Appendix 13 of BD5104

Palaeo-ecological assessments on past burn frequencies and peat accumulation

The purpose of this Appendix is to further describe the methods and findings relating to the palaeo-ecological assessments which are described in Section 4.3.3 of the main body of the report for project BD5104. The methods summaries, results and discussions are not repeated here but instead the full details of the methods, some more detailed graphical results and information on the statistical analyses are given.

Sampling

A total of 6 cores were taken from the three sites across the North York Dales (see **Figure 90** in the main report) between 30th March 2016 and 1st April 2016 which were preserved by keeping in a cold store for one month and then freezing in the laboratory. Two 1 meter long peat cores were taken from each site within a 50 cm area from within the burn sub-catchment (at plot No 3 for all sites) using a 5 x 5 cm box corer (see **Figure 13** in the main report) for humification (von Post), bulk density (BD), macro-charcoal (>120 µm particle size) and spheroidal carbonaceous particles (SCP) profile analysis. Where applicable, results of the paired cores were pooled.

Humification assessment

The peat cores were first examined to assign a humification value based on the von Post scale. This scale originated in the 1920s and the version used is the modified scale presented in Ekono (1981). Humification indicates the degree of decomposition of peat, with lower humification indicated by light or brown peat with more plant material, and higher decomposition in dark or black peat with a more uniform texture. This scale is a relatively subjective measurement based on observation including squeezing of peat. However, the core had to be used for analysis intact and so it was not possible to squeeze the extracted peat to estimate water colour, one of the characteristics used in the von Post values. Scale values were therefore based on plant material, texture and colour only. The von Post scale ranges from 1 (least humified) to 10 (most humified).

Carbon content

Carbon content was obtained from the overall peat carbon (C) stock assessment as part of the plot surveys (see Section 4.2.2 in the main report and Appendix 2). C contents of the control (i.e. burnt) plots (as the peat cores were also taken from burnt plots) for the 0-5 cm, 10-15 cm, 20-25 cm peat layers were included in this analysis and continuous estimates were based on a linear interpolation between these depths for the individual sites. Carbon content was measured using carbon and nitrogen (C/N) elemental analysis (see Appendix 2 for further information) on 5 g of peat which was removed from two corners of the 5 cm subsample sections, and passed through a ball mill for 2 minutes at 25 reps/second. About 80 mg of the milled samples was then sealed in pre-weighed tin foil capsules and run through a vario Macro, Elementar Analysensysteme GmbH, Hanau, Germany C/N analyser according to a standard operating procedure ('Plant500'; Environment Department, University of York). Results were factored to glutamic acid standards.

Bulk density

To determine bulk density (BD), 2 cm^3 contiguous subsamples at 0.5 cm resolution were cut from the 1 meter long cores from each site over the SCP depth layer (i.e. not going lower than the deepest SCP record). A saw and a chisel were used to sample from the frozen cores (see **Figure 90** in the main report) and dimensions were measured with a Vernier calliper (see De Vleeschouwer et al. 2010). Samples were dried at 105°C in 10-30 ml crucibles for a minimum of 48 hours (or longer until constant weight was achieved) with samples being cooled in a desiccator and BD was calculated as g dry matter per cm^3.

Carbon stocks

Carbon stocks were derived by multiplying carbon content ($\%C_{org}$) with the BD of the corresponding peat profile section, using interpolated values for $\%C_{org}$ between sections.

Macro-charcoal analysis

Peat cores from each site (two for Nidderdale but only a single core was analysed for Mossdale and Whitendale) were analysed for macro-charcoal content following the sieving method described by Mooney and Tinner (2011). Contiguous 2 cm^3 subsamples at 0.5 cm resolution to a depth of 25 cm were left in a 10-15% solution of hydrogen peroxide (H_2O_2) for a minimum of 24 hours in order to bleach the organic matter allowing for counting of the charcoal particles which remain unchanged by the H_2O_2. Bleached samples were gently washed through nested sieves of two mesh sizes to capture two size fractions (>120 µm and >500 µm) of charcoal particles. These were counted separately on a petri dish with a coarse grid under a light microscope at x20 magnification but counts were combined for the final burn frequency analysis (i.e. peak determination).

Spheroidal carbonaceous particle analysis

Spheroidal Carbonaceous Particles (SCPs) were analysed according to Swindles (2011) with some adaptations due to the specific nature of the peat. Contiguous 2 cm^3 subsamples of the peat cores from each site were taken to a depth of 16 cm at 0.5 cm resolution. These were dried overnight at 105°C and 0.1 g of dried sample was then prepared using an acid digestion in 30 ml of concentrated nitric acid (HNO_3), which was left for 24 hours at room temperature before being put on a hot plate at 140°C of up to 10 hours (i.e. until the solution was reduced to approximately 5 ml and all organic material had dissolved). Subsequently 10 ml of deionised water were added and the suspension was transferred to a 15 ml polypropylene centrifuge tube for centrifuging at 1500 r.p.m. for five minutes. The supernatant was decanted into a sink and the residue was washed twice more with deionised water, centrifuged and the supernatant decanted. The final residue was decanted into a small (~15 ml or less) centrifuge tube and as much water as possible was removed using a Pasteur pipette (the remaining sample weight was determined). A small quantity of the liquid residue (a drop) was removed and placed on a coverslip (the remaining sample residue was weighted again to determine the actual sample weight analysed for SCPs). The coverslip was left in a fume hood overnight to evaporate all water. A known quantity of the final solution was mounted on 22 mm rectangular slides using Histomount. SCPs were counted under a light microscope at x400 magnification (12 transects were counted and the observed area up-scaled to the entire coverslip area) and expressed as # gDM^{-1} (number of particles per gram of dry mass of peat) according to Swindles (2011). SCPs of approximately 2 microns and larger were identified based on their spheroidal three-dimensional morphology (determined by focusing in and out on the particle using a light microscope) and distinctive black colour. SCP particles are usually between 10 and 70 µm in diameter and may have a pitted or lacy surface texture (Swindles, 2011). The trace of SCPs in the cores from this study was undetectable below a depth 15 cm.

Burn frequency estimates

Past fire frequencies were based on the number of identifiable charcoal peaks (for the combined size fractions) per time period (1950-2015; 1850-1950; 1700-1850). For this the surface burn layer marked 2013 (managed burn), the SCP dating (defined by the SCP peak, its onset and decline) was used to obtain a site specific depth corresponding to the years 1975, 1950 and 1850 (as per Swindles, 2010) and the year 1700 was assumed to be the same for all three sites (25 cm peat depth) based on dating a very similar blanket bog with similar peat depth and at similar altitude at Moor House (Swindles et al, unpublished). Therefore, the oldest age was the most uncertain as it had to be assumed that past accumulation rates were similar across the three sites (which is likely as none of the sites were knowingly managed for grouse before 1850). If a charcoal peak occurred on an age threshold, it was counted only in the upper layer.

Peat and carbon accumulation rates

Peat accumulation across the peat profile was calculated by using the peat depth increments (over time as derived by the SCP method), and carbon accumulation was based on the carbon increments over the SCP identified time periods (see burn frequency method section above) or depth layers. For carbon accumulation rates this involved using the interpolated BD and %C_{org} data (see carbon stock method section above).

Statistical Analyses

Differences in the peat depth, carbon stock and accumulation rates between the three sites were analysed using one-way ANOVA and Kruskal-Wallis H tests. For accumulation rates, data were grouped by periods defined by the onset and decline of SCPs and analysed using the Kruskal-Wallis H test.

Results (in addition to the main report)

The humification assessment observed fairly similar patterns across the three sites with humification increasing with depth (see **Table A13.1**). However, at all sites there was a slight increase in humification from the surface (H3-H4) to around 10 cm depth (H5-H6) with a subsequent decline (H4-H5). At both Whitendale and Nidderdale the humification was highest (H7-H9) at around 20 cm depth with decreasing humification towards the lowest section (H5) whilst Mossdale increased with depth (to H8).

Table A13.1 Humification (von POST) values for individual peat depth sections identified by visual assessment of the peat for the three sites. Additional comments highlight observations in addition to colour and texture.

Site	Depth (cm)	von Post Scale Value	Notes
Whitendale	0-3	H4	Some undecomposed plants at top; slightly pasty
	3-7	H6	Reddish layer with less plant material, pasty
	7-14	H5	Pasty with some root material
	14-24	H9	"Fudgy", pasty, uniform - gradual, indistinct transition at bottom
	24+	H5	Noticable root fibres
Nidderdale	0-5	H3	Mostly leaf matter, little decomposition.
	5-10	H5	Slightly decomposed, plants had some features
	10-13	H4	Grass/sedge leaves and seeds identifiable, soft and slightly pasty
	13-20	H5	Some identifiable grass/sedge leaves, more pasty and wet than previous layer
	20-28	H7	Pasty, some root structures, less plant material than other layers
	28+	H5	Pasty, but slightly granular, some root and a very few grass/sedge leaves
Mossdale	0-5.5	H3	Moss visible, some still greenish, very fibrous, slightly decomposed
	5.5-15	H5	Some root material and small sticks/branches, pasty with few identifiable plants
	15-34	H4	More plant material and grass/sedge leaves
	34-58	H6	Some root fibres, but more uniform mass and pasty; air pocket at bottom margin
	58+	H8	Very uniform, "fudgy", very occasional root fibre

The SCP profiles revealed a clear peak at around 5-6 cm peat depth (**Figure A13.1**). However, whereas the two counts at Mossdale and Whitendale gave very similar peak profiles, Nidderdale cores showed a shift in the peak (5 cm vs. 3.5 cm) and the average value was taken for all three sites. Moreover, whereas the 1st count at Mossdale and Whitendale and all 2nd counts were done by the same person, the 1st count at Nidderdale was done by a different person, which could explain the observed difference.

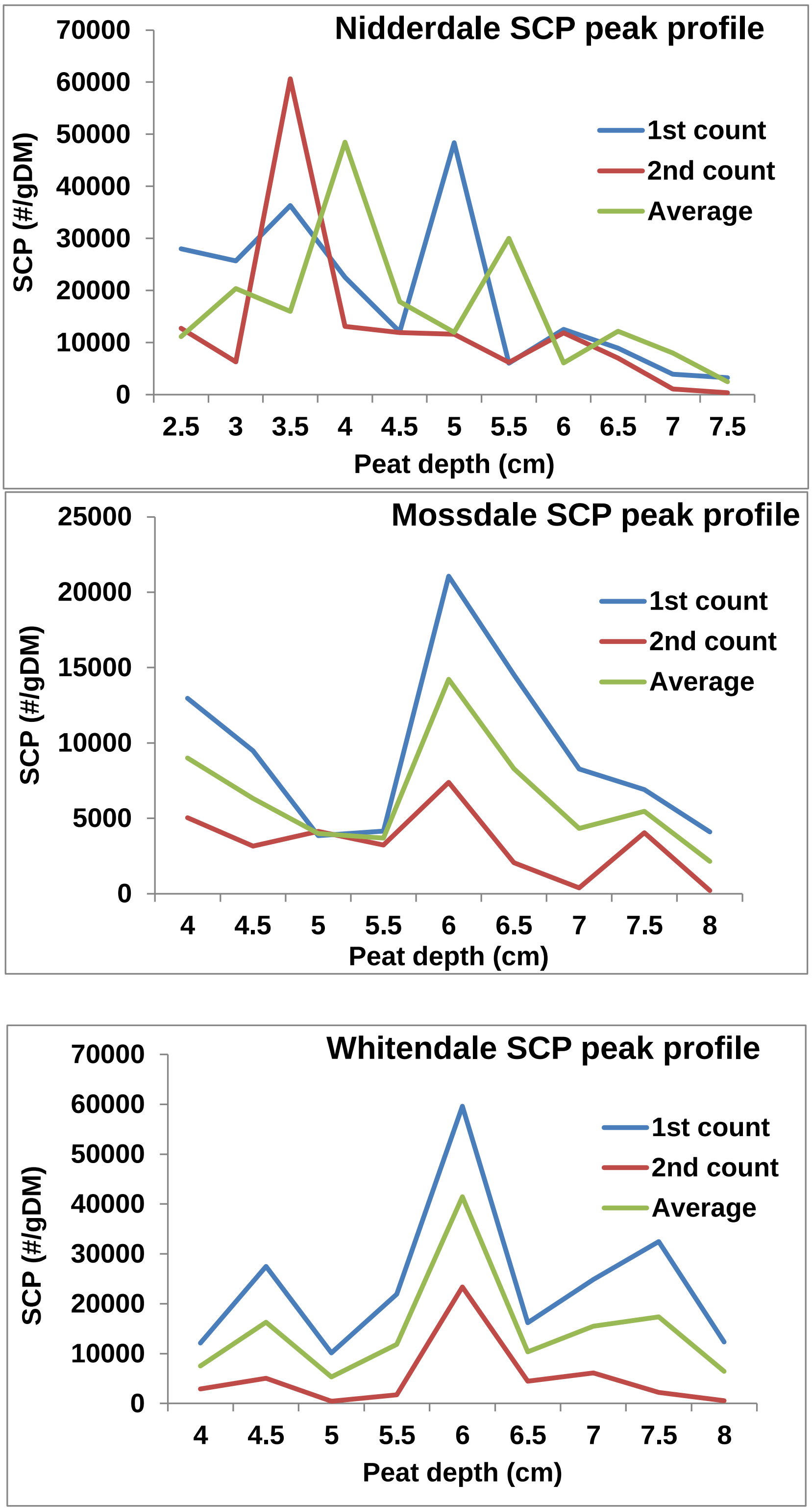

Figure A13.1 Spheroidal carbonaceous particle (SCP) counts per peat sample dry weight over the surface peat depth (cm) range around the SCP peak comparing the two individual counts (blue and red line) *versus* the average for Nidderdale (**top**), Mossdale (**middle**) and Whitendale (**bottom**). The peak used for the dating analysis was based on the peak of the average (green) line.

The BD analysis revealed an overall increase from Mossdale to Nidderdale to Whitendale when averaged across the top peat section (0-15 cm) depth (**Figure A13.2** and **Figure 91** in the main report).

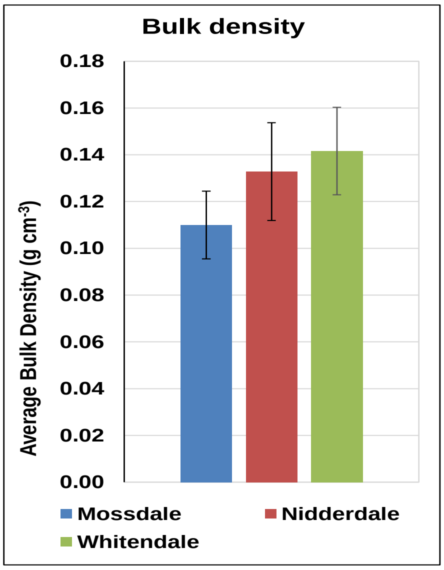

Figure A13.2 Average bulk density across the top peat profile section (0-15 cm) for the three sites (Nidderdale, Mossdale, Whitendale). Results for the Nidderdale site represent the mean of two cores.

Peat C accumulation rates compared well to published data from other peatland sites over corresponding time periods (see **Table A13.2**).

Table A13.2 Comparison of C accumulation rates between the three sites in this study and published values for peatlands across England and Scotland. Note that the only values which are experimentally derived are from this study and Garnett (1998). Billett et al. (2010) provided a best estimate assuming 50% C content and 98% loss-on-ignition. Lochnagar is 788 m a.s.l and has ~1600 mm annual rainfall according to Yang et al. (2002) and Gordon et al. (1998) and may be burnt (Dalton et al., 2005).

Location	Site Type	Management	Sample ID	Carbon Accumulation Rates Between Periods		Burn frequencies between periods (every # years)		Sampling Date	Source
				1950 – 1970s	1865 - 1950	1950 – 1970s	1865 - 1950		
Butterburn Flow	Raised Mire	NA	BFA BFB Mean	82.2 119.0 100.6	73.1 39.7 56.4	NA	NA	1999	Billett *et al.*, 2010 (data from Charman, 2007)
Lochnagar	'Alpine' Sloping Blanket Mire	Possible burning / grazing	LAB-A	56.9	39.6	NA	NA	1997	Billett *et al.*, 2010 (data from Yang *et al.*, 2001)
Mossdale	Blanket Bog	Prescribed Burn	MC3	46.08 ± 4.25	34.08 ± 3.42	25	21	2012	This Study
Nidderdale	Blanket Bog	Prescribed Burn	NC3	91.04 ± 22.51	44.93 ± 6.31	13	28	2012	
Whitendale	Blanket Bog	Prescribed Burn	WC3	57.01 ± 9.57	44.98 ± 2.98	13	43	2012	
Moor House	Blanket Bog	Prescribed Burn	MH2		30.00	10	?	1996	Garnett, 1998

Location	Site Type	Management	Sample ID	Rates Between Periods: 1955 – end date		End Date	Burn frequencies between periods	Source
				Lower estimate	Upper Estimate		1955 – 2015	
Mossdale	Blanket Bog	Prescribed Burn	MC3	75.9 ± 19.8		2015	17	This Study
Nidderdale	Blanket Bog	Prescribed Burn	NC3	77.06 ± 22.6		2015	13	
Whitendale	Blanket Bog	Prescribed Burn	WC3	82.81 ± 26.1		2015	10	
Moor House	Blanket Bog	Prescribed Burn	VEG 1	19.6	60.0	2005	10?	Hardie *et al.*, 2007
			VEG 2	82.6	123.0			
			VEG 3	>72.6	>72.6			
			SOIL 1	33.2	88.0			
			SOIL 2	44.6	79.8			
			SOIL 3	30.4	71.0			

The average charcoal count for the Nidderdale site (**Figure A13.3**; shown as SQRT transformed count data to assist peak identification - shown are the individual counts for each of the two analysed peat cores) indicated clear peaks throughout time with generally less frequent peaks but increasing charcoal amounts towards the peat surface (< 10 cm).

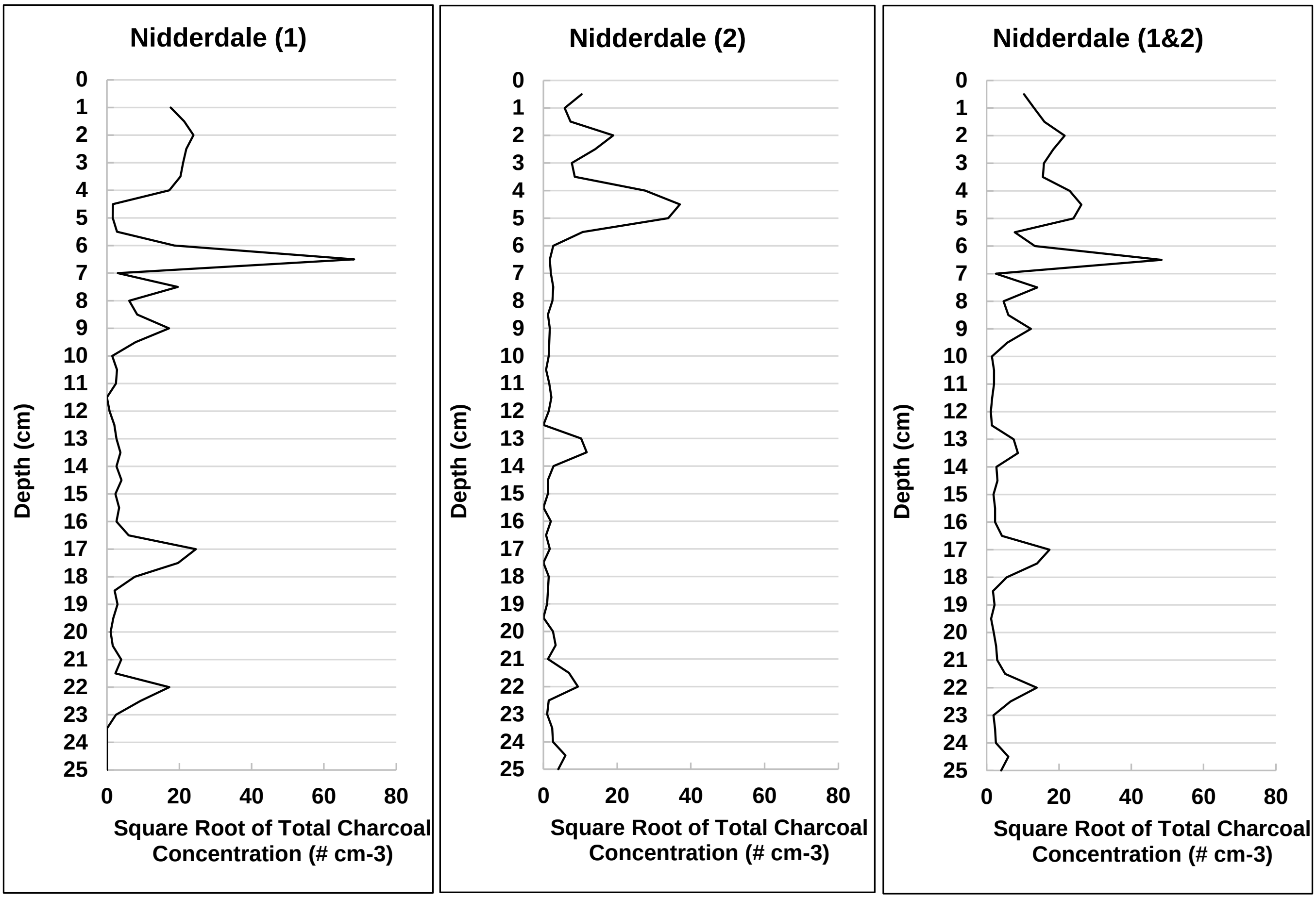

Figure A13.3 Charcoal counts (as the square root of the number of counts for the combined size classes > 120 µm per cm^{-3} peat sample) across the two peat profiles (0-25 cm) for Nidderdale, either single or combined (right) used for calculating burn frequencies.

The average charcoal count for the Mossdale and Whitendale sites (**Figure A13.4**; shown as SQRT transformed count data to assist peak identification - only one core was analysed per site) also indicated clear peaks throughout time, again with generally less frequent peaks but increasing charcoal amounts towards the peat surface (< 10 cm).

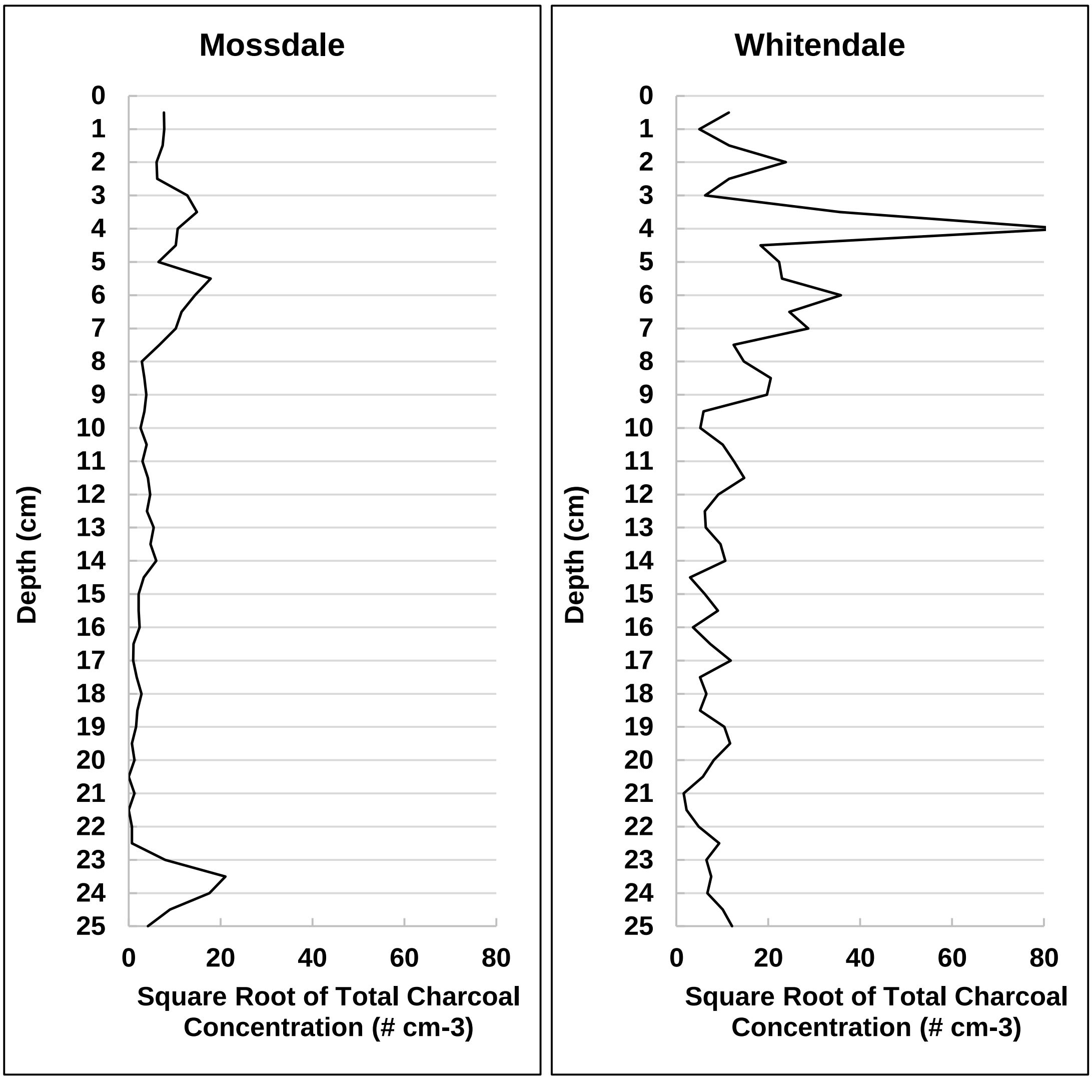

Figure A13.4 Charcoal counts (as the square root of the number of counts for the combined size classes > 120 µm per cm^{-3} peat sample) across the peat profiles (0-25 cm) for Mossdale and Whitendale used for calculating burn frequencies. Note that for comparison the same x-axis scale was used.

Site specific log transformed regression between peat accumulation, carbon accumulation rates, carbon content (%C_{org}), bulk density (BD) and charcoal concentrations (**Table A13.3**) highlighted site differences and the importance of charcoal in relation to peat and carbon accumulation.

Table A13.3 Regression model statistics for the natural log (ln) transformed charcoal concentrations against peat and carbon accumulation rates, carbon content and bulk densities as shown in **Figure 94** in the main report.

Mossdale	**P value**	**Significance**	**Adj. R2**	**n**	**DF**
ln charcoal ~ peat accumulation	0.000056	***	0.43	30	28
ln charcoal ~ ln carbon acc	0.000013	***	0.48	30	28
ln charcoal ~ carbon content	0.000113	***	0.40	30	28
ln charcoal ~ BD	0.002990	**	0.25	30	28
Nidderdale					
ln charcoal ~ peat accumulation	0.000174	***	0.38	30	28
ln charcoal ~ ln carbon acc	0.000044	***	0.44	30	28
ln charcoal ~ carbon content	0.000004	***	0.53	30	28
ln charcoal ~ BD	0.032200	*	0.12	30	28
Whitendale					
ln charcoal ~ peat accumulation	0.097900		0.06	30	28
ln charcoal ~ ln carbon acc	0.025400	*	0.14	30	28
ln charcoal ~ carbon content	0.017270	*	0.16	30	28
ln charcoal ~ BD	0.026400	*	0.13	30	28

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