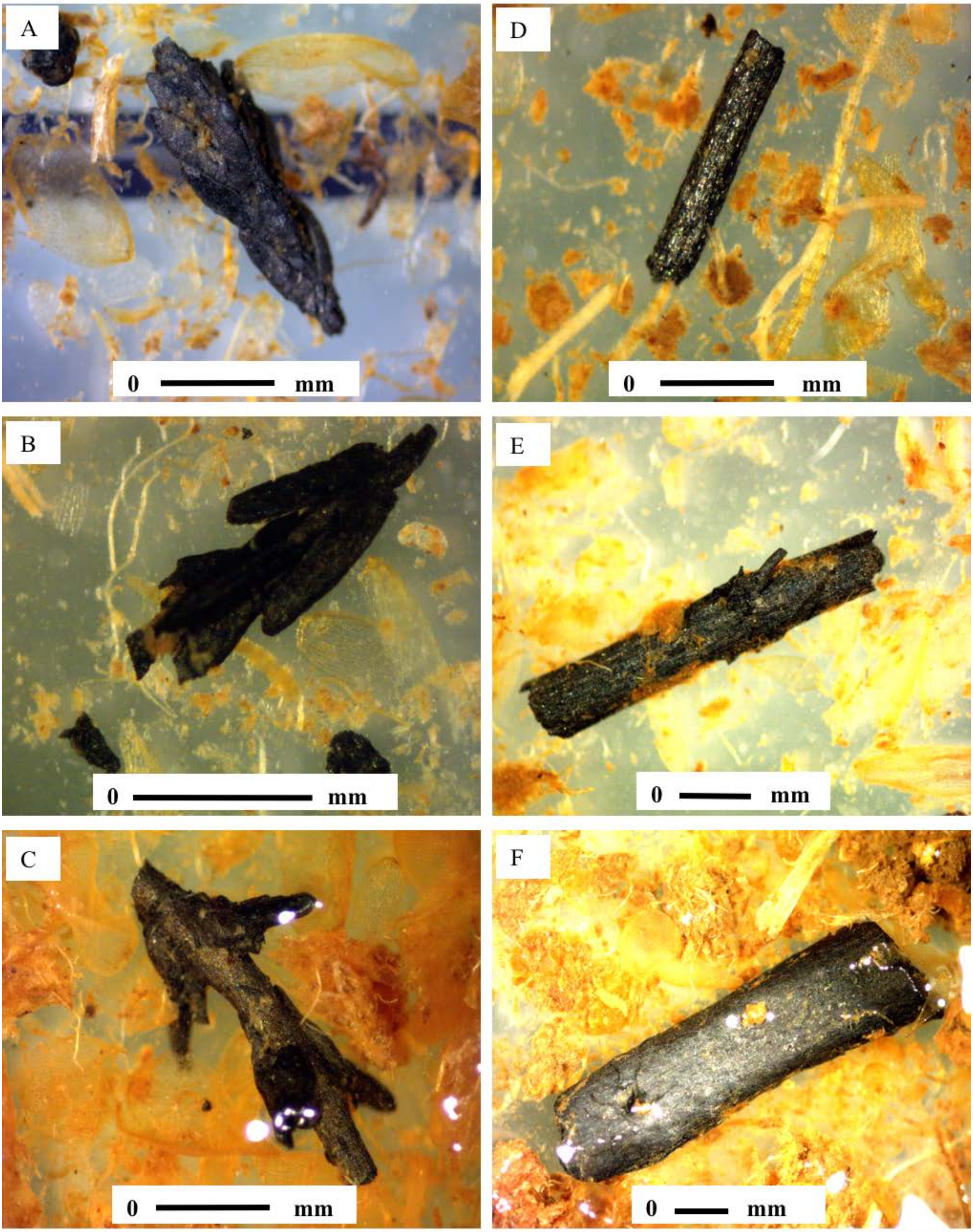

Figure 2. Charcoal from the All Saints Bog core. A–C: charred *Calluna* fragments; D–F: charred wood. Depths at which they were found: A) 120–130cm, B) 30–40cm, C) 100–110cm, D) 70–80cm, E) 100–110cm, F) 60–70cm.

Fire history of All Saints Bog

Figure 4 shows the raw abundance counts of macrofossil charcoals found at All Saints Bog plotted against depth through the core. The All Saints Bog core was analysed from 10–190 cm depth, i.e. part of the record (the 0–10cm sample) of charcoal abundance is missing (the top 10cm was missing from the core). Overall, there is little charcoal compared to the volume of peat. However, some distinctive peaks in charcoal abundance, taken to represent periods of enhanced fire activity on the bog, can be recognised.

The majority of charcoal fragments can be identified as wood or plant material, i.e. *Calluna vulgaris* flowers and leaves such as those shown in Figures 1 and 2. These, therefore, could either provide evidence that the surface fuels on the bog burned periodically and were subsequently incorporated into the peat (e.g. Hudspith *et al.* 2014) or they could represent the undecomposed burned (and therefore charred) constituents of peat. It is not possible to tell which is which. Therefore, they simply provide a record of fire activity of some kind on the bog.

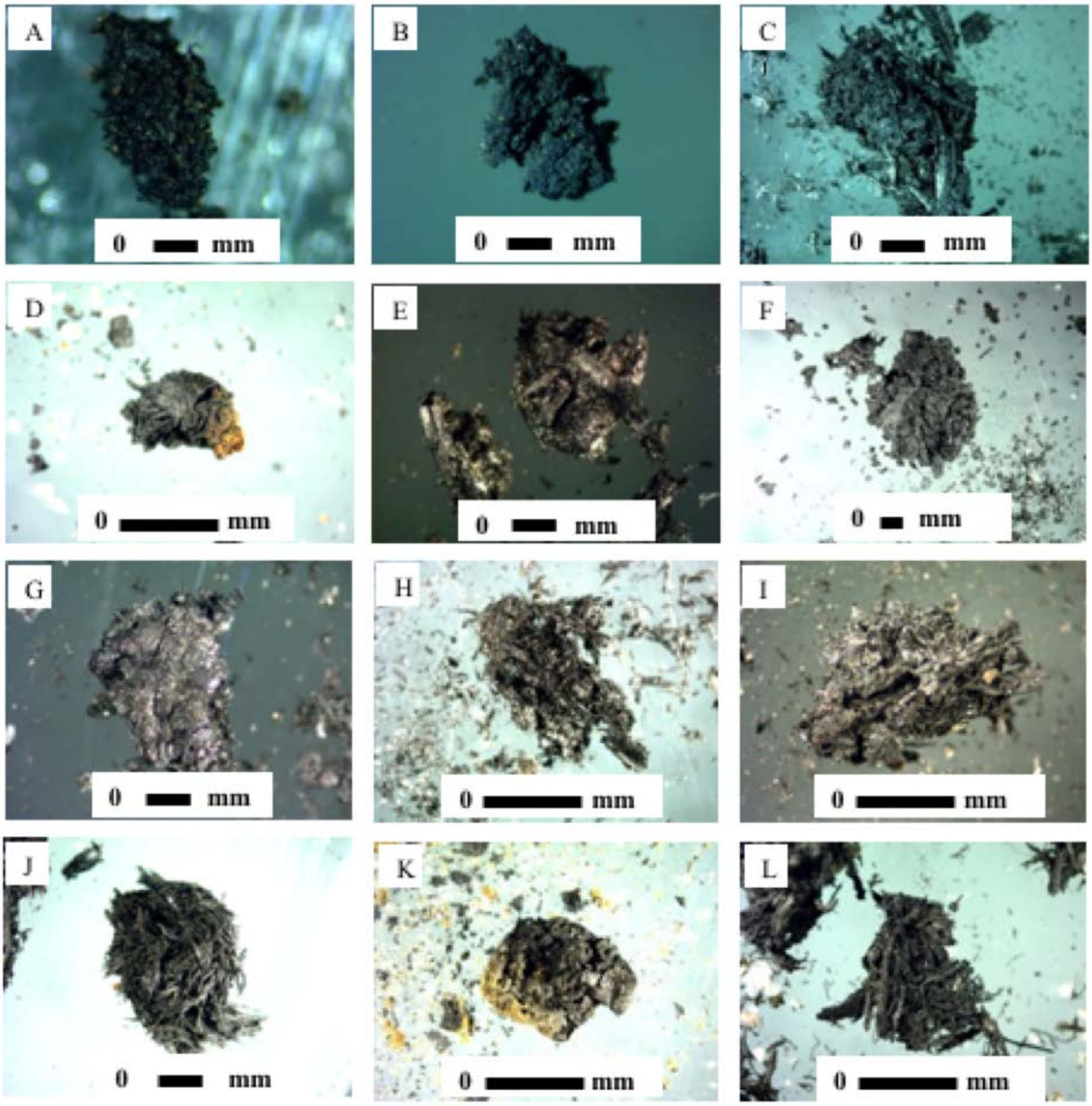

Figure 3. Charred peat identification Plate. Charred peat aggregates created in the laboratory from the global peatland samples obtained from the Geography Department at the University of Exeter. A: All Saints Bog; B: Sebangau Swamp; C: Manacrin Moor; D: Walton Moss; E: Crater Pool; F: Electric Bog; G: Fallahogy Bog; H: Fagelmossen; I: Dosenmoor; J: Instrument Bog; K: North Uist; L: Railway Bog.

Evidence of charred aggregates of decomposed peat was also apparent in several sections of the All Saints Bog core. Figure 5 shows example images of some of the charred aggregated partially decomposed organics found. The depths at which charred partially decomposed aggregates could be identified have been highlighted in Figure 4.

DISCUSSION

Charred peat particles

Many of the morphologies produced by laboratory charring of peat samples from 14 peatlands across the globe would be indistinguishable from those formed during the burning of surface fuels, e.g. preserved charred flowers, wood, seeds *etc*. (Figures 1, 2). However, charred aggregates of partially decomposed organics could also be observed. These varied in size, but can be described as being reasonably small (< 5mm), forming relatively spherical aggregates which contrasted strongly with the typical angular shape of charred plant material present in the peat matrix. These charred aggregates of partially decomposed organics, therefore, must have been peat before they were burned. The recognition of these charred partially decomposed aggregates may provide researchers with the ability to begin searching for smouldering fires in peatland palaeo-archives, and ultimately provide the ability to identify periods in Earth's past when the peat itself, i.e. not only the surface fuels of a peatland, carried fires.

Evidence of peat burning in the palaeo-archive

Similar partially decomposed charred aggregates were found in the All Saints Bog palaeo-archive. Overall, these represented only 3–8 % of the charcoal

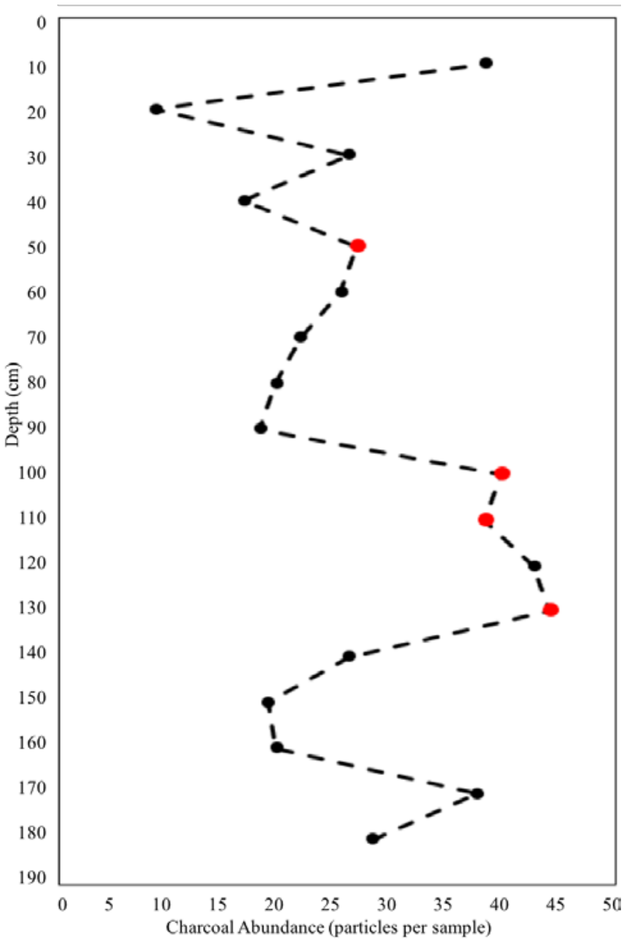

Figure 4. All Saints Bog charcoal abundance. Black dots represent the depths at which peat was sampled through the core and the red dots represent the samples in which charred peat aggregates were found.

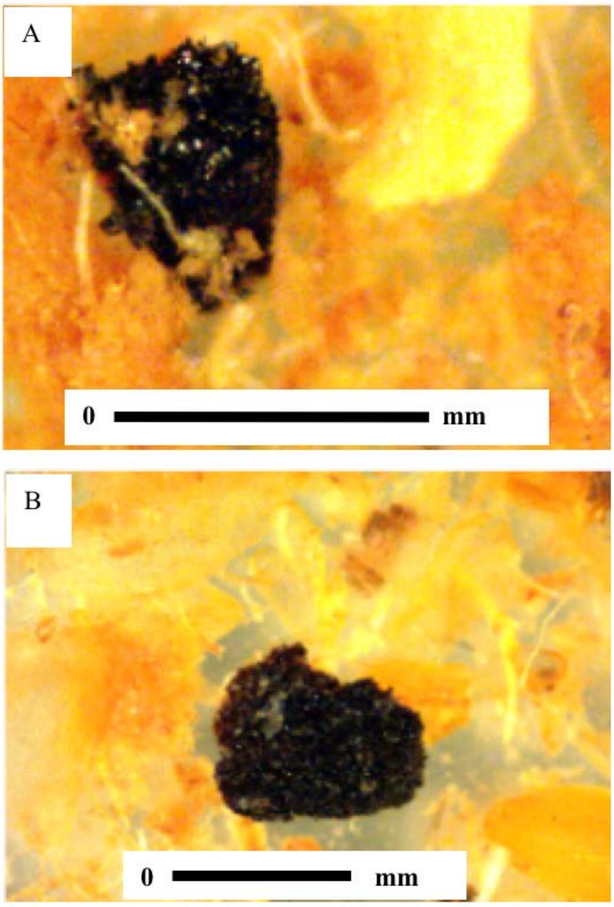

Figure 5. All Saints Bog charred decomposed peat aggregates. Images are from two of the four samples in which evidence of charred peat was found. A: a charred peat aggregate from depth 50–60cm; B: a charred peat aggregate from depth 100–110 cm.

assemblages; however, this is not surprising because smouldering combustion consumes both virgin fuel and the charcoal it creates, typically leaving only mineral ash (Rein 2013). Therefore, charcoal will remain from a smouldering fire only where the smouldering front met a barrier such as a surface edge or a change in peat bulk density (Prat-Guitart *et al.* 2016a) or peat moisture content (Prat-Guitart *et al.* 2016b) that could prevent combustion going to completion so that charcoal could remain. Therefore, we conclude that the fragments of charred partially decomposed organics found in the palaeo-archive of All Saints Bog indicate that the peat itself burned periodically, probably over a period of several thousand years.

Figure 4 shows the variations in abundance of all charcoal found throughout the All Saints Bog core. Also marked (in red) are the samples that contain charred peat. The periods of peat burning appear to coincide with both periods of overall increased fire activity (as evidenced by increases in all forms of charcoal) on the bog. It may be that the evidence of peat burning may highlight drier periods in the bog's history. Therefore, the charred peat aggregates may indicate periods of more severe fires, where either burning of surface fuels led to ignition of the dry peat soil beneath or the radiant heat from fires in the surface fuels pyrolysed part of the dry peat surface below. If ignition of surface peat occurred, this may have led to smouldering fires at depth in the peat matrix (Rein 2013).

The presence of indicators of peat burning in the palaeo-archive is surprising, because smouldering fires will consume much of the charred material they create (Rein 2013, Zaccone *et al.* 2014) until they meet a barrier to spread (e.g. Prat-Guitart *et al.* 2016a, 2016b). This makes the search for evidence of palaeo-peat fires analogous to searching for a needle in a haystack. It may be that the charred peat aggregates at All Saints Bog result only from heating of the peat surface by flaming fires carried in the vegetation above. This makes it difficult to discern whether the peat itself was carrying a significant smouldering fire; however, the surface peat must have been relatively dry in order for it to become pyrolysed. Therefore, whilst evidence of charred peat is presented in this article, the aim is simply to highlight its nature so that charred peat aggregates might be more readily recorded as standard practice by those quantifying charcoals in peat archives. It is hoped that further studies can begin to build a larger picture of the occurrence of charred peat in peatland records in order for the discipline to take the first steps towards identifying evidence of major episodes of peat burning in the palaeo-archive.

CONCLUSIONS

This study has created and identified the nature of charred peat and has shown that charred decayed organic aggregates may be useful for identifying historical peat fires. We have applied these findings to search for and find evidence of peat burning in the palaeo-archive of a temperate peatland, All Saints Bog. We suggest that these particles may be used as evidence of smouldering fires throughout the Holocene peatland archive. This is potentially of great utility because fire and the effect it has on C cycling in peatlands is a key uncertainty that it is necessary to constrain in order for peatlands to be fully included in earth system models (Limpens *et al.* 2008, Ballhorn *et al.* 2009). Gaining a better understanding of the interactions between climate and smouldering fires and their influence on C cycling in peatland archives may help to improve future predictions of global C cycle – climate change feedbacks. It is hoped that the recognition and descriptions of charred peat presented here will provide the first steps towards allowing researchers working on the palaeo-archive to begin documenting the history of smouldering fires in peatlands.

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