

A potential loss of carbon associated with greater plant growth in the European Arctic

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Plant and soil C/N stocks, ^{14}C profiles, and soil C mean residence time:

Destructive harvests¹ were used to make direct measurements of the C and N stocks in above-ground shrub biomass, birch leaves, and roots (Supplementary Table 1). C and N storage in the woody biomass of birch trees was estimated based on previous biomass studies carried out in the forests of the Abisko National Park², and published values for the C and N contents of birch wood³.

In each ecosystem, 50 m by 50 m grids were established, and a gouge auger, (inner diameter of 30 mm, Eijkelkamp Agrisearch Equipment, Netherlands) was used to take soil cores every 10 m across this area. In addition, seven soil pits were dug in each ecosystem, and aluminium Kubiena tins were used to take soil samples, with the minimum degree of compaction, for bulk density determinations, and C and N analyses of soil from each horizon. These data were used to determine the median soil profile depths, and thus identify a representative profile for carrying out the isotopic (^{13}C and ^{14}C) measurements.

At the tundra-heath site, the mean depth of the organic soil layer was ~8 cm (median also 8 cm) with little mineral material (A horizon) present (Supplementary Table 2). In contrast, in the birch forest, the organic layer was on average only ~2 cm thick (median 1.5 cm) but this layer was underlain by clear E (eluvial/albic) and B (illuvial/spodic) mineral soil

horizons. C and N stocks in the tundra-heath soils were 2-3 times greater than in the birch forest soils (Supplementary Table 2). Additional measurements made at multiple forest and tundra locations in the general area confirmed that our sites were representative of the soil profiles found in these ecosystems. Furthermore, within the ecotone, starting at an altitude of 539 m we also ran a transect across an area of heath between two patches of mountain birch forest. Soil coring took place every 25 m. On the heath, the mean horizon depths were: O = 8.03 cm, OA = 1.74 cm, A = 1.50 cm; B = 0.63 cm (N = 7), while the horizon depths in the forest were: O = 2.12 cm, OA = 0.74 cm, A = 2.05 cm; B = 1.01 cm (N = 9). Therefore, the difference in the soil profiles between mountain birch forest and heath within the ecotone were similar to those found between our main study sites (separated by 190 m in altitude). This suggests that plant community distribution, rather than the direct effects of altitudinally-mediated differences in temperature, plays the key role in controlling patterns of soil C storage in this landscape.

The samples from the surface organic layers were highly enriched in ^{14}C in both ecosystems (Table 1). On the tundra-heath, this enrichment declined with depth, with evidence of bomb- ^{14}C (>100 %modern) penetrating to all but the deepest layer. In the forest, the ^{14}C enrichment was lower in the 1-2 cm depth sample than in the surface sample (Table 1). In the upper mineral soil, the majority of the C present appeared to be relatively old (~1000 years old).

We calculated soil C mean residence times (MRTs) by modelling the transient isotopic enrichment due to bomb- ^{14}C incorporation^{4,5}. This modelling approach is inappropriate when soil ^{14}C concentrations are so low as to imply insignificant contributions from bomb- ^{14}C and, therefore, when soil ^{14}C content was < 97 %modern we used the radiocarbon age as an estimate for MRT⁶. The MRT for soil C at the tundra-heath site increased from ~20 years in the surface (0-1 cm) layer to ~500 years in the deepest (6.5-

7.5 cm) layer (Table 1). At the birch site, the MRT for the organic layers was ~20 and ~70 years for the 0-1 and 1-2 cm layers, respectively. Because of its much lower ^{14}C concentration, implying insignificant penetration/preservation of bomb- ^{14}C , the MRT of the C in the mineral soil was estimated from the conventional radiocarbon age (1075 years). In both ecosystems, the modelling demonstrated that the bomb- ^{14}C enriched layers should dominate the soil CO_2 efflux. Importantly, and in contrast to conventional radiocarbon dating, the low contribution of pre-bomb C to the overall flux means that we can interpret an increase in the ^{14}C content of the CO_2 released from our ecosystems as evidence of ‘older’ C being mineralised, but that this ‘older’ C is only a few decades old (post-1950s).

Plot set up:

During late summer 2006, within 10 m of the main soil pit in each ecosystem (i.e. the one used for ^{13}C and ^{14}C determinations), three pairs of 50 x 50 cm plots were established. Of each pair of plots, one was left as a control (vegetated plots), while in the other, all above-ground vascular plant material was removed by clipping. Mosses were not removed to avoid causing an unacceptable change in soil temperature and moisture regimes⁷. Trenches were also dug on all four sides of the clipped plots to sever links between any remaining live roots and photosynthetically active tissues (plant-free plots). The clipping and trenching was repeated each month during the growing season to maintain the plots free of vascular plants. To avoid cutting through surface roots and below-ground shoots in the vegetated plots, which can cause mortality of ericaceous shrubs, all collars were sealed to the soil surface using putty (Plumber’s Mait®, Evo-Stik, Stafford, UK). Incubation tests carried out under controlled laboratory conditions indicated that this type of putty did not release measurable amounts of CO_2 , and, as a minimum of 6 ml of pure CO_2 was collected for each ^{14}C determination (see below), there could have been no significant isotopic contamination of the respired CO_2 . At

the centre of each plot, a PVC collar (7 cm tall and 16 cm in diameter) was established. Plant-free plots were covered with green shading mesh to reduce the extent to which these plots warmed up on sunny days relative to the vegetated plots.

Measuring net ecosystem exchange and dark respiration:

All flux measurements were made at the same time of day; early afternoon. Net ecosystem exchange in the vegetated and plant-free plots was measured using a PP Systems Infra-red gas analyser (IRGA; EGM-4, PP Systems Ltd., Herts, UK) linked to a CPY-2 chamber. The rate of change in the CO₂ concentration within the chamber was measured for 90 seconds, and flux rates calculated using a linear fit to the data. A linear regression was used as fluxes calculated by quadratic fits were found to be less repeatable. The IRGA also provides a flux estimate after just 14 seconds. Acknowledging the potential for linear fits to underestimate respiration rates, whenever the initial flux differed from the final flux measurement by more than 10%, the measurement was repeated. Measurements of photosynthetically active radiation (PAR) were made during each measurement using a quantum sensor inside the flux chamber.

Respiration measurements were made during daylight hours by darkening the plants within the respiration collar for 2 minutes prior to measurement, and then measuring the flux with a darkened chamber. The internal quantum sensor demonstrated that PAR levels were reduced to 0 inside the chamber.

Calculating rates of plant versus soil respiration:

We estimated the relative contributions of vascular plant respiration and soil respiration to total CO₂ production at the vegetated plots using equations 1 and 2:

$$(1) \quad \text{Vascular plant respiration} = \frac{\text{Vegetated plot resp} - \text{Plant-free plot resp}}{\text{Vegetated plot resp}}$$

$$(2) \quad \text{Soil respiration} = \frac{\text{Plant-free plot resp}}{\text{Vegetated plot resp}}$$

Rates of photosynthesis

Rates of photosynthesis were calculated as the difference between net ecosystem exchange and dark respiration. In both ecosystems, photosynthesis peaked during the middle of the growing season (Supplementary Figure 1). Therefore, rates of new C input were greatest during the middle of the growing season.

Root respiration:

As well as the vegetated and plant-free plots, collars were set up to quantify the contribution of roots to below-ground respiration. During late summer 2006, below-ground respiration collars were sealed to the soil surface with putty (i.e. the collars were not inserted into the soils). By contrast, soil respiration collars were inserted into the soil down to the glacial till, severing all roots. All above-ground vascular plant biomass was removed from within both collar types. Fluxes were measured using the IRGA and darkened flux chamber. Root respiration was calculated as the difference between the respiration rates measured at the below-ground respiration collars and the soil respiration collars. Following the same procedure as in equation 1, the proportional contribution of roots was calculated by dividing root respiration by the respiration rate measured at the below-ground respiration collars.

The rate of root respiration, and its contribution to below-ground respiration, tended to be greatest mid season, and was especially low late season in the birch forest (Supplementary Figure 2). Thus, the contribution of root respiration to below-ground

respiration followed a similar seasonal pattern to the contribution of vascular plant respiration to total respiration in the vegetated plots (Figure 3).

Contributions of vascular plant respiration in the two ecosystems:

The contribution of vascular plant respiration to respiration in the vegetated plots was higher on the tundra-heath than in the birch forest. However, this cannot explain the differences in the patterns of $^{14}\text{CO}_2$ release observed in the two ecosystems. On the tundra-heath, as the contribution of plant respiration increased from early to mid season (Figure 3), so did the difference in the ^{14}C contents of the CO_2 respired from the vegetated and plant-free plots, indicating an increase in the proportional contribution of recently-fixed C (*i.e.* C with a ^{14}C content similar to the contemporary atmosphere). In contrast, in the birch forest, the difference in the ^{14}C content of the CO_2 respired from the two plots types, first decreased between early and mid season (Figure 2c), despite the contribution of plant respiration increasing slightly (Figure 3), and then increased between mid and late season, despite the contribution of plant respiration declining strongly. Thus, the contribution of recently fixed C to respiration in the vegetated plots actually appeared to be lowest when partitioning measurements indicated that plant respiration was greatest. This can only be explained if the activity of birch roots during the middle of the growing season stimulated the decomposition of a ^{14}C -enriched pool of organic matter (an older pool of organic matter, but with a maximum age of ~50 years old). Thus there is only evidence for positive priming in the birch forest.

$^{14}\text{CO}_2$ collection, analysis, and correcting for atmospheric contamination:

As the collars could not be inserted deep into the soil, leaks reduced the CO_2 concentration which built up in the chamber, especially on windy days. To reduce this problem, limit the

amount of atmospheric CO₂ entering the chamber, and make it possible to collect sufficient samples of respired CO₂ for ¹⁴C analysis, a thin latex sheet was connected to the collar and laid out around the collar base (held down by metal chains) to cover the entire 50 cm by 50 cm plot. Large chambers (9 litres in volume) were connected to the collars using rubber seals and the chambers held down using guy ropes. The CO₂ concentration inside each chamber was allowed to build up for 2-3 hours. Then an established sampling system⁸ was connected in a closed-loop configuration and the air circulated through the soda lime cartridge in order to scrub the CO₂ concentration within the chamber down to ambient (~380 ppm). This procedure was repeated until the estimated contamination with atmospheric CO₂ inside the chamber was less than 50 ppm. However, despite taking these steps, it was not possible to prevent some contamination with atmospheric CO₂. Therefore, this contamination had to be quantified and corrected for (see below). After soda lime scrubbing, the CO₂ concentration was again allowed to build up within the chamber, but this time the CO₂ produced was collected on a molecular sieve cartridge containing zeolite molecular sieve, type 13X (1/16" pellets, BDH Laboratory Supplies, Leics, UK). A minimum of 6 ml of CO₂ was collected on each molecular sieve, and in some instances (when the build-up within the chamber was low) this required multiple samplings.

To allow the ¹⁴C results to be corrected for atmospheric contamination, intact monoliths were collected and incubated in closed systems (1800 ml Lock & Lock® container, Hana Cobi Plastic Co Ltd., Seoul, Korea) in the field. The headspaces were scrubbed free of atmospheric CO₂ allowing a pure sample of respired CO₂ to be collected on a molecular sieve cartridge for subsequent δ¹³C analysis. Samples of atmospheric CO₂ were collected on each sampling occasion (by circulating air sampled from a height of ~1 m, through a molecular sieve cartridge for one hour) and their δ¹³C values were also measured. Finally, two air samples collected from the tundra-heath site were also analysed for ¹⁴C.

All ^{13}C and ^{14}C measurements were completed at the NERC Radiocarbon Facility and Scottish Universities Environmental Research Centre AMS Facility⁸⁻⁹; sample ^{14}C activity was, following convention^{10,11}, normalised to a $\delta^{13}\text{C}$ of -25 ‰ to account for mass-dependent isotope fractionation effects using equation 3:

$$(3) \quad A_{\text{SN}} = A_{\text{S}} * \left(\frac{1 + (-25/10^3)}{1 + (\delta^{13}\text{C}_{\text{S}}/10^3)} \right)$$

Where A_{SN} is the ^{14}C activity ($^{14}\text{C}/^{13}\text{C}$ ratio) of the sample normalised to a $\delta^{13}\text{C}$ of -25 ‰, A_{S} is the raw ^{14}C activity ($^{14}\text{C}/^{13}\text{C}$ ratio) of the sample and $\delta^{13}\text{C}_{\text{S}}$ is the $^{13}\text{C}/^{12}\text{C}$ ratio of an aliquot of the recovered sample carbon dioxide measured by isotope ratio mass spectrometry (with respect to the Vienna PDB standard; V-PDB).

Radiocarbon results were expressed as %modern relative to 95% of the activity of the NBS Oxalic Acid international radiocarbon standard following standard conventions (equation 4)¹⁰, and as conventional radiocarbon ages, when %modern was <100 (equation 5).

$$(4) \quad \% \text{modern} = (A_{\text{SN}} / A_{\text{ON}}) * 100$$

$$(5) \quad \text{Conventional radiocarbon age (years BP)} = -8033 * \ln (A_{\text{SN}} / A_{\text{ON}})$$

Where A_{SN} is the activity (i.e. $^{14}\text{C}/^{13}\text{C}$ ratio normalised to a $\delta^{13}\text{C}_{\text{V-PDB}}$ of -25 ‰) of the sample and A_{ON} is the activity ($^{14}\text{C}/^{13}\text{C}$ ratio) of the NBS Oxalic Acid international radiocarbon standard (by convention normalised to a $\delta^{13}\text{C}_{\text{V-PDB}}$ of -19 per mil¹⁰).

The normalisation of the ^{14}C results to a $\delta^{13}\text{C}_{\text{V-PDB}}$ of -25 per mil means that the ^{14}C %modern values (and radiocarbon ages) are expressed to a standard $\delta^{13}\text{C}$ value, which accounts for all mass-dependent fractionation effects, irrespective of environment¹⁰. This is a

standard procedure in radiocarbon dating since, without it, two samples of the same age but with different isotopic fractionation (e.g. C₃ or C₄ plants), would have differing radiocarbon ages.

The proportional contamination of the collected CO₂ samples by atmospheric CO₂ (PropAir) was calculated using equation 6.

$$(6) \quad \text{PropAir} = \frac{\delta^{13}\text{C}_{\text{closed}} - \delta^{13}\text{C}_{\text{sample}}}{\delta^{13}\text{C}_{\text{closed}} - \delta^{13}\text{C}_{\text{air}}}$$

Where $\delta^{13}\text{C}_{\text{closed}}$ is the $\delta^{13}\text{C}$ value of a pure sample of respired CO₂ collected in the closed system, $\delta^{13}\text{C}_{\text{sample}}$ is the $\delta^{13}\text{C}$ value of the CO₂ sample collected from a vegetated or plant-free plot, and $\delta^{13}\text{C}_{\text{air}}$ is the $\delta^{13}\text{C}$ value of the air on the day of collection.

The ¹⁴C contents of the collected CO₂ samples were then corrected for the atmospheric contamination using equation 7.

$$(7) \quad \Delta^{14}\text{C}_{\text{respired}} = \frac{\Delta^{14}\text{C}_{\text{sample}} - (\text{PropAir} * \Delta^{14}\text{C}_{\text{air}})}{1 - \text{PropAir}}$$

Where $\Delta^{14}\text{C}_{\text{respired}}$ is the ¹⁴C content of the respired CO₂, $\Delta^{14}\text{C}_{\text{sample}}$ is the ¹⁴C content of the collected sample, PropAir was calculated using equation 6, and $\Delta^{14}\text{C}_{\text{air}}$ is the ¹⁴C content of the air (see also summary in Supplementary Table 3).

Age of respired CO₂:

The average age of the respired CO₂ (relative to the sampling date) was calculated from its bomb-¹⁴C concentration by reference to records of direct atmospheric ¹⁴CO₂ measurements¹², and using the assumption that the respired CO₂ had originally been fixed after the 1963 peak in atmospheric bomb-¹⁴C concentrations. This assumption was justified based on the results of the MRT modelling which indicated a very low contribution of pre-bomb C to the CO₂ released from these freely-drained soils (Table 1).

Based on calibrating against the atmospheric bomb-¹⁴C record¹², on the tundra-heath, the average age (since fixation) of the CO₂ released from the plant-free plots increased from ~4 years old in late May to a maximum of ~10 years old during July (Supplementary Table 4). The age of the CO₂ released from the vegetated plots increased from ~3 years old in late May to ~5 years old by September. In the birch forest, the respired CO₂ from the plant-free plots was, on average, 4 years old in late May, ~8 years old in July and ~7 years old in September (Supplementary Table 4). The CO₂ released from the vegetated plots was 'modern' in late May, ~5 years old in July and ~3 years old in September.

Evaluation of the clipping and trenching:

The clipping and trenching treatment had a small effect on soil temperature (Supplementary Table 5). Soil temperatures at a depth of 2 cm were on average ~0.3°C and ~0.9°C higher in the plant-free plots in the birch forest and tundra-heath, respectively. This difference was only statistically significant on the tundra-heath ($P = 0.028$), with significant differences also being observed between the vegetated and plant-free plots on several dates during the growing season (Supplementary Table 5; $P < 0.05$). Differences between treatments declined with depth, with few significant differences being detected at either 5 or 8 cm in either

ecosystem. Overall, the effect of clipping and trenching on soil temperatures was relatively minor, and was less than the difference in soil temperatures between the two ecosystems.

The clipping and trenching treatment did not have a significant effect on soil moisture in either ecosystem, although a significant difference between the treatments was observed on one date on the tundra-heath (Supplementary Table 5). In summary, clipping and trenching had little effect on the soil physical conditions.

Clipping and trenching results in the death and subsequent decomposition of root material in the plots, which can alter the process of decomposition. In both ecosystems, the plots were clipped and trenched more than 8 months prior to the ^{14}C measurements commencing, thus avoiding the stimulation of soil organic matter decomposition that may have been caused by an initial flush of substrate inputs from dying roots. The low rates of decomposition that occur in these cold environments means that CO_2 from root decomposition is likely to have still contributed to the overall flux during measurements. However, the plant-free plots provide an estimate of the ^{14}C content of the CO_2 being released from these ecosystems in the absence of new C inputs. Critically, the similarity in terms of the ^{14}C contents of the CO_2 released from the plant-free plots in the two ecosystems (Figure 2a), demonstrates that differences between the vegetated plots, especially in terms of the seasonal patterns of $^{14}\text{CO}_2$, are the result of the differences in the plant communities. Therefore, the combination of clipping and trenching with the $^{14}\text{CO}_2$ measurements, made it possible to detect plant-induced stimulation of the decomposition of older organic matter during the middle of the growing season in the birch forest.

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Supplementary Table 1 | C and N stocks in plant tissues in each ecosystem.

Site	Plant tissue	C stock (g m ⁻²)	N stock (g m ⁻²)
Tundra-heath	Leaves (shrubs)	146.7 ± 13.0	2.9 ± 0.3
	Stems (shrubs)	180.6 ± 22.4	2.1 ± 0.4
	Roots	520.8 ± 76.2	6.9 ± 0.8
	Total	848.1	11.9
Birch forest	Leaves (birch trees)	69.6 ± 7.6	3.2 ± 0.4
	Leaves (understorey shrubs)	68.3 ± 7.2	1.4 ± 0.1
	Stems (birch trees)	1265*	8.43*
	Stems (understorey shrubs)	70.0 ± 7.6	0.8 ± 0.1
	Roots	578.2 ± 130.0	8.8 ± 1.8
	Total	2051.1	22.63

Mean values ± 1SE are shown (n = 5).

*Values are based on biomass measurements for mountain birch forest near Abisko², and on the C and N contents of above-ground woody birch biomass³.

Supplementary Table 2 | The thickness of the different soil horizons, bulk densities, C and N stocks for each ecosystem.

Site	Horizon	Thickness (cm)	Bulk density	%C	%N	C stock (g m ⁻²)	N stock (g m ⁻²)
Tundra-heath	O	8.33 ± 0.71	0.159 ± 0.015	44.6 ± 1.56	1.28 ± 0.080	5907.1	169.5
	O/A	0.29 ± 0.16	0.649 ± 0.107	11.1 ± 2.13	0.73 ± 0.152	208.9	13.7
	A	0.49 ± 0.21	0.976 ± 0.095	2.09 ± 0.47	0.10 ± 0.025	100.0	4.9
	Total	9.11				6216.0	188.2
Birch forest	O	2.22 ± 0.16	0.129 ± 0.006	48.6 ± 2.34	1.45 ± 0.097	1391.8	41.5
	O/E	0.42 ± 0.29	0.481 ± 0.003	17.8 ± 0.72	0.58 ± 0.189	358.8	11.8
	E	2.42 ± 0.30	0.922 ± 0.058	2.97 ± 0.59	0.084 ± 0.017	662.7	18.8
	Bs	0.98 ± 0.38	0.937 ± 0.038	1.82 ± 0.15	0.048 ± 0.015	167.1	4.4
	Total	6.04				2580.4	76.5

For the horizon thickness data, mean values ± 1SE are shown (n = 36). Bulk density, %C and %N were calculated from a subset of seven soil pits. The horizon labels are as follows: O = organic, A = mineral, E = eluvial, Bs = illuvial.

Supplementary Table 3 | Summary data showing how the $^{14}\text{CO}_2$ data were corrected for atmospheric contamination.

Date	Site	Treatment	Replicate	Collected CO_2		Lab code	Monolith	Air		Contamination	Respired ^{14}C
				^{14}C (%modern)	$\delta^{13}\text{C}$ ratio		$\delta^{13}\text{C}$ ratio	^{14}C (%modern)	$\delta^{13}\text{C}$ ratio		corrected
31/05/2007	Tundra	<i>Plant-free</i>	1	107.43	-22.9	SUERC-14793	-27.0	105.29	-8.38	0.220	108.03
31/05/2007	Tundra	<i>Plant-free</i>	2	107.83	-22.1	SUERC-14797	-27.0	105.29	-8.38	0.263	108.74
31/05/2007	Tundra	<i>Plant-free</i>	3	106.49	-21.7	SUERC-14799	-27.0	105.29	-8.38	0.285	106.97
31/05/2007	Tundra	<i>Vegetated</i>	1	106.53	-21.0	SUERC-14796	-27.0	105.29	-8.38	0.322	107.12
31/05/2007	Tundra	<i>Vegetated</i>	2	106.41	-22.2	SUERC-14798	-27.0	105.29	-8.38	0.258	106.80
31/05/2007	Tundra	<i>Vegetated</i>	3	106.72	-20.8	SUERC-14800	-27.0	105.29	-8.38	0.333	107.43
28/05/2007	Birch	<i>Plant-free</i>	1	106.90	-19.8	SUERC-14801	-26.7	105.29	-8.38	0.377	107.87
28/05/2007	Birch	<i>Plant-free</i>	2	106.98	-21.5	SUERC-14803	-26.7	105.29	-8.38	0.284	107.65
28/05/2007	Birch	<i>Plant-free</i>	3	106.11	-19.2	SUERC-14807	-26.7	105.29	-8.38	0.409	106.68
28/05/2007	Birch	<i>Vegetated</i>	1	105.46	-19.8	SUERC-14802	-26.7	105.29	-8.38	0.377	105.56
28/05/2007	Birch	<i>Vegetated</i>	2	105.34	-19.8	SUERC-14806	-26.7	105.29	-8.38	0.377	105.37
28/05/2007	Birch	<i>Vegetated</i>	3	105.08	-19.8	SUERC-14808	-26.7	105.29	-8.38	0.377	104.95
20/07/2007	Tundra	<i>Plant-free</i>	1	108.24	-20.4	SUERC-15264	-26.1	105.29	-8.38	0.322	109.64
20/07/2007	Tundra	<i>Plant-free</i>	2	109.27	-20.0	SUERC-15266	-26.1	105.29	-8.38	0.344	111.36
20/07/2007	Tundra	<i>Plant-free</i>	3	109.05	-18.5	SUERC-15270	-26.1	105.29	-8.38	0.429	111.87
20/07/2007	Tundra	<i>Vegetated</i>	1	107.25	-19.7	SUERC-15265	-26.1	105.29	-8.38	0.361	108.36
20/07/2007	Tundra	<i>Vegetated</i>	2	106.58	-20.8	SUERC-15269	-26.1	105.29	-8.38	0.299	107.13
20/07/2007	Tundra	<i>Vegetated</i>	3	107.15	-18.5	SUERC-15271	-26.1	105.29	-8.38	0.429	108.55
17/07/2007	Birch	<i>Plant-free</i>	1	108.18	-21.6	SUERC-15272	-26.9	105.29	-8.38	0.286	109.34
17/07/2007	Birch	<i>Plant-free</i>	2	108.91	-21.2	SUERC-15274	-26.9	105.29	-8.38	0.308	110.52
17/07/2007	Birch	<i>Plant-free</i>	3	108.30	-21.2	SUERC-15276	-26.9	105.29	-8.38	0.308	109.64
17/07/2007	Birch	<i>Vegetated</i>	1	108.04	-21.5	SUERC-15273	-26.9	105.29	-8.38	0.292	109.17
17/07/2007	Birch	<i>Vegetated</i>	2	107.67	-21.5	SUERC-15275	-26.9	105.29	-8.38	0.292	108.65
17/07/2007	Birch	<i>Vegetated</i>	3	106.99	-21.2	SUERC-15279	-26.9	105.29	-8.38	0.308	107.75
07/09/2007	Tundra	<i>Plant-free</i>	1	108.00	-19.7	SUERC-16113	-26.7	105.29	-8.38	0.380	109.67
07/09/2007	Tundra	<i>Plant-free</i>	2	107.86	-19.1	SUERC-16115	-26.7	105.29	-8.38	0.413	109.66
07/09/2007	Tundra	<i>Plant-free</i>	3	107.82	-19.1	SUERC-16117	-26.7	105.29	-8.38	0.412	109.60
07/09/2007	Tundra	<i>Vegetated</i>	1	107.11	-18.4	SUERC-16114	-26.7	105.29	-8.38	0.453	108.62
07/09/2007	Tundra	<i>Vegetated</i>	2	106.79	-18.3	SUERC-16456	-26.7	105.29	-8.38	0.459	108.06
07/09/2007	Tundra	<i>Vegetated</i>	3	106.95	-17.7	SUERC-16120	-26.7	105.29	-8.38	0.493	108.56
09/09/2007	Birch	<i>Plant-free</i>	1	108.95	-22.2	SUERC-16121	-26.9	105.29	-8.38	0.252	110.18
09/09/2007	Birch	<i>Plant-free</i>	2	108.07	-22.4	SUERC-16123	-26.9	105.29	-8.38	0.244	108.97
09/09/2007	Birch	<i>Plant-free</i>	3	108.20	-21.9	SUERC-16125	-26.9	105.29	-8.38	0.271	109.29
09/09/2007	Birch	<i>Vegetated</i>	1	106.63	-21.7	SUERC-16122	-26.9	105.29	-8.38	0.280	107.16
09/09/2007	Birch	<i>Vegetated</i>	2	106.89	-21.8	SUERC-16124	-26.9	105.29	-8.38	0.274	107.50
09/09/2007	Birch	<i>Vegetated</i>	3	106.10	-21.7	SUERC-16126	-26.9	105.29	-8.38	0.280	106.41

The ^{14}C data were corrected using equations 6 and 7 (see above). The laboratory codes are given for each of the ^{14}C determinations.

Supplementary Table 4 | The average age (since C fixation from the atmosphere) of the CO₂ released from the plant-free and vegetated plots in each ecosystem on each sampling date, based on the ¹⁴CO₂ data presented in Figures 2a & b.

Date	Age of respired CO ₂ (years)			
	Tundra-heath		Birch forest	
	Plant-free	Vegetated	Plant-free	Vegetated
May/June	4 (3-6)	3 (3-4)	4 (2-4)	0 (0-1)
July	10 (7-12)	5 (3-5)	8 (7-9)	5 (4-7)
September	7 (7-8)	5 (5-6)	7 (6-8)	3 (2-4)

The average age is presented together with the age ranges (in brackets) for the three collars in each treatment.

Supplementary Table 5 | The soil temperature and moisture contents measured in the plant-free and vegetated plots on each date that flux measurements were made during the growing season. The sub-tables show **a the tundra-heath and **b** the birch forest field sites.**

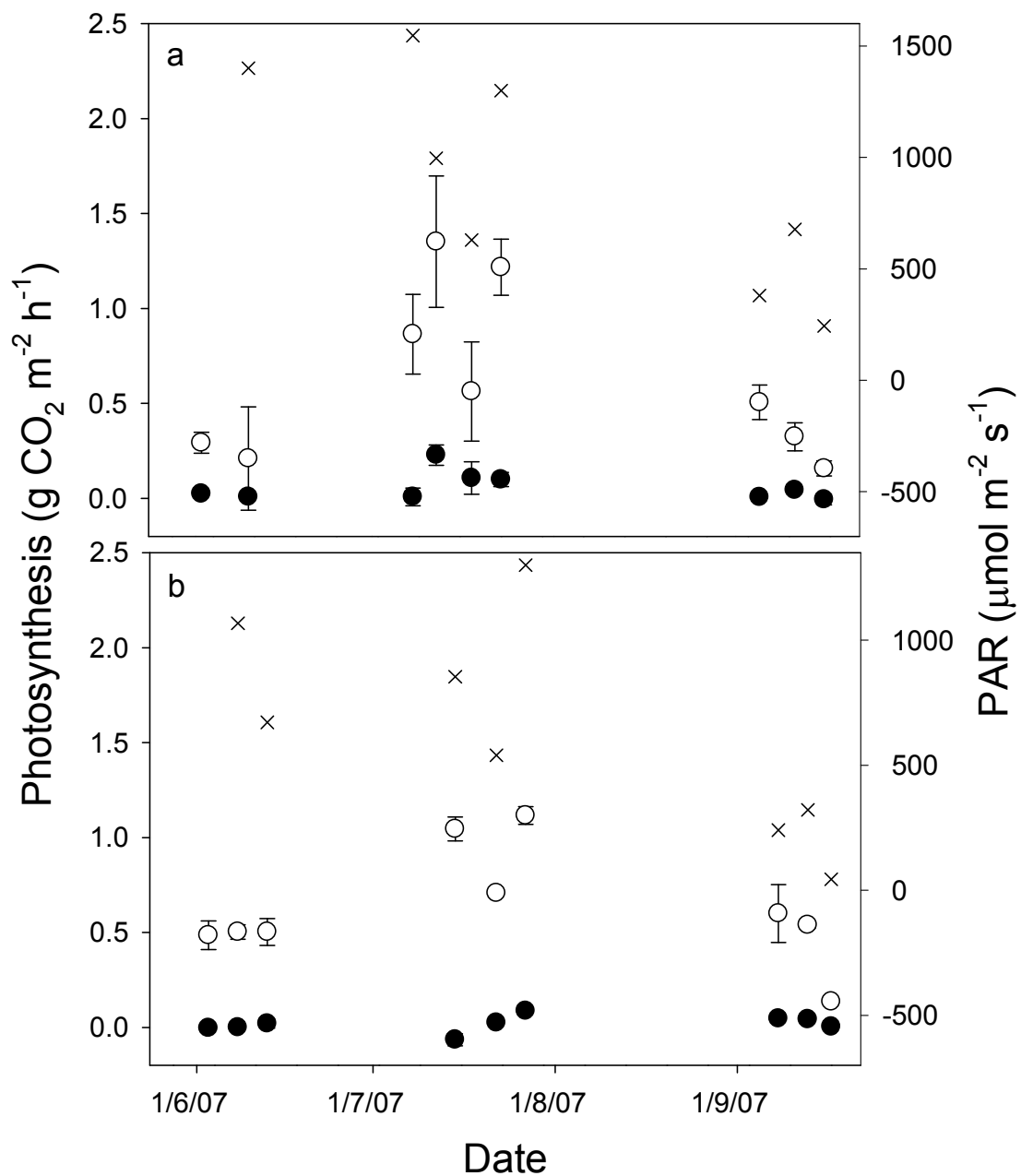
a Tundra-heath

Date	Temperature (°C)						Soil moisture (m ³ m ⁻³)			
	2cm		5cm		8cm		3cm		6cm	
	Plant-free	Vegetated	Plant-free	Vegetated	Plant-free	Vegetated	Plant-free	Vegetated	Plant-free	Vegetated
07/06/2007	9.76±0.28	8.25±0.27	6.98±0.29	6.47±0.20	4.41±0.26	4.74±0.50	0.156±0.010	0.139±0.027	0.219±0.010	0.231±0.051
12/06/2007	4.17±0.25	3.62±0.26	3.39±0.27	3.16±0.39	2.84±0.26	2.76±0.43	0.164±0.003	0.185±0.039	0.251±0.005	0.327±0.061
08/07/2007	12.19±0.51	11.06±0.36	9.13±0.49	8.85±0.06	6.91±0.29	7.32±0.51	0.109±0.014	0.084±0.039	0.176±0.020	0.159±0.058
12/07/2007	12.99±0.14	12.35±0.28	10.76±0.34	10.61±0.17	8.43±0.36	8.84±0.37	0.126±0.018	0.095±0.012	0.213±0.019	0.228±0.033
18/07/2007	8.64±0.67	9.23±0.19	8.48±0.05	8.53±0.17	7.26±0.20	7.77±0.40	0.098±0.017	0.096±0.035	0.257±0.007	0.250±0.057
23/07/2007	15.88±0.20	12.64±0.95	11.34±0.33	10.05±0.67	7.61±0.22	7.57±0.23	0.127±0.012	0.091±0.033	0.222±0.019	0.213±0.052
27/07/2007	15.23±0.27	13.07±0.59	11.34±0.15	10.42±0.44	8.44±0.12	8.49±0.21	0.195±0.014	0.200±0.039	0.283±0.014	0.307±0.058
05/09/2007	2.30±0.33	2.83±0.43	2.53±0.09	2.84±0.29	2.81±0.08	3.03±0.17	0.208±0.009	0.270±0.016	0.359±0.004	0.418±0.034
11/09/2007	5.72±0.14	5.35±0.17	4.54±0.14	4.37±0.09	3.67±0.08	3.73±0.09	0.247±0.017	0.232±0.017	0.333±0.029	0.353±0.049
16/09/2007	6.20±0.10	5.50±0.20	5.07±0.06	4.76±0.11	4.22±0.07	4.04±0.12	0.329±0.018	0.305±0.029	0.418±0.001	0.408±0.038
Average	9.31±0.29	8.39±0.37	7.36±0.22	7.01±0.26	5.66±0.19	5.83±0.30	0.176±0.013	0.170±0.029	0.273±0.013	0.289±0.049

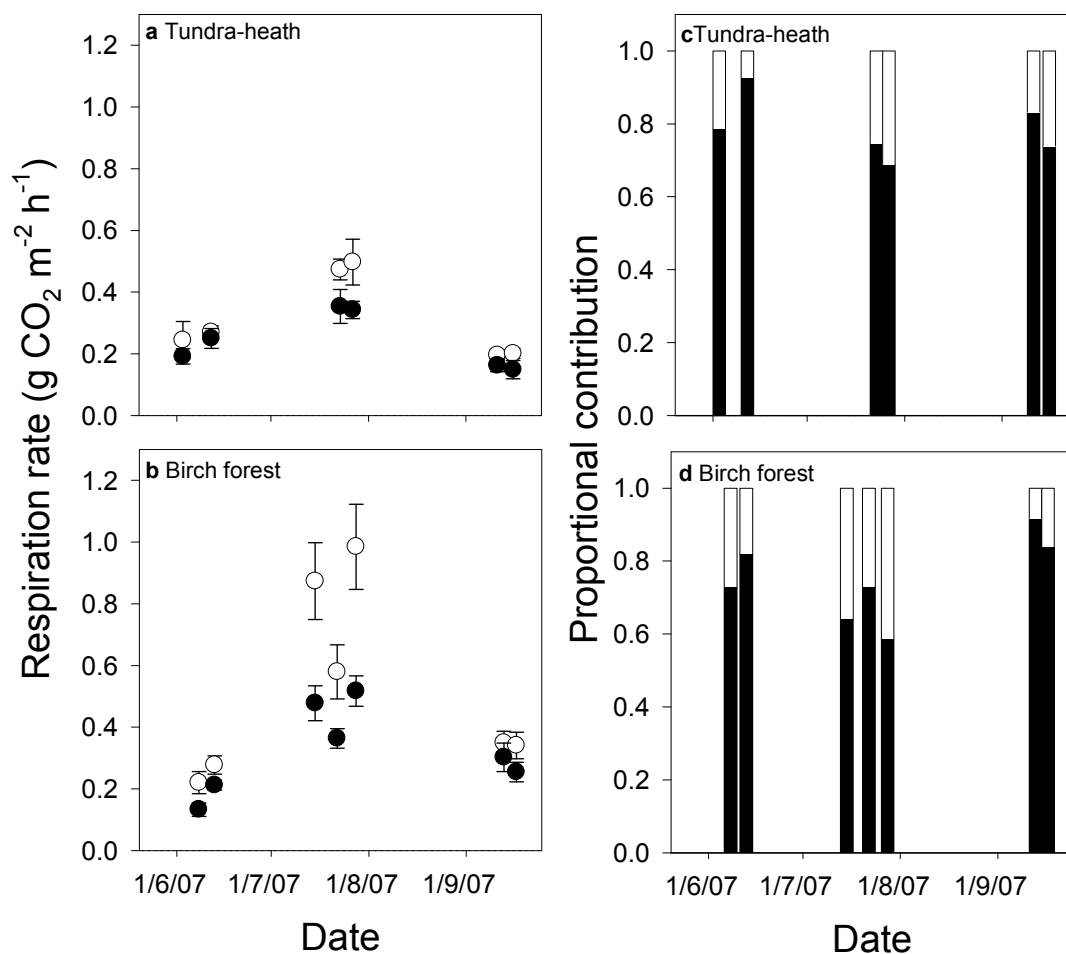
b Birch forest

Date	Temperature (°C)						Soil moisture (m ³ m ⁻³)			
	2cm		5cm		8cm		3cm		6cm	
	Plant-free	Vegetated	Plant-free	Vegetated	Plant-free	Vegetated	Plant-free	Vegetated	Plant-free	Vegetated
03/06/2007	9.25±0.26	8.33±0.06	6.79±0.32	6.02±0.33	5.73±0.34	4.87±0.55	0.095±0.008	0.090±0.006	0.191±0.020	0.194±0.013
08/06/2007	12.74±0.52	11.69±0.04	8.47±0.34	8.21±0.20	6.89±0.40	6.40±0.45	0.020±0.007	0.027±0.002	0.149±0.016	0.132±0.009
13/06/2007	7.45±0.17	6.90±0.12	5.91±0.19	5.68±0.18	5.12±0.33	5.11±0.28	0.090±0.015	0.087±0.014	0.195±0.020	0.160±0.005
07/07/2007	11.97±0.52	11.82±0.22	11.69±0.63	11.67±0.28	11.51±0.72	11.43±0.37	0.077±0.026	0.060±0.022	0.112±0.028	0.095±0.017
15/07/2007	13.61±0.34	13.04±0.69	11.80±0.38	11.31±0.43	10.99±0.43	10.88±0.44	0.046±0.023	0.061±0.022	0.168±0.034	0.153±0.031
22/07/2007	13.14±0.51	13.05±0.19	11.19±0.52	11.01±0.34	10.34±0.60	10.11±0.44	0.027±0.016	0.025±0.013	0.103±0.018	0.138±0.035
28/07/2007	14.67±0.28	14.47±0.15	12.55±0.33	12.58±0.10	11.92±0.42	11.81±0.28	0.142±0.028	0.128±0.029	0.237±0.029	0.216±0.025
08/09/2007	5.95±0.23	6.03±0.29	5.59±0.07	5.78±0.16	5.56±0.06	5.72±0.08	0.243±0.024	0.256±0.031	0.313±0.037	0.328±0.034
13/09/2007	6.21±0.12	6.27±0.14	5.60±0.08	5.69±0.06	5.47±0.06	5.57±0.06	0.254±0.027	0.251±0.016	0.311±0.035	0.307±0.025
17/09/2007	5.33±0.08	5.37±0.01	5.51±0.03	5.54±0.04	5.59±0.01	5.67±0.02	0.308±0.024	0.302±0.027	0.390±0.020	0.395±0.020
Average	10.03±0.30	9.70±0.19	8.51±0.29	8.35±0.21	7.91±0.34	7.76±0.30	0.130±0.020	0.128±0.018	0.217±0.026	0.212±0.021

Mean values ± 1SE are shown. Values in bold and italics indicate a significant difference between the plant-free and vegetated plots ($p < 0.05$).



Supplementary Figure 1 | Rates of photosynthesis (calculated as the difference between the rate of net ecosystem exchange and dark respiration) measured at ambient light for the vegetated (open circles; this does not include birch trees in the forest) and plant-free (filled circles) plots during the 2007 growing season. Panels show a, the tundra-heath and b, the birch forest. Mean photosynthesis rates are displayed, ± 1 SE ($n = 3$). Photosynthetically active radiation (PAR, crosses), measured at the same time as net ecosystem exchange, is also plotted against the right hand y-axis.



Supplementary Figure 2 | Below-ground respiration measurements and partitioning calculations. The respiration rates measured from the below-ground respiration (open circles) and soil respiration (filled circles) collars during the 2007 growing season are shown, **a** for the tundra-heath and **b** for the birch forest. Mean respiration rates are displayed, $\pm 1\text{SE}$ ($n = 5$). Stacked bars indicate the proportional contribution of soil (black) and root (white) respiration to respiration at the below-ground collars, **c** for the tundra-heath and **d** for the birch forest.