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Soil carbon inventories and carbon-13 on a latitude transect in Siberia

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ABSTRACT

We present soil organic carbon (SOC) inventories and carbon isotope compositions from over 900 samples collected in areas of minimally disturbed mature vegetation on freely drained soils (excluding peatlands) on a 1000 km transect along the Yennisey River, central Siberia. Carbon inventories over 0–30 cm depth range widely from 1.71 to 7.05 kg m^{-2}. While an effect of changing climate or vegetation along the transect cannot be ruled out, the observed differences in SOC inventories are largely the result of variations in mineral soil texture, with inventories in fine-textured soils being approximately double those in coarse-textured soils. The δ^{13}C values of SOC in the 0–5 cm interval ranged from −26.3 to −28.0‰, with δ^{13}C values for the 5–30 cm interval being 0.9 ± 0.8‰ (1σ) enriched in ^{13}C relative to the 0–5 cm samples. The average δ^{13}C value for the 0–5 cm interval for all samples was -27.1 ± 0.6‰ (1σ) and for the full 0–30 cm interval the average was -26.5 ± 0.5‰ (1σ). In general, δ^{13}C values were higher in coarse-textured soils and lower in fine-textured soils. The results of detailed sampling of soils in *Pinus sylvestris* forest growing on sand near the Zotino flux tower suggest an SOC inventory in these soils of 2.22 ± 0.35 kg m^{-2} over 30 cm and an average δ^{13}C value of -26.3 ± 0.2‰ over the 0–5 cm depth interval and -25.9 ± 0.3‰ over 0–30 cm. Recent burning had no effect on SOC inventories, but clearing has led to an average 25% decrease on SOC inventories from 0–30 cm over 12 yr. Neither burning nor clearing had a discernible effect on the δ^{13}C value of SOC.

1. Introduction

Soil organic carbon is the major terrestrial reservoir of carbon and contributes substantially to the fluxes of CO_2 between the terrestrial biosphere and the atmosphere. High-latitude biomes contain a significant proportion of all SOC and are the locus of major fluxes of carbon between the terrestrial and atmospheric carbon pools (Schulze et al., 1999). The forests of Siberian Russia represent 60% of the total area of boreal forest (Dixon et al., 1994), with many soil types containing large inventories of SOC (Rozhkov et al., 1996).

Stable carbon isotopes are a useful tracer of the movements of carbon between the various terrestrial carbon pools and the atmosphere (e.g. Battle et al., 2000). While there have been attempts to model global patterns in carbon isotope discrimination during photosynthesis (e.g. Lloyd and Farquhar, 1994), such

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models cannot be directly applied to the SOC pool due to the effects of additional processes that operate during the cycling of carbon through the SOC pool.

The most significant of these processes are the isotopic fractionation effects that accompany microbial degradation of SOC and the 'terrestrial Suess effect'. Microbial degradation leads to a variable degree of isotopic fractionation between SOC, microbial biomass, and the CO_2 that is produced during microbial respiration (Santrùcková et al., 2000). The terrestrial Suess effect means that the $\delta^{13}C$ value of carbon in the SOC pool is not in isotopic equilibrium with the modern atmosphere (Fung et al., 1997). As a result, the $\delta^{13}C$ value of CO_2 respired from SOC is subject to a variable lag between photosynthetic uptake and microbial respiration that is a function of decomposition rate. There is currently a lack of data, systematically collected and analysed over broad areas, that can be used to establish regional trends both in SOC inventories and the $\delta^{13}C$ value of SOC, for areas in comparable geomorphic positions as a function of the most important variables – climate and soil texture.

This study was undertaken with the aim of elucidating trends in the quantity and carbon isotope composition of SOC in mineral soils (excluding peatlands) under mature vegetation in central Siberia, and the factors controlling the observed trends. In order to overcome local heterogeneities and thus be able to discern general trends both in carbon inventories and isotopic composition, a stratified sampling approach was adopted for this study (Bird et al., 2001). A large number of individual soil cores were collected (over 900), but these were 'bulked' into a smaller number of samples representative of each locality sampled.

2. Sample sites and experimental methods

2.1. Sample sites

The Yennisey River bisects Siberia from the mountains of central Asia in the south, to the Arctic Ocean in the north. Sampling for this study was undertaken on a 1000 km long transect along the River from 56°N, near Krasnoyarsk, to 67°N, near Igarka, at altitudes decreasing to the north from ~270 m near Krasnoyarsk to ~30 m at Igarka (Fig. 1). The field program formed a component of the one-month BOBCAT (Boat on a Boreal Carbon Tour) campaign of the Max Planck Institute for Biogeochemistry aboard the Russian vessel *Zont* in July and August 1998.

Fig. 1. Locations sampled on the Yennisey River transect.

Climates along the Yennisey are characterized by short, hot summers and very cold winters. Mean annual temperatures decrease to the north from 0.8 °C at Krasnoyarsk to −7.4 °C at Igarka (Lieth et al., 1999) and the number of months with mean temperatures above zero decreases to the north, from seven to five. Mean monthly maximum temperatures during summer (July) vary considerably less than mean annual temperatures, from 18 °C at Krasnoyarsk to 15 °C at Igarka. Mean annual precipitation does not vary consistently along the transect but at all locations is between 430 and 550 mm, with approximately 50% of the annual total falling during the growing season (Lieth et al., 1999).

The transect passed through boreal forest and taiga biomes characteristic of northern Russia. All soils were developed on alluvium derived from the Yennisey

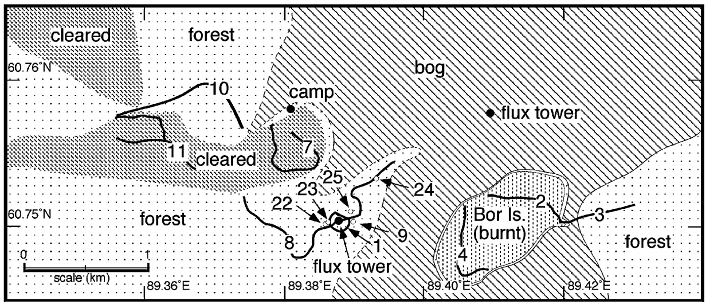

Fig. 2. Location of transects sampled at the Zotino eddy-flux site.

River, ranging widely in texture from coarse to fine. Where soils were coarse-textured, vegetation was dominated by *Pinus sylvestris*. On finer-textured soils vegetation was more variable, with locally dominant species including *Larix sibirica, Picea obovata, Betula spp*. and *Pinus sibirica*.

Reconnaissance sampling amounting to one transect at each location was conducted at eleven sites along the river, with sampling restricted to areas of mature, comparatively undisturbed vegetation. More intensive sampling was conducted in a 2 × km area around the Zotino forest eddy flux tower (Wirth et al., 1999, Wirth et al., in press, Arneth et al., 2002; Tchebakova et al., 2002; Fig. 2). At Zotino, eight transects were sampled through relatively undisturbed *Pinus sylvestris* forest growing in deep sand classified as an pergelic cryochrept inceptisol (USDA), although the morphology was podzolic (Wirth et al., 1999). The maximum age of tree observed was 383 yr, and stands generally ranged in age from 200 to 300 yr. Fires are a comparatively frequent event, but the last fire in the area of the flux tower was 95 yr prior to sampling.

In addition to minimally disturbed mature forest, two transects were collected from forest that had been burnt during an experimental fire on Bor Island in 1993 (Goldammer and Furyaev, 1996), and two transects were collected from areas logged 12 yr prior to sampling. One soil pit was sampled to a depth of 1 m in mature forest, 200 m from the Zotino flux tower.

2.2. *Sampling and analysis*

Three 0–5 cm soil cores (3.5 cm diameter) were collected from each of ten separate locations, on a transect generally 0.5–1 km in length. The three cores from each site on the transect were bagged together to represent one 0–5 cm sample. In addition, one 5–30 cm soil core was collected from each of the ten locations on each transect. As the purpose of the sampling was to attempt to encompass variability in the regions sampled, no attempt was made to restrict sampling to areas of forest of particular age or having a particular disturbance history, and emphasis was placed instead on getting the widest coverage possible. However, in order to avoid complications with waterlogging and peat accumulation, all samples were collected from well drained positions on shallow slopes or topographic high points. In one case, SIB-19, only one set of ten cores from 0–30 cm was obtained due to time constraints during sampling. Where possible, a description of the soil was made from a single soil pit at one location on the transect.

No distinction was made between organic surface layers and mineral soil, and the depth interval sampled represents depth from the top of the litter layer, immediately below living groundcover (usually moss or lichen). No distinction was made between 'plant fragments' retaining their original morphology and 'soil organic matter' that no longer can be identified as a plant material, and no attempt was made to further fractionate the SOC by density or by further chemical treatment. For the purposes of this study SOC is simply defined as being organic carbon <2000 μm in size and 'litter', either above or below ground, as >2000 μm.

Due to the short time available for sampling each area, no attempt was made to sample local vegetation with a view to constraining the δ^{13}C value of carbon input from live vegetation. There is likely to be a large range of δ^{13}C values between species, as well as amongst the various tissue types of each species (roots, leaves, wood etc., and sub-divisions within each of these broad types). There is also likely, to be a large range of δ^{13}C values in 'average' biomass to be expected as a result of annual to centennial fluctuations in local environmental conditions (moisture, irradiance, etc.). Thus, meaningful attempts to constrain the δ^{13}C value of carbon input to the soil by the analysis of standing plant biomass at the time of soil sample collection are, in any event, impossible.

After weighing in the field, the material from the individual soil samples was split, with approximately half of the each sample being added into a bulk 'transect' sample. Each transect is thus represented by 30 original 0–5 cm cores bulked into one sample and 10 original 5–30 cm cores bulked into one sample. Each transect sample was dried in the field to halt microbial activity and obtain a moisture content.

The bulked samples were later sieved in the laboratory to obtain the <2000 μm fraction, and the dry bulk density of each sample was calculated from the dry weight of the <2000 μm fraction of the sample and the known core volume. The bulk samples were thoroughly mixed, and a representative aliquot taken for further work.

One aliquot of <2000 μm material was crushed in a ring mill, and the amount and δ^{13}C value of SOC were determined by elemental analysis followed by on-line isotopic analysis using a Prism III mass spectrometer operated in continuous flow mode. The uncertainty associated with an individual analysis is ± 0.1‰. All results are reported as parts per thousand (per mil) deviations from the value defined for the international V-PDB standard.

A weighed aliquot of each 5–30 cm transect sample was wet sieved in order to provide an approximation of the proportion of total mineral material in the <63 μm fraction. The proportion of mineral material in the <63 μm fraction was corrected for the presence of organic matter using the measured carbon content of the <63 μm fraction (organic matter assumed to be 50% carbon).

3. Results and discussion

The location of each sampled area is given in Table 1, along with soil type, vegetation type, soil bulk density, soil texture, carbon inventory and carbon isotope composition for the two depths sampled. The proportion of <63 μm mineral material in the 5–30 cm interval of the samples ranged widely from 1.7 to 69.3% of the total mineral material, and soil densities decreased irregularly from 1.27 to 0.34 g cm^{-3} as the amount of fine mineral material increased.

3.1. The Yenisey River transect

Carbon inventories on the Yennisey transect ranged from 0.49 to 1.48 kg m^{-2} in the 0–5 cm interval and 1.71 to 7.05 kg m^{-2} over the full 30 cm interval (Table 1). The δ^{13}C values of the 0–5 cm samples ranged from -26.3 to -28.0‰, with δ^{13}C values for the 5–30 cm interval being 0.9 ± 0.8‰ (1σ) enriched in ^{13}C relative to the 0–5 cm samples. The average δ^{13}C value for the 0–5 cm interval for all samples was -27.1 ± 0.6‰ (1σ), and for the full 30 cm interval the average was -26.5 ± 0.5‰ (1σ).

Figure 3 shows the measured carbon inventories from 0–5 cm and 5–30 cm along the Yennisey transect. The average inventory from 0–30 cm for samples from the southern half of the transect is 3.20 ± 1.1 kg m^{-2} (up to and including SIB-19 in Fig. 4), while for the northern transects it is 5.40 ± 1.2 kg m^{-2}. Measured inventories tend to be lower than reported by Rozhkov et al. (1996), because this study excludes the peatlands that contain the bulk of SOC in the boreal region.

There is no strong rainfall gradient along the transect and, in addition, while there is a strong gradient in mean annual temperature, the gradient in temperature during the growing season is comparatively small. Arneth et al. (2002) found that there was no climate related trend in the cellulose δ^{13}C values from specimens *Pinus sylvestris* collected during the BOBCAT campaign.

The elucidation of any climate-dependent trend in the data is confounded by the fact that soil textures varied widely along the transect, and soil texture appears to exert the main control on soil carbon inventories. This effect is clearly illustrated by comparing the inventories for SIB-18 (7.05 kg m^{-2}; fine-textured) and SIB-19 (1.71 kg m^{-2}; coarse-textured) which were collected within a few kilometres of each other near the Yeloguy River.

Figure 4 shows the relationship between 0–30 cm carbon densities and the proportion of <63 μm mineral material. Carbon inventories approximately double from coarse- to fine-textured soils, an observation consistent with the findings of Schimel et al. (1985) that the retention of SOC is proportional to clay mineral content. A direct effect of either climate or vegetation type on isotope discrimination cannot be ruled out, but as the fine-textured locations cluster towards the northern end of the transect, this gives the appearance of a stronger relationship between carbon inventories and climate/vegetation than is likely to be the case.

Table 1. *Location, climate, vegetation and soil properties of samples collected on the Yennisey transect*

Location	Longitude °E	Latitude °N	Veg.	Soil	Soil density 5–30 cm (g cm^{-3})	Mineral 5–30 cm (% $< 63\ \mu$m)	Carbon density			δ^{13}C value		
							0–5 cm (kg m^{-2})	5–30 cm (kg m^{-2})	0–30 cm (kg m^{-2})	0–5 cm (‰)	5–30 cm (‰)	0–30 cm (‰)
SIB-30 (KRA)	92.95	56.37	Pine	Greyzem	0.94	23.3	1.37	2.73	4.09	−26.7	−25.6	−26.0
SIB-26 (NA)	90.71	59.29	Pine	Podsol	1.27	1.7	1.55	1.25	2.80	−27.0	−25.2	−26.2
SIB-28 (NA)	90.87	59.41	Pine	Podsol	1.27	1.7	1.36	2.29	3.65	−26.7	−25.4	−25.9
ZOTINO (ZO)	89.36	60.75	Pine	Podsol	1.05	3.0	1.37	0.98	2.22	−26.3	−25.4	−25.9
SIB-21 (VI)	89.02	62.29	Taiga	Luvisol	0.90	46.8	1.09	2.12	3.20	−27.3	−26.8	−27.0
SIB-20 (VI)	88.96	62.47	Taiga	Luvisol	0.69	69.3	0.49	4.43	4.92	−27.5	−26.5	−26.6
SIB-19	87.53	63.07	Pine	Podsol	1.26	1.2	n.d.	n.d.	1.71	n.d.	n.d.	−26.0
SIB-18	87.76	63.20	Taiga	Fluvisol	0.48	61.0	1.28	5.77	7.05	−26.3	−26.2	−26.2
SIB-17 (PO)	87.63	64.35	Taiga	Gleysol	0.60	27.2	1.20	4.53	5.72	−28.0	−27.0	−27.2
SIB-12	87.70	65.95	Taiga	n.d.	0.60	19.8	1.48	3.12	4.60	−27.7	−26.8	−27.1
SIB-15	87.25	66.13	Taiga	n.d.	0.34	36.3	0.92	2.92	3.84	−27.9	−26.8	−27.1
SIB-14	86.45	67.40	Tundra	n.d.	0.65	21.6	0.82	5.02	5.84	−26.7	−26.9	−26.9

For further information on climate see Lieth et al. (1999). The sample ZOTINO represents the average value for forest transects in the Zotino area (see Table 2). Letters in brackets refer to the location designators of Arneth et al. (2002). Tundra, forest tundra; n.d., not determined.

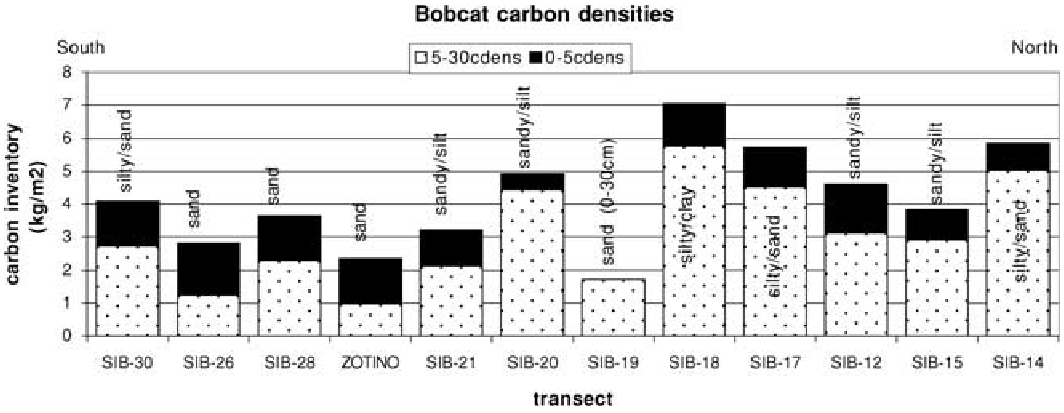

Fig. 3. SOC inventories in the 0–5 and 5–30 cm intervals of the samples analysed on the Yennisey transect. Field textural classification is also shown.

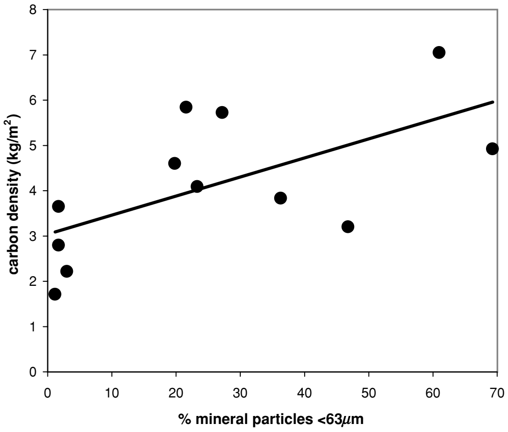

Fig. 4. Relationship between carbon inventory in the 0–30 cm interval and fraction of soil mineral material <63 μm in the 5–30 cm interval of samples from the Yennisey transect.

It should be noted that in the case of coarse-textured soils with comparatively thin (<5 cm) surface organic horizons, a large proportion of the total carbon inventory to 1 m is present in the 30 cm interval sampled. In the case of the fine-textured soils, the very thick surface organic horizons meant that only a few centimetres of the underlying mineral soil was sampled.

The δ^{13}C values of all samples are presented in Fig. 5 and show an irregular trend to decreasing δ^{13}C value with increasing latitude that is also an artefact of soil texture effects, although this may include a component of an isotope effect directly related to climate and/or vegetation type. The average δ^{13}C value for the 0–5 cm interval of the coarse-textured soils (<10% of <63 μm mineral material) is -26.4 ± 0.3‰ (1σ), and for the full 0–30 cm interval is -25.9 ± 0.3‰ (1σ). The comparable average δ^{13}C values for the samples on finer textured soils (>10% of <63 μm) are -27.3 ± 0.6‰ (1σ) and -26.8 ± 0.4‰ (1σ), respectively.

The average δ^{13}C values of the 0–5 cm interval of the soils in this study are similar to the average values of 27.3 ± 0.6‰ obtained for the 0–2 cm interval of a range 'high-latitude' soils by Bird et al. (1996), and -26.8 ± 0.3 obtained for the 0–5 cm interval of Canadian boreal forest soils by Bird et al. (2002). The results are also consistent with a δ^{13}C value of -26.8 ± 0.5‰ calculated for carbon dioxide respired from Canadian boreal forest ecosystems along the BOREAS transect (Flanagan et al., 1996). Many other studies have published soil carbon-isotope analyses for specific locations in the boreal zone, but the data generally scatter over a wide range (approximately –25 to –28‰), making them difficult to compare with the results of this study.

The observed difference of 0.8–0.9‰ between fine- and coarse-textured samples at both depths between the fine- and coarse-textured soils could be the result of several factors: (i) coarse-textured soils have a lower water-holding capacity, with the result that isotopic discrimination during photosynthesis is decreased; (ii) different plant species (pine versus taiga) may exert a different degree of isotope discrimination during photosynthesis; (iii) isotopic differences that might result from differences in discrimination due to soil microbial activity.

(iv) The difference is also likely to result from differences in the thickness of the upper organic soil layers. Figure 6 shows the difference in δ^{13}C value between

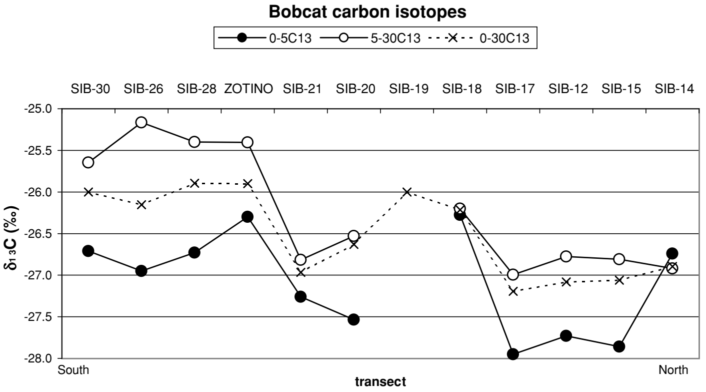

Fig. 5. Carbon isotope composition of SOC in the 0–5, 5–30 and calculated total 0–30 cm interval of samples on the Yennisey transect.

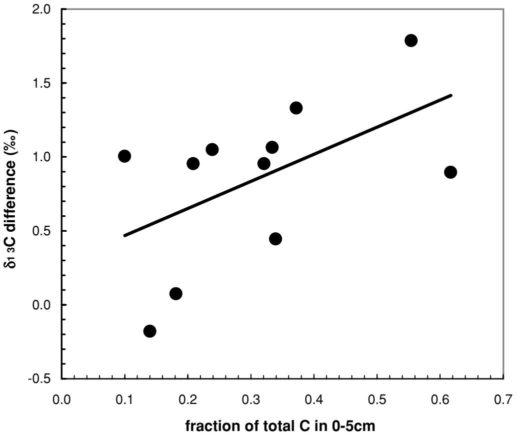

Fig. 6. Relationship between the difference in the δ^{13}C value of SOC in the 0–5 and 5–30 cm interval and the proportion of the total 30 cm SOC inventory that is present in the 0–5 cm interval.

Table 2. *SOC inventories (in kg m^{-2}) and δ^{13}C values of SOC from transects in undisturbed and disturbed mature forests near the Zotino site*

	Forest ($n = 8$)	Burnt ($n = 2$)	Cleared ($n = 2$)
SOC inventory			
0–5 cm	1.37 ± 0.24	1.45 ± 0.26	0.92 ± 0.02
5–30 cm	0.98 ± 0.21	0.98 ± 0.09	0.77 ± 0.02
0–30 cm	2.22 ± 0.35	2.43 ± 0.24	1.69 ± 0.04
δ^{13}C (‰)			
0–5 cm	−26.3 ± 0.2	−26.2 ± 0.3	−26.6 ± 0.0
5–30 cm	−25.4 ± 0.4	−25.1 ± 0.5	−24.7 ± 0.3
0–30 cm	−25.9 ± 0.3	−25.8 ± 0.4	−25.7 ± 0.2

the 0–5 and 5–30 cm samples for each transect plotted as a function of the fraction of the total inventory that is in the 0–5 cm interval (a proxy for the thickness of the surface organic layer). It can be seen that the difference in the δ^{13}C value between the 0–5 and 5–30 cm intervals increases as the proportion of total carbon in the 0–5 cm interval increases.

In coarse-textured soils the difference between the δ^{13}C value of carbon in the 0–5 and 5–30 cm interval is large because a considerable proportion of 'old' heavily degraded, high-^{13}C carbon from the mineral soil was sampled in the 5–30 cm sample. In the case of the finer-textured soils, most of the carbon in both the 0–5 and 5–30 cm samples was derived from the thick organic surface layer, with a small proportion from the mineral soil.

3.2. *The Zotino eddy flux site*

Table 2 provides the carbon inventories and δ^{13}C values for the 12 transects (360 individual cores) sampled from the Zotino area (Fig. 2). The average inventory over 30 cm for all minimally disturbed forest transects at Zotino was 2.22 ± 0.35 kg m^{-2}, with about 60% of this amount being in the 0–5 cm interval of the soil.

Wirth et al. (1999) reported that above-ground biomass in a range of mature (here taken to be >50 yr old) *Pinus sylvestris* stands at Zotino ranged from 5.98 to 13.09 kg m^{-2} where the groundcover was lichen, and up to 29.84 kg m^{-2} where the groundcover was moss. The considerably smaller relative range of SOC inventories from this study attests to the ability of the stratified sampling approach to smooth out local heterogeneity.

Detailed comparison with SOC data from other studies is difficult because different sampling protocols and depth intervals were used. Nevertheless, the average inventory deduced in this study is consistent with a figure of 2.80 kg m^{-2} to 50 cm, with 40% of this total in the 0–3 cm interval as reported by Ross et al. (1999) for a single site in a 215-yr-old stand on similar soil near Zotino. Wirth et al. (in press) report inventories in the surface organic layers and mineral soil to 25 cm (approximately equivalent to 30 cm total depth) at six sites that are broadly similar to the average for this study, but range both higher and lower from 1.55 to 4.45 g cm^{-2}. These inventories include >2000 μm organic carbon and also ground cover (moss/lichen). As these estimates are not limited to <2000 μm material, it is not surprising that they range higher than the average from this study, and the greater variability reflects site-specific differences that are 'averaged' by the stratified sampling approach.

The transects through minimally undisturbed forests sampled stands of differing age and fire history, and this is reflected in the variation in observed carbon inventories despite the 'averaging' effect of the stratified sampling approach. The average deviation from the mean of individual transect inventories is ±16–21% (1σ) of the average for all transects. Based on replicated sampling, the stratified sampling approach can estimate inventories to about ±5% and δ^{13}C values to better than ±0.2‰ (Bird, unpublished data). Therefore the range of carbon inventories at Zotino represent real variability across the area, as is also suggested by the site-specific studies discussed above. This variability is presumably related to differences in disturbance histories as well as water and nutrient availability.

The δ^{13}C values of SOC for the Zotino forest transects also reflect a real variability that is greater than that expected from the sampling procedure alone. The range in values (up to ±0.5‰) suggests local differences that may be related to differences in photosynthetic discrimination related to water availability or to differing soil degradation processes. The average value for the forested transects of -26.3 ± 0.2‰ for 0–5 cm is consistent with previously reported values for high latitude soils (Bird et al., 1996; Bird and Pousai, 1997; Bird et al., 2002), and several per mil higher than δ^{13}C values for surface soil in low latitude forests (average -28.4 ± 0.7‰; Bird and Pousai, 1997).

The average δ^{13}C value of carbon in 5–30 cm interval of the Zotino forest soils (-25.4 ± 0.4‰) is 0.9‰ higher than for the 0–5 cm interval. There may be several reasons for this difference. First, microbial degradation in well aerated soils generally leads to an enrichment in the δ^{13}C value of the SOC remaining after degradation and carbon deeper in the soil is likely to be more degraded than carbon in the surface layers (Santrùcková et al., 2000).

The second reason may be a difference in residence time between the two soil layers. Bird et al. (2002) have demonstrated from radiocarbon analysis of soils from a transect through the Canadian boreal-tundra zone that SOC even in the upper 0–5 cm interval has a residence time of 30–50 yr for coarse material, and up to a century for fine material, at locations with similar climates to those at Zotino. These represent minimum values for carbon deeper in the soil. Thus, much of the SOC is derived from biomass formed 50–100 yr ago in equilibrium with an atmosphere that had a higher δ^{13}C value (Friedli et al., 1986). This lag between photosynthetic uptake of carbon, incorporation into the soil, and its ultimate respiration back to the atmosphere has been termed the 'terrestrial Suess effect' (Fung et al., 1997). A further possibility is that SOC in the deeper soil layers is dominated by root-derived carbon that may have a chemical composition, and therefore isotopic composition, more similar to woody above-ground tissues, and hence have a higher δ^{13}C value than the needles deposited as litter in the surface layers.

The effects of disturbance by fire and logging can be assessed by comparing the results for transects collected in burnt and recently cleared areas with the average for minimally disturbed forest. The experimental burning of forest on Bor Island, near the Zotino flux site, appears to have made little difference to soil carbon inventories with an average over 0–30 cm of 2.43 ± 0.24 kg m^{-2} (Table 2). This may possibly be because the loss of surface SOC during the fire has been approximately balanced by subsequent inputs from dead standing biomass.

Clearing, on the other hand, has led to a substantial drop in soil carbon inventories in 12 yr (Table 2). Inventories in the 0–5 cm interval have decreased by one third (0.92 ± 0.02 kg m^{-2}), in the 5–30 cm interval by one fifth (0.77 ± 0.02 kg m^{-2}), and over the full 0–30 cm interval by one quarter (1.69 ± 0.04 kg m^{-2}).

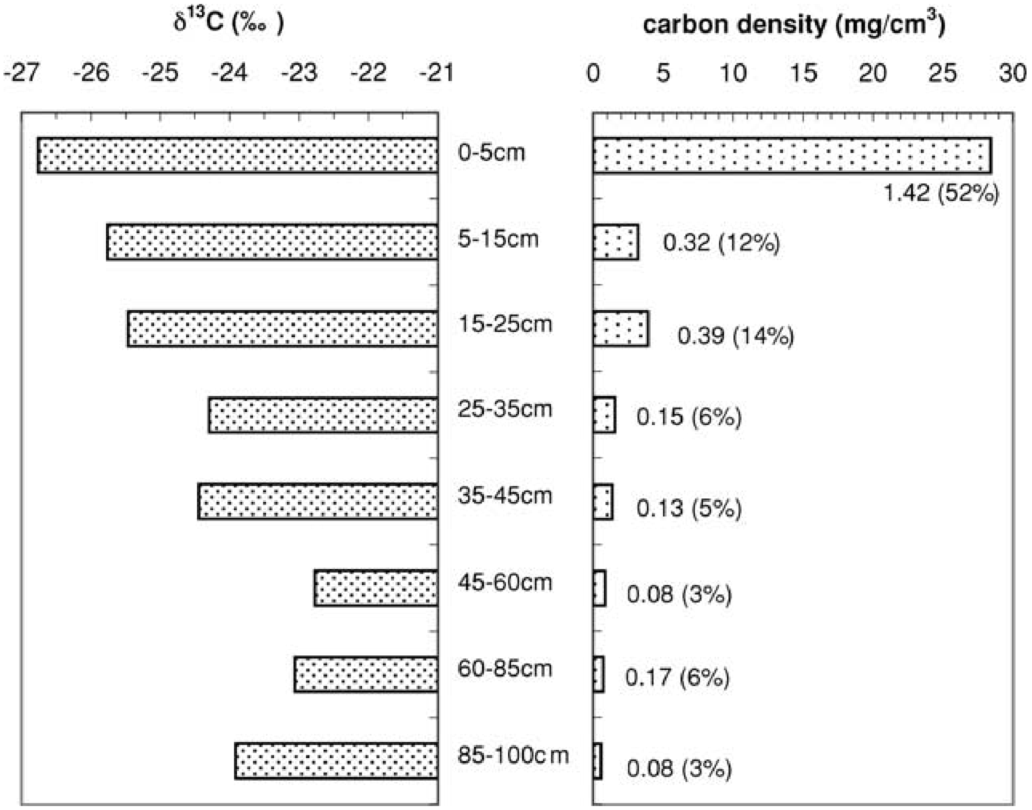

Fig. 7. SOC inventories and carbon isotope composition as a function of depth in soil near the flux tower at Zotino. The inventory over each depth interval is given as a number beside the horizontal bar (in kg m^{-2}) with the proportion of the total SOC to 1 m given in parentheses.

Neither fire nor clearing had a significant impact on the $\delta^{13}C$ value of the SOC (Table 2).

3.3. *Depth profile at SIB-9, Zotino*

One soil pit ~200 m from the Zotino flux tower, was sampled to obtain information on carbon inventories and $\delta^{13}C$ values below the 30 cm interval sampled along the transects (Fig. 7). The data show that carbon inventories decrease dramatically below the surface interval and are very low below 30 cm depth, with the soil below 30 cm containing only 20% of the total inventory of 2.74 kg m^{-2} to 100 cm. This rapid drop reflects the slow rates of bioturbation and illuviation in the mineral soil that pertain in the dry, cold climate at Zotino, and a concentration of the majority of plant roots (including *Vaccinium, Cladonia* and *Polytrichum* in the understory) close to the nutrient-rich surface layers.

The $\delta^{13}C$ value of SOC continues to increase below 30 cm depth to a maximum value of -22.8‰ in the 45–60 cm interval. As these values are several per mil higher than expected for roots from standing biomass, the continued increase in $\delta^{13}C$ value at depth must reflect the influence of the terrestrial Suess effect and the effects of microbial degradation (as discussed above). The weighted $\delta^{13}C$ value for all SOC to 100 cm is -25.8‰.

4. Conclusions

While climate or vegetation changes may have a direct effect on isotope discrimination along the transect, the major control on soil carbon inventories and $\delta^{13}C$ values in the samples analysed for this study appears to be soil texture. Measured 0–30 cm soil carbon inventories in fine-textured soils are approximately double those in coarse-textured soils, although the measured inventories span a much greater range than this, from 1.71 kg m^{-2} for coarse-textured SIB-18 to a maximum of 7.05 kg m^{-2} for fine-textured SIB-18.

Detailed sampling at the Zotino site suggests that local variability due to disturbance histories and water/nutrient availability results in variations of about ±20% around the average value. While fire did not measurably affect soil carbon inventories to 30 cm depth, logging led to a rapid reduction of 25% in SOC inventories to 30 cm.

The carbon isotope results for the 0–5 cm interval from this study and the results from Bird et al. (2002) provide a data set based on about 1000 individual 0–5 cm soil cores. The combined data covers a range in mean annual temperatures from -14 to 2.3 °C, mean annual precipitation from 120 to 550 mm and soil textures from 1.2 to 69.3% of <63 μm mineral material. The combined data suggest that regional SOC $\delta^{13}C$ values at any location in the boreal-tundra regions of Siberia and Canada (excluding peatlands) is -26.9 ± 0.6 (1σ). The $\delta^{13}C$ value of SOC in the 0–5 cm interval is likely to be higher than this average value (up to about -26‰) in areas where the climate is relatively cold and/or dry or the soil is coarse-textured. Conversely, the $\delta^{13}C$ value of SOC in the 0–5 cm interval is likely to be lower than the average (as low as about -28‰) in areas where the climate is relatively warmer and/or wetter or the soil is fine-textured. Further work is required to separate more clearly the interacting effects of climate and soil texture on the $\delta^{13}C$ value of SOC.

In addition, the results from this study suggest that the $\delta^{13}C$ value of SOC in the 0–30 cm interval will be approximately equivalent to the $\delta^{13}C$ value of SOC in the 0–5 cm interval in fine-textured soils with deep organic horizons, but an average of ∼1‰ higher in coarse-textured soils with thin surface organic horizons.

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