Appendix 6 of BD5104
Carbon flux measurements and modelling

The purpose of this Appendix is to further describe the methods relating to soil respiration (SR) and net ecosystem exchange (NEE) fluxes using an infrared gas analyser (IRGA) which are described in Sections 4.2.13 and 4.2.14 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 are given. Additionally, further details for up-scaling the NEE fluxes are given, along with details on the construction of the carbon budgets for the different sites and managements.

Methods

Each permanent plot on each site had a circular area chosen and marked for NEE and SR flux measurements. The NEE and SR fluxes at a single site were always measured on the same day as each other in order to reduce climate variations between plots in a single measurement set. The measurement dates are given in **Table A6.1**.

Table A6.1 Measurement dates for gas flux measurements (CO_2 and CH_4) during the project period 2012-2016 at the three project sites Nidderdale, Mossdale and Whitendale.

Nidderdale	Mossdale	Whitendale
24/07/2012	26/07/2012	25/07/2012
09/10/2012	10/10/2012	12/10/2012
04/12/2012	05/12/2012	11/12/2012
25/06/2013	26/06/2013	27/06/2013
17/07/2013	18/07/2013	19/07/2013
02/09/2013	03/09/2013	04/09/2013
26/11/2013	27/11/2013	28/11/2013
08/04/2014	09/04/2014	10/04/2014
23/06/2014	24/06/2014	25/06/2014
08/09/2014	09/09/2014	10/09/2014
10/11/2014	11/11/2014	12/11/2014
10/03/2015	11/03/2015	12/03/2015
30/06/2015	01/07/2015	02/07/2015
18/08/2015	19/08/2015	20/08/2015
25/11/2015	08/12/2015	04/12/2015
14/03/2016	15/03/2016	16/03/2016
18/07/2016	19/07/2016	20/07/2016
25/10/2016	26/10/2016	27/10/2016

Soil respiration (SR)

A 15 cm diameter circle with no vascular plants was marked by removing the moss layer from the surface to create a bare peat measurement area (including respiration from roots and soil; SR). A similar circle was cut twice a year to a depth of 25 cm using a soil corer to sever roots (giving soil only respiration; SRc). From July 2015 onwards, fluxes were also measured on 10 cm diameter areas, which were next to vascular plants (i.e. more roots than the bare patches) and had the moss temporarily removed, within or directly next to the NEE circles to give a more accurate representation of the autotrophic root respiration (respiration of soil and lots of plant roots; NEEnew).

For all SR flux measurements, the IRGA was connected to a 10 cm automated survey chamber (Model 8100-102, Li-Cor, Lincoln, NE, USA). A 10 cm diameter, 5 cm tall uPVC collar (Plumb Center, Wolseley UK Ltd, Leamington Spa, UK) with a bevelled bottom edge was placed firmly (i.e. in full contact with the soil but without cutting sub-surface roots and thus altering the root-derived flux contribution; as per Heinemeyer et al., 2011) in the centre of the SR circles with the survey chamber on top. The CO_2 concentration in the chamber was measured every second for 45-60 seconds.

The LiCor Viewer software was used to derive the CO_2 fluxes from the most linear 30 s portion, based on the R^2 value, of each measurement (Li-Cor Biosciences, 2007). The chamber volume and collar surface area were used to express all CO_2 fluxes in µmol CO_2 m^{-2} s^{-1}. Each SRc flux was subtracted from the corresponding SR flux from the same plot, which was measured at the same time, to derive a flux for the root respiration only (Rr). Similarly, the root respiration fluxes for the vegetated ground were calculated by subtracting the SRc fluxes from the NEEnew fluxes (Ra NEEnew).

Q_{10} calculations

The SR fluxes were used to derive the Q_{10} values of temperature sensitivity for the mean SR, SRc and Ra NEEnew fluxes (i.e. including or excluding roots) for each management in the pre- and post-management periods, based on Atkin et al. (2000) as described in Heinemeyer et al. (2012). Linear regressions of the $\log_{10}$ of soil CO_2 effluxes against soil or air temperature were performed, for which the slope, β, was inserted into the equation:

$$Q_{10} = 10^{[10 \times \beta]} \qquad \textbf{Eq.A6.1}$$

to calculate the Q_{10} values. The Standard Error (SE) for the Q_{10} values was derived by solving **Eq.A6.1** for the upper and lower 95% confidence limits of β obtained from the regression output and dividing the difference between them by 3.92 (equal to the range either side of 1.96; Higgins & Green, 2011).

Net Ecosystem Exchange (NEE)

A 30 cm diameter circle, which included *Calluna* and other vascular plants, was marked with a metal peg to allow exact relocation on subsequent measurement occasions. A custom built clear Perspex chamber (Biology Mechanical Workshop, University of York, UK) with an internal diameter of 29.5 cm and a height of 20 cm, connected to an infrared gas analyser (IRGA; Model 8100, Li-Cor, Lincoln, NE, USA), was used for NEE measurements. All plants which were rooted within the NEE circle were manually bundled together to allow accurate chamber placement, and a photosynthetic active radiation (PAR) sensor (QS5 – PAR Quantum Sensor, Delta-T Devices, Cambridge, UK; connected to the Li-Cor external sensor interface and attached to a stick) was positioned within the NEE circle so that it would not be covered by vegetation or shadows and the chamber was carefully placed over the stems and sensor. On plots where the vegetation was taller than 20 cm (all plots in the pre-management period and DN plots throughout), an extra collar of the same clear Perspex and either 20 or 40 cm tall (depending on the vegetation height) was placed over the vegetation with the chamber placed on top and taped around to seal the join. A pressure vent (Li-Cor) was attached to the top of the chamber to avoid over pressuring during chamber placement, whilst also limiting Venturi (wind) effects. A temperature sensor (Therm 30K OHM@25C, part number: 434-08943, Li-Cor, Lincoln, NE, USA) connected to the IRGA was inserted to 5 cm peat depth next to the chamber and the chamber was sealed to the atmosphere by means of wet *Sphagnum* moss (taken form unmanaged areas at the site) being tucked around the base.

The CO_2 concentration within the chamber was measured every second (s) for 90 s per light level. These measurements were made in more than 90% of the total PAR (“Full Light” measurement; trials prior to this study determined that the amount of light reflected by the Perspex of the chamber was less than 10%; A. Heinemeyer, unpublished data). Without removing the chamber, a shading mesh was placed over the chamber ("30% Light" measurement; on average 30% of total light penetrated the chamber) and CO_2 concentrations recorded for another 90 s. Depending on the light conditions and amount of vegetation in the chamber, a second shading mesh was placed over the first ("10% Light" measurement; on average 10% of total light penetrated the chamber) and another 90 s flux was recorded. For the final 90 s flux, a custom made cover (Environment Department, University of York, UK) was placed over the chamber, blocking out all light (ecosystem respiration or "R_{eco}" measurement). The *Sphagnum* moss seal was removed from plots after measurements to prevent establishment on the NEE circles and to avoid excess relocation around the site.

The LiCor Viewer software was used to derive the CO_2 fluxes from the most linear 40-60 s portion (Li-Cor Biosciences, 2007) of each NEE measurement under each light condition. For all 2012 NEE measurements and all NEE measurements on DN plots, the measured *Calluna* volume (see Section 4.2.5.2 of the main body of the project BD5104 report for the rationale for and results of *Calluna* volume measurements) was subtracted from the chamber volume. All CO_2 fluxes were adjusted for (corrected) chamber volume and collar surface area and all fluxes were expressed in µmol CO_2 m^{-2} s^{-1}.

Up-scaling NEE fluxes

The NEE fluxes were up-scaled temporally (monthly and annually) and spatially (i.e. area) from fluxes measured in the field across the range of light levels to annual NEE estimates. This was performed separately for the FI, LB and DN managements at each of the three sites. For each measurement date, a light response curve was modelled for each of the three selected managements at each site (i.e. a curve was modelled for FI measurements at Nidderdale in July 2012, a separate curve for FI measurements at Nidderdale for October 2012, etc.), using the equation:

$$CO_2 \text{ flux}=\left(\frac{P_{max}\times PAR}{PAR+K_m}\right)+R_{eco} \qquad \textbf{Eq.A6.2}$$

where CO_2 flux is the modelled CO_2 flux at a particular light level, P_{max} is the maximum CO_2 uptake of the curve, PAR is the amount of light in µmol m^{-2} s^{-1}, K_m is a calculated constant and R_{eco} is the modelled maximum CO_2 release (equivalent to the R_{eco} measurement with the dark chamber cover). Following Brown (2001), P_{max}, K_m and R_{eco} were calculated using the Solver function in Excel (Microsoft, 2010), which was set to maximise the R^2 of the modelled curve through the measured data points (see **Figure A6.1** for comparison of measured *versus* modelled light response curves for Nidderdale DN plots in October 2012; Nidderdale DN plots in 2012 will be used as an illustrative example throughout this explanation).

This enabled filling in of all terms except PAR in **Eq. A6.3**. For Nidderdale DN plots in October 2012, this gave the equation:

$$CO_2 \text{ flux}=\left(\frac{-10\times PAR}{PAR+1010}\right)+2.6 \qquad \textbf{Eq.A6.3}$$

There were three set of NEE measurements made in 2012 and four sets in each of the other three years. For each year, the calculated P_{max} values for each site and management combination were regressed against the average air temperature inside the chamber during that measurement set (e.g. the average air temperature in the chamber for all DN plots measured at Nidderdale in October 2012), giving a linear equation (e.g. **Figure A6.2**, top). Similarly, the calculated R_{eco} values were regressed against the same chamber temperature averages, producing exponential equations (e.g. **Figure A6.2**, bottom).

Monthly averages of PAR were calculated from the hourly measured automatic weather station (AWS) recordings at each site. For each year, the K_m values for each site and management (i.e. uncut, burnt and mown with brash left) combination were regressed against the monthly PAR measurements for the months in which NEE measurements occurred. This produced a linear equation for which the intercept was set to zero (e.g. **Figure A6.3**). As the NEE fluxes of the mowing treatments did not differ significantly (see **Figures 76-78** in the main report), only the main catchment scale mowing management with leaving brash (LB) was considered for up-scaling.

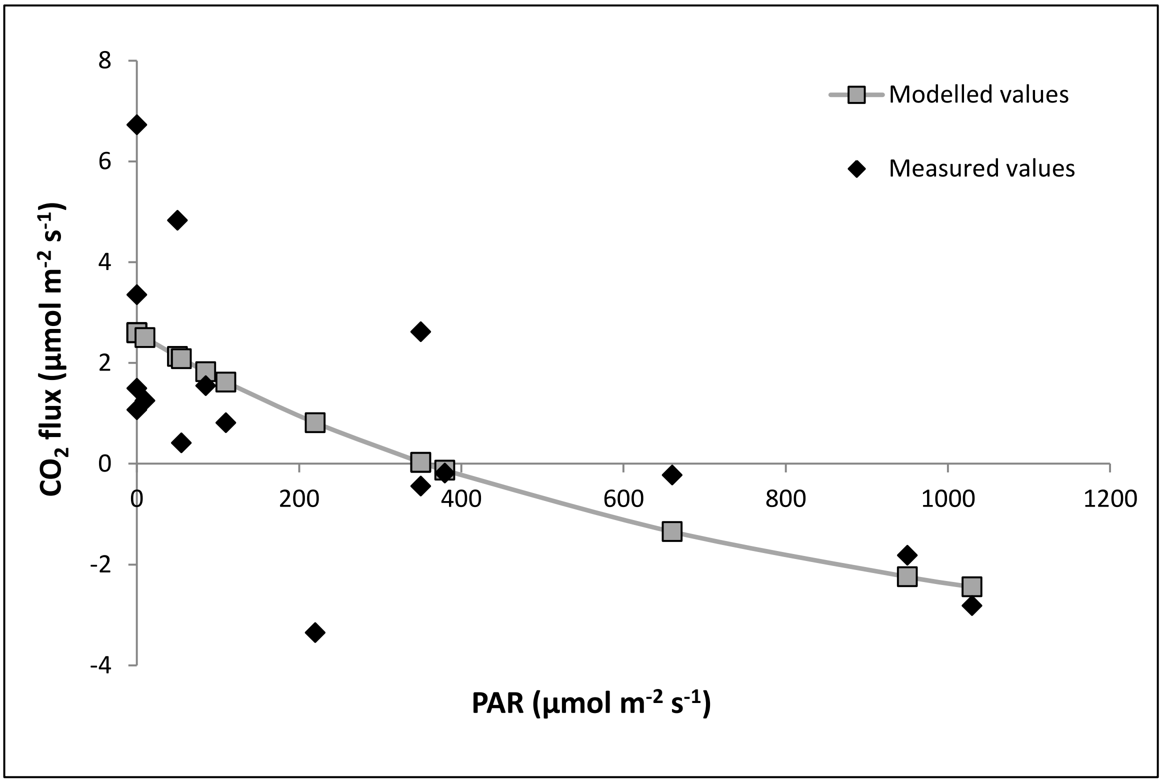

Figure A6.1 Comparison of the measured CO_2 fluxes at different PAR levels to the modelled values which were used to construct the light response curve for Nidderdale DN plots in October 2012, and from which the parameters P_{max}, K_m and R_{eco} are derived in **Eq. A6.2**.

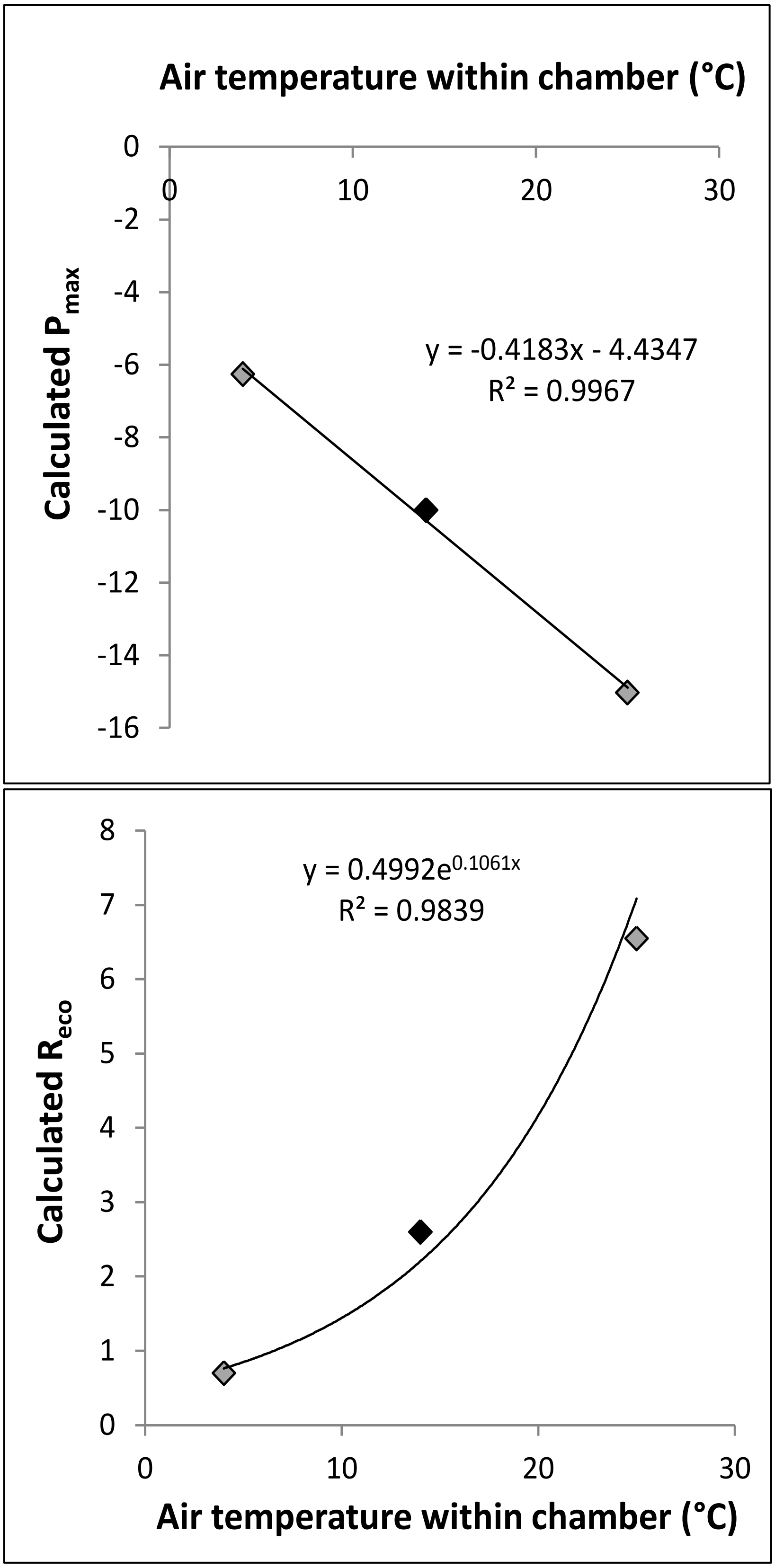

Figure A6.2 Regression between chamber air temperature and (**top**) the calculated P_{max} values (linear) and (**bottom**) the calculated R_{eco} values (exponential) for Nidderdale DN plots in 2012. The points incorporating the calculated P_{max} and R_{eco} values from **Eq.A6.3** are in black to enable identification. The regression equations are displayed with R^2 values.

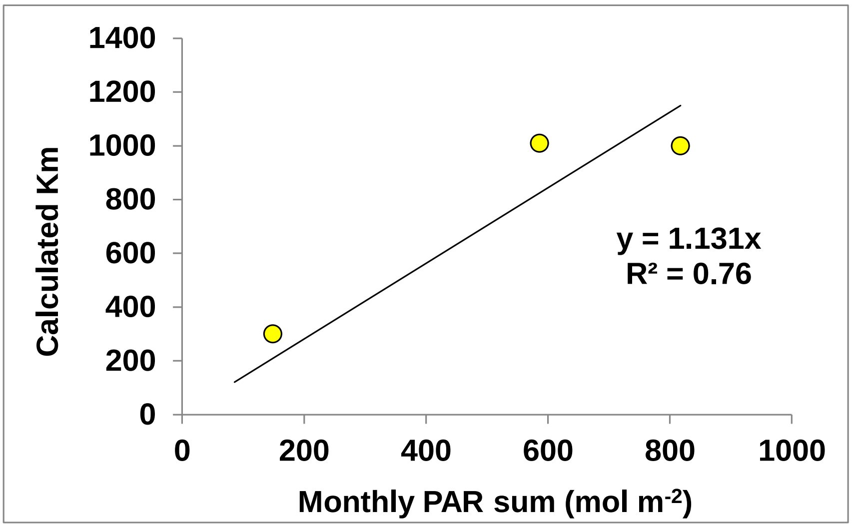

Figure A6.3 Linear regression between the calculated K_m values for Nidderdale DN plots in 2012 and the corresponding monthly PAR sum (based on hourly data) measurements. The point incorporating the calculated K_m value from **Eq.A6.3** is shown in black to enable identification. The regression equation is displayed with the R^2 value.

Values for R_{eco} (the maximum C release) and P_{max} (the maximum NEE C uptake) were calculated on an hourly basis for each site and management using the equations derived from regression with chamber temperature (e.g. **Figure A6.2**), where x was the hourly air temperature recorded by the AWS. Likewise, the equation derived from the regression of K_m and PAR (e.g. **Figure A6.3**) was used with the average monthly PAR measurements from the AWS to calculate a value of K_m (i.e. PAR-Slope) for each month of each year for each site and management combination. The annual K_m (i.e. PAR-Slope) and NEE (R_{eco}, P_{max}) equations (**Table A6.2** and **A6.3**, respectively) revealed an overall fairly stable relationship (i.e. similar equation parameters), particularly for the uncut treatment, whereas equation parameters changed (declined) immediately after management (i.e. burnt and mown plots) with subsequent recovery (increase) over time.

Table A6.2 Equations for the predicted monthly photosynthetic active radiation (PAR) slope (Km) light response curve parameter (PAR-to-flux slope) based on regression of the measured PAR slope (for each flux campaign) against the monthly PAR totals (x) obtained from the weather stations at Nidderdale (Nidd), Mossdale (Moss) and Whitendale (Whit) during each year or pair of years for the three major management regimes (Uncut, Burn, Mown [for left brash; LB]).

PAR SLOPE	NIDD		MOSS		WHIT	
UNCUT	EQN	r2	EQN	r2	EQN	r2
2012	= 1.4065x	0.8	= 0.6649x	0.52	= 0.6307x	0.18
2012-2013	= 1.2058x	0.32	= 0.7683x	0.8	= 0.7421x	0.8
2013-2014	= 1.3239x	0.36	= 0.7857x	0.82	= 0.9261x	0.49
2014-2015	= 1.228x	0.32	= 0.6785x	0.57	= 0.9345x	0.31
2015-2016	= 1.131x	0.76	= 0.7447x	0.14	= 1.0487x	0.21

PAR SLOPE	NIDD		MOSS		WHIT	
BURN	EQN	r2	EQN	r2	EQN	r2
2012	= 1.3651x	0.87	= 0.41x	-0.09	= 1.2822x	0.84
2013	= 0.3764x	0.51	= 0.3237x	0.58	= 0.4019x	0.66
2014	= 0.5176x	0.61	= 0.5371x	0.97	= 0.4926x	0.74
2014-2015	= 0.7458x	0.64	= 0.905x	0.61	= 0.6205x	0.58
2015-2016	= 1.0106x	0.78	= 1.5878x	0.59	= 0.5377x	0.27

PAR SLOPE	NIDD		MOSS		WHIT	
MOWN	EQN	r2	EQN	r2	EQN	r2
2012	= 0.9183x	0.4	= 0.7	0.83	= 1.0353x	0.74
2013	= 0.4949x	0.94	= 0.4511x	0.94	= 0.4318x	0.83
2014	= 0.7378x	0.59	= 0.4068x	0.84	= 0.643x	0.87
2014-2015	= 0.9877x	0.55	= 0.8786x	0.38	= 0.5903x	0.65
2015-2016	= 1.133x	0.70	= 1.6279x	0.49	= 0.7057x	0.59

Table A6.3 Equations for light response curve parameters, based on regressions of an exponential fit for ecosystem respiration (R_{eco}; dark respiration) and a linear fit for maximum net ecosystem exchange (NEE) P_{max}; in full light) against air temperature (x) for Nidderdale (Nidd), Mossdale (Moss) and Whitendale (Whit) during each year or pair of years for the three major managements (Uncut, Burn, Mown [for left brash; LB]).

UNCUT	**Reco**	**NIDD** EQN	r2	**MOSS** EQN	r2	**WHIT** EQN	r2
	2012	= 0.4992e0.1061x	0.90	= 0.7758e0.138x	0.94	= 0.0558e0.2715x	0.82
	2012-2013	= 0.7155e0.0831x	0.87	= 0.9655e0.0763x	0.52	= 0.4403e0.1046x	0.66
	2013-2014	= 0.9102e0.0708x	0.88	= 0.8365e0.0887x	0.62	= 0.6872e0.0887x	0.85
	2014-2015	= 1.2657e0.0598x	0.66	= 0.5184e0.1076x	0.69	= 0.3161e0.1339x	0.95
	2015-2016	= 1.1887e0.068x	0.66	= 0.7149e0.1073x	0.82	= 0.5521e0.1108x	0.82
	NEE max	**NIDD** EQN	r2	**MOSS** EQN	r2	**WHIT** EQN	r2
	2012	= -0.4183x - 4.4347	0.99	= -0.6846x - 6.4984	0.91	= -0.4879x - 0.1857	0.76
	2012-2013	= -0.2746x - 8.2623	0.23	= -0.579x - 6.0869	0.43	= -0.3929x - 2.9321	0.35
	2013-2014	= -0.3998x - 7.7006	0.24	= -0.787x - 5.1301	0.37	= -0.7132x - 0.954	0.40
	2014-2015	= -0.4652x - 7.132	0.23	= -0.8611x - 1.2343	0.37	= -1.1142x + 1.0483	0.58
	2015-2016	= -0.7926x - 4.019	0.51	= -1.0215x - 1.7404	0.46	= -1.1667x + 0.8979	0.75

BURNT	**Reco**	**NIDD** EQN	r2	**MOSS** EQN	r2	**WHIT** EQN	r2
	2012	= 0.4059 e0.116x	0.97	= 0.49e0.17x	0.99	= 0.1963e0.2135x	0.72
	2013	= 0.1524e0.116x	0.97	= 0.2699e0.0751x	0.88	= 0.3293e0.0758x	0.81
	2014	= 0.107e0.1409x	0.96	= 0.3985e0.0772x	0.62	= 0.3134e0.0708x	0.71
	2014-2015	= 0.192e0.1124x	0.80	= 0.3505e0.0714x	0.71	= 0.2005e0.1075x	0.81
	2015-2016	= 0.336e0.0972x	0.81	= 0.3886e0.0895x	0.52	= 0.3451e0.1144x	0.72
	NEE max	**NIDD** EQN	r2	**MOSS** EQN	r2	**WHIT** EQN	r2
	2012	= -0.4453x - 3.2705	0.39	= -0.5796x - 4.094	0.99	= -2.0267x + 7.9933	0.77
	2013	= -0.0279x - 0.1014	0.64	= -0.0199x - 0.328	0.29	= -0.0372x - 0.3263	0.21
	2014	= -0.1762x + 0.5289	0.76	= -0.1568x + 0.0884	0.50	= -0.0903x + 0.3	0.77
	2014-2015	= -0.2833x + 0.0849	0.24	= -0.2546x + 0.8809	0.64	= -0.3035x + 1.6449	0.38
	2015-2016	= -0.3957x - 0.1313	0.55	= -0.801x + 3.9176	0.33	= -0.4211x + 0.9631	0.90

MOWN	**Reco**	**NIDD** EQN	r2	**MOSS** EQN	r2	**WHIT** EQN	r2
	2012	= 0.5692e0.1071x	0.88	= 0.9718e0.1278x	0.96	= 0.0733e0.2622x	0.91
	2013	= 0.1565e0.1023x	0.94	= 0.2257e0.0938x	0.95	= 0.3003e0.0858x	0.90
	2014	= 0.1336e0.1436x	0.85	= 0.1377e0.1934x	0.95	= 0.2234e0.1308x	0.96
	2014-2015	= 0.3177e0.0922x	0.61	= 0.3392e0.1098x	0.83	= 0.1569e0.1457x	0.95
	2015-2016	= 0.5589e0.073x	0.54	= 0.3119e0.123x	0.83	= 0.3193e0.1191x	0.80
	NEE max	**NIDD** EQN	r2	**MOSS** EQN	r2	**WHIT** EQN	r2
	2012	= -0.2427x - 5.3852	0.3	= -0.8466x - 6.3035	0.92	= -1.4786x + 7.1629	0.99
	2013	= -0.0442x - 0.0721	0.74	= -0.0917x - 0.9549	0.10	= -0.0634x - 0.6488	0.20
	2014	= -0.1845x + 0.2777	0.53	= -1.1876x + 9.5253	0.99	= -0.4795x + 3.1425	0.89
	2014-2015	= -0.2279x - 0.309	0.30	= -0.9929x + 6.6515	0.96	= -0.5298x + 3.6587	0.86
	2015-2016	= -0.4152x - 1.4423	0.37	= -1.52x + 8.6532	0.70	= -0.5673x + 1.958	0.69

The obtained values for PAR slope, R_{eco} and NEE max were used in **Eq.A6.2** to calculate the NEE flux for each hour of each year and for each management within each site. The hourly calculated NEE fluxes were summed to derive the monthly and yearly net C budgets. Fluxes were converted from µmol CO_2 m^{-2} s^{-1} to g C m^{-2} y^{-1}.

The modelled NEE fluxes were compared to the measured fluxes in order to validate the accuracy of the annual NEE budgets (see **Figure 84** in the main report). The average was taken of the measured NEE fluxes (only the Full Light portion was used as the shaded portions were only needed to fit the light response curves) for each site and management combination on each measurement date. The corresponding modelled fluxes were calculated by taking the average of the hourly calculated values for the period covering the whole measurement period. This was assumed to be the same period for each group of measurements for the same site and management combination. Specifically, the time periods used for Nidderdale were 09.30-13.30 for DN and LB plots and 12.30-15.30 for FI plots, those for Mossdale were 08.30-13.30 for DN and LB plots and 12.30-15.30 for FI plots, and those for Whitendale were 10.30-15.30 for DN and LB plots and 08.30-11.30 for FI plots.

A paired Student's t-test (using the function "t.test" in the R "stats" package; R Core Team, 2016) was used to determine whether the measured NEE fluxes were significantly different from the modelled fluxes. Although modelled fluxes tended to be closer to zero than the measured fluxes were, there was no significant difference between the measured and modelled NEE fluxes ($t_{134} = 1.64$, $p = 0.1043$). This suggested that the model was adequate to be used to up-scale the NEE fluxes.

Estimation of respiration components and carbon cycle parameters

The combination of measured NEE and SR component fluxes in 2015 and 2016 allowed the 'breaking-down' of the total flux, providing information on respiration components and key carbon cycle parameters (see Heinemeyer et al., 2012 for more details on this approach), namely gross primary productivity (GPP), net primary productivity (NPP) and carbon use efficiency (CUE) and their ratios (**Figure A6.4**). In brief, above ground respiration (R_{ab}) was derived by subtracting total soil respiration from the NEEnew areas (R_s) from R_{eco} measurements made within vegetated areas. Root respiration (R_r) was derived by subtracting soil heterotrophic decomposition (R_h), obtained from measurements made on the deep cut (SRc) and vegetation free areas, from R_s. Gross primary productivity (GPP) was derived as the sum of R_{eco} and the additive inverse of NEE. Net primary productivity (NPP) was derived by subtracting plant respiration components (i.e. R_{ab} and R_r) from GPP. Carbon use efficiency (CUE) was derived by dividing GPP by NPP.

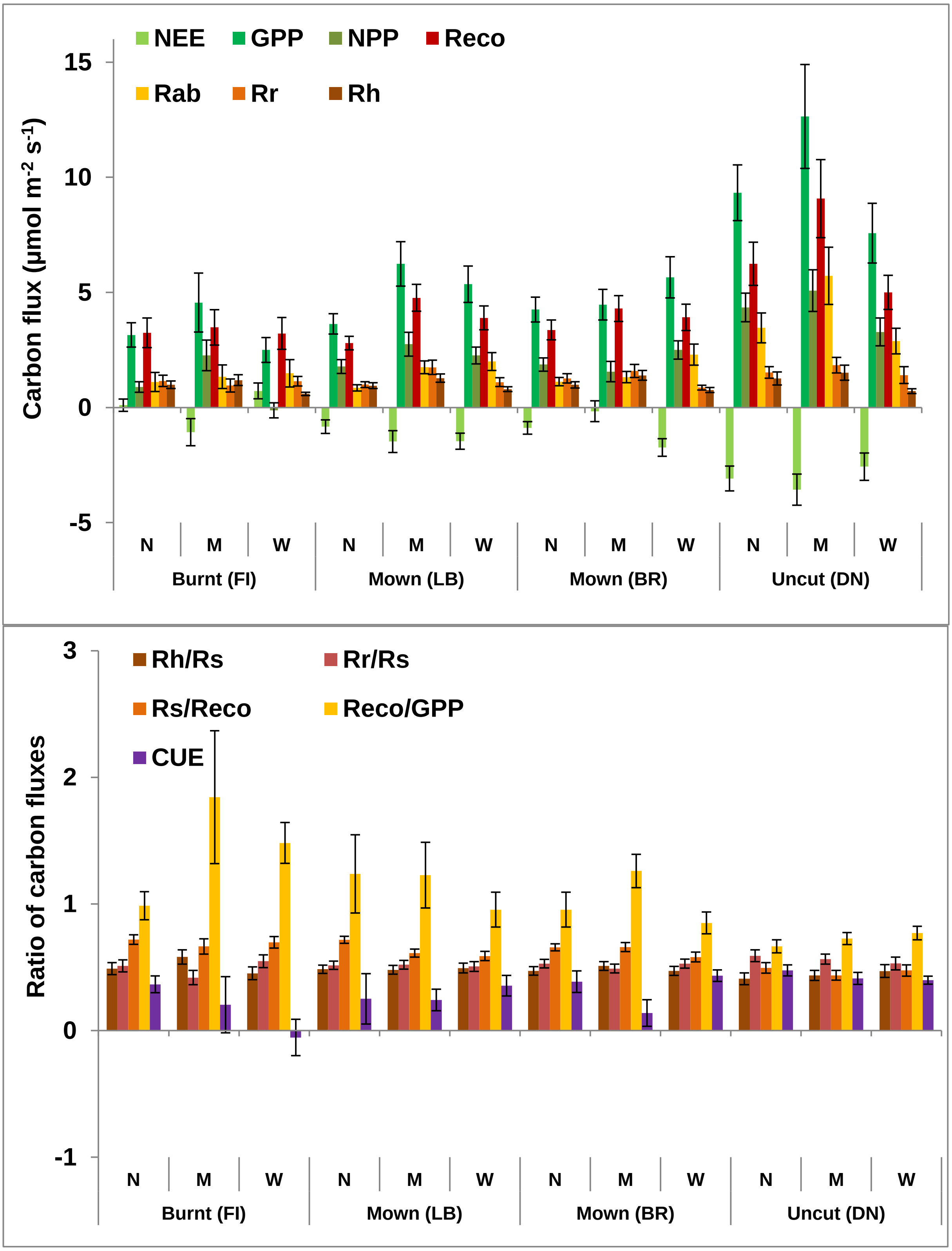

Figure A6.4 Carbon flux and respiration components obtained from manual chamber measurements of light and dark net ecosystem exchange fluxes (NEE and R_{eco}, respectively). Individual flux components are detailed in the **top** graph and flux ratios in the **bottom** graph. Above ground respiration (R_{ab}) was derived by subtracting total soil respiration (R_s) from R_{eco} measurements made within vegetated areas. Root respiration (R_r) was derived by subtracting soil heterotrophic decomposition (R_h), obtained from measurements made on the deep cut and vegetation free areas, from R_s. Gross primary productivity (GPP) was derived as the sum of R_{eco} and the additive inverse of NEE. Net primary productivity (NPP) was derived by subtracting plant respiration components (i.e. R_{ab} and R_r) from GPP. Carbon use efficiency (CUE) was derived by dividing GPP by NPP. Shown are the mean (n = 6) values ± SE for Nidderdale (N), Mossdale (M) and Whitendale (W) during the post-management period (specifically, July 2015 to October 2016) for burnt (FI), mown plots with (BR) or without (LB) brash removal (with *Sphagnum* pellet addition plots combined) and uncut (DN) plots.

Net Ecosystem Carbon Balance (NECB)

For the site NECBs in 2012, all the measurements for NEE, CH_4, DOC and POC (see Appendix 5 for full details of DOC and POC measurements and Appendix 8 for details of CH_4 measurements) were averaged across the three managements which were up-scaled as this period was before management implementation. In 2013, 20% of the sub-catchments was either mown or burnt, leaving about 80% of the entire site unmanaged (with the remaining 20% being either (10%) mown or (10%) burnt). Therefore, NEE and CH_4 were averaged across managements proportionally for each site for 2013 and 2014, i.e.:

$$\text{Average site NEE} = (0.8 \times \text{DN NEE}) + (0.1 \times \text{LB NEE}) + (0.1 \times \text{FI NEE}) \quad \textbf{Eq. A6.4}$$

where DN NEE is the up-scaled NEE flux for the DN management at a site, FI NEE is the up-scaled NEE flux for the FI management and LB NEE is the up-scaled NEE flux for the LB management.

DOC and POC exports were averaged across the two sub-catchments of a site to derive the site DOC and POC exports. This meant that the three main management types were all incorporated in the same proportions as used for NEE and CH_4 due to each stream receiving runoff from the whole sub-catchment, which contained unmanaged areas. For 2015 and 2016, the same principle was applied for calculating the site NECBs but an additional 20% of heather areas in each sub-catchment was managed meaning about 50% of the whole of each catchment was unmanaged (equal to ~60% of the site with the other 40% across each site either (20%) mown or (20%) burnt).

For the management NECBs, the NEE and CH_4 fluxes were averaged for each management across the three sites. Similarly, the DOC and POC exports for the FI and LB managements were averaged across the three sites. As there was no DN sub-catchment, the average of the FI and LB DOC and POC exports were used for the DN management DOC and POC exports, as much of each sub-catchment was unmanaged.

Data analysis

All statistical analyses were carried out in R version 3.3.1 (R Core Team, 2016). Following Zuur *et al.* (2009), residuals were plotted against fitted values and visually assessed for normality and homogeneity of variance. The critical p-value chosen for significance was 0.05. Linear mixed effects models employing the "lmer" function from the "lmerTest" package (Kuznetsova *et al.*, 2016) were used to test for management and site effects on the Full Light and R_{eco} fluxes and each set of SR fluxes (i.e. SR, SRc, Ra and Ra NEEnew). Due to producing many small fluxes (i.e. close to 0) and very few large fluxes, Full Light NEE, R_{eco} and all SR data were square-root transformed for analysis. The managements, sites and time period (either pre-management, i.e. before management implementation, or post-management, i.e. after management implementation) were used as fixed effects, as were the interactions between them. The month in which measurements were made was also included as a fixed effect as were appropriate environmental variables; PAR and soil temperature (Tsoil) were included in the Full Light NEE model and Tsoil was in the R_{eco} and SR models. A random intercept was included for each model, with a nested structure of blocks in sites (to account for spatial heterogeneity) in years (to account for repeated measurements).

Following the 10-step protocol in section 5.10 of Zuur *et al.* (2009), variables were dropped stepwise from each linear mixed effects model and the log-likelihood ratio and AIC value were used to assess whether a variable should be dropped or kept in the model. For the final models (for a summary output see **Table A6.4**), the "Satterthwaite" option was used to calculate the denominator degrees of freedom as the time periods resulted in an unbalanced design (Spilke *et al.*, 2005). Where significant interactions were found, the "glht" function with the "Tukey" option from the "multcomp" package (Hothorn *et al.*, 2008) was used to compare groups within the interaction terms.

Table A6.4 Results from linear mixed effects models and anovas between each C measurement and its explanatory variables. Only those explanatory variables which an assessment of the log-likelihood ratio (used after dropping variables stepwise) determined as explaining sufficient variation are shown. Measurement types followed by (sqrt) were square-root transformed before being used in the models. Variables followed by 2 were squared before being used in the models. PAR was divided by 100 before being incorporated into the model. WTD_4wk is the average WTD from the four weeks before measurements were taken. Rain_4wk is the sum of rainfall from the four weeks before measurements were taken. Marginal p-values are shown in italics.

Type of measurement	Explanatory variable	Coefficient	df (numerator, denominator)	F-value	p-value
Full Light NEE (sqrt)	PAR	-0.2497	1, 982	135.37	**<0.0001**
	PAR^2	0.0121	1, 1087	81.50	**<0.0001**
	$Tsoil^2$	0.0015	1, 1057	74.76	**<0.0001**
	Month	-	8, 962	27.49	**<0.0001**
R_{eco} (sqrt)	Tsoil	0.0687	1, 1194	52.44	**<0.0001**
	$Tsoil^2$	-0.0013	1, 1129	29.85	**<0.0001**
	Month	-	8, 1173	40.39	**<0.0001**
Soil respiration (R) (sqrt)	$Tsoil^2$	0.0008	1, 1092	146.19	**<0.0001**
	Month	-	8, 940	64.63	**<0.0001**
Heterotrophic respiration (Rc) (sqrt)	Tsoil	0.0293	1, 897	149.78	**<0.0001**
	Month	-	8, 1021	27.18	**<0.0001**
Autotrophic respiration (Ra_calc) (sqrt)	Month	-	8, 112	12.12	**<0.0001**
Ecosystem respiration (NEEnew) (sqrt)	Tsoil	0.0181	1, 417	5.46	**0.0200**
	Month	-	6, 417	18.44	**<0.0001**
Autotrophic respiration (Ra_NEE) (sqrt)	$Tsoil^2$	0.0209	1, 419	3.98	**0.0466**
	Month	-	6, 413	23.01	**<0.0001**
CH_4 all (sqrt) (truncated at 2000 nmol m^{-2} s^{-1})	WTD_4wk	0.0520	1, 125	8.83	**0.0030**
	Tsoil	0.3136	1, 758	4.45	**0.0352**
	$Tsoil^2$	-0.0072	1, 771	3.81	***0.0512***
	Month	-	8, 1093	14.27	**<0.0001**
CH_4 GC, respiration only (GC-R) (sqrt)	Tsoil	0.2970	1, 542	8.05	**0.0047**
	$Tsoil^2$	-0.0081	1, 542	7.55	**0.0062**
	Month	-	6, 542	4.35	**0.0003**
CH_4 UGGA, respiration only (LGR-R)(sqrt)	WTD_4wk^2	-0.0023	1, 265	3.51	***0.0621***
	Month	-	3, 265	11.65	**<0.0001**
CH_4 UGGA, incl. veg (LGR-NEE) (sqrt) (truncated at 2000 nmol m^{-2} s^{-1})	Tsoil	0.3816	1, 408	17.66	**<0.0001**
	WTD_4wk	0.0668	1, 408	3.82	***0.0514***
	% Sedge cover	0.0405	1, 408	21.09	**<0.0001**
	Month	-	6, 408	4.62	**0.0001**
DOC concentration	Daily stream flow	-0.0036	1, 164	4.33	**0.0389**
	Month	-	11, 38	2.44	**0.0205**
POC concentration	Rain_4wk	-0.0013	1, 48	4.87	**0.0322**
	Month	-	11, 36	11.63	**0.0002**

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