USE OF BOMB-PRODUCED ^{14}C TO EVALUATE THE AMOUNT OF CO_2 EMANATING FROM TWO PEAT BOGS IN FINLAND

HÖGNE JUNGNER,[1] ELONI SONNINEN,[1] GÖRAN POSSNERT[2] and KIMMO TOLONEN[3]

ABSTRACT. We used moss increment counting to obtain well-defined samples of the topmost peat layers of two *Sphagnum fuscum* hummocks. The two ombrotrophic bogs, Lakkasuo in central Finland and Korvinsuo in eastern Finland, are of different ages, covering 3 and 9 ka, respectively. Using AMS dating, we traced bomb-produced ^{14}C through the topmost parts of the two peat profiles. A well-defined ^{14}C activity peak was found in both sequences dating the corresponding layer to AD 1965. A comparison between the maximum peat activities and the corresponding atmospheric values for the period of interest provides an opportunity to evaluate the amount of CO_2 emanating from the decaying peat bog, and taken up by the living sphagnum plants.

Considerable variations in $\delta^{13}C$ values were also observed. These variations indicate, at least partly, annual variations in the emission rate of CO_2 from decomposition of older peat in the bog, and are connected with climatic factors such as temperature and precipitation.

INTRODUCTION

Global peatlands form an important carbon reservoir. Intensive research on climate change has led to great interest in the dynamics of the carbon balance in this reservoir. Recent measurements of the fluxes of carbon carried from the peat by gas emissions (*e.g.*, CO_2, CH_4) and leaching (dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC)) form the basis for modeling the carbon cycle in peatlands.

Dörr and Münnich (1980, 1986) have studied the carbon isotope ratios in CO_2 emissions from decomposition in soils. Grootes *et al.* (1989) investigated the influence of biospheric CO_2 on ^{14}C concentrations in tree cellulose. Aravena *et al.* (1993) studied the carbon isotope composition of deep carbon gases in an ombrogenous peatland in northwestern Ontario, and found that gases were 1000–2000 yr younger than the enclosing peat. As an explanation for the age discrepancy, they suggested downward movement of DOC. White *et al.* (1994) combined $\delta^{13}C$ measurements in sedges and mosses, and used these data for reconstructing past atmospheric CO_2 concentration during the Holocene.

In a previous study (Tolonen *et al.* 1992), we were able to detect the high ^{14}C activity due to nuclear bomb tests in the 1960s in surface peat from a *Sphagnum fuscum* hummock in central Finland. By comparing the activity measured from the peat with known atmospheric values, we also tried to estimate the fraction of CO_2 emanating from decomposing deeper layers of the bog and refixed into growing peat.

Having no roots, sphagnum plants collect CO_2 directly from the atmosphere. The carbon fixed in the plants can therefore give information about the isotopic composition in the ambient air just at the surface of the bog, where the annual increments are formed. The intake CO_2 is a mixture of atmospheric CO_2 and CO_2 emitted from the bog. The emitted CO_2, in turn, consists of different components. Root respiration has a short turnover time and, consequently, its ^{14}C content is similar to that of the intake CO_2. Carbon dioxide released from deeper peat layers originates from decomposition of organic matter. In addition, methane formed in anaerobic layers below the water table and oxi-

[1]Dating Laboratory, University of Helsinki, FIN-00014 Helsinki, Finland
[2]The Svedberg Laboratory, Uppsala University, S-75121 Uppsala, Sweden
[3]Department of Biology, University of Joensuu, FIN-80101 Joensuu, Finland

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dized in upper aerobic layers contributes to the CO_2 emissions (Svensson and Sundh 1993). These components have a long turnover time, and their ^{14}C composition depends on the age of the decaying peat.

We present here $\Delta^{14}C$ and $\delta^{13}C$ data from two peat bogs of different ages in Finland. Some data from one of the sites were reported previously (Tolonen *et al.* 1992). The aim of this study is to use carbon isotopes to evaluate carbon emissions from peatlands.

Methods

Samples were collected from two sites: bog K, Korvinsuo, Ilomantsi (62°46'N, 30°56'E, *ca.* 147 m asl, 536 ha) (Tolonen 1967), and bog L, Lakkasuo, Orivesi (61°48'N, 24°19'E, *ca.* 150 m asl, *ca.* 150 ha) (Laine *et al.* 1986). Korvinsuo mire is an almost treeless ombrotrophic ridge-hollow complex with wide moss hollows, mud-bottom communities and sphagnum peat banks on the middle plain. The samples were cored in May 1993 on the deepest part (4.35 m) of the bog. The lowermost peat layer has been dated to *ca.* 9 ka. Lakkasuo is an ombrotrophic *Sphagnum fuscum* pine bog with small wet hollows. The samples were obtained in September 1991 at point 4L27 (Alm, Tolonen and Vasander 1993). The total thickness of the peat on the site is 3.65 m and the bottom layer has been dated to about 3 ka.

In both mires, a *Sphagnum fuscum* hummock, *ca.* 40 cm high, was cored with a pistonless tube sampler. We used the moss increment dating method, originally published by Pakarinen and Tolonen (1977) and refined by Tolonen, Davis and Widoff (1988). The samples extracted from bog L for analysis of their carbon isotopic composition represented 3–5-yr accumulation, according to moss increment counting. For bog K, we sampled more precisely to obtain material representing single years. The samples selected for analysis comprised well-cleaned stems of *Sphagnum*. Different pretreatments were tested. The results reported for bog L are from acid-treated samples, but cellulose and the insoluble fraction from an acid-alkali-acid (AAA) treatment were also tested. The cellulose fraction gave $\delta^{13}C$ values that were systematically *ca.* 1‰ enriched compared to the fractions retrieved from the acid or AAA treatment. $\Delta^{14}C$ values obtained for the three different fractions of a sample from bog L agreed within analytical limits of uncertainty. We used the cellulose fraction for all bog K samples.

For accelerator mass spectrometry (AMS) measurements, the pretreated samples were combusted and converted to graphite according to routine procedures in the Svedberg Laboratory in Uppsala. The samples analyzed for $\delta^{13}C$ in Helsinki were combusted with copper oxide in sealed glass tubes at 550°C or in a closed line at 860°C.

Results

The results from ^{14}C measurements are presented in Table 1 and plotted *versus* depth in Figure 1. The slight decrease in activity for the depth range 50–27 cm for bog L corresponds to the decrease in atmospheric $\Delta^{14}C$ values during the first half of the 20th century. Then the activity increases sharply at 35–32 cm and 27–20 cm in bog K and L, respectively, corresponding to the change in atmospheric ^{14}C activity in 1963 and 1964. The steep rise indicates that each sample consists of material from one to a few years as supported by the result from moss increment counting. The maximum activity measured from the two peat columns are $\Delta^{14}C$ = 660‰ at 30 cm and 564‰ at 20 cm for bog K and L, respectively. From the maxima, there is a continuous decrease in activity towards the surface to a $\Delta^{14}C$ value just below 150‰, in concordance with the change observed in atmospheric ^{14}C activity from the bomb test period to present.

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The $\delta^{13}C$ values given in Table 1 were obtained from parallel samples measured in Helsinki. The $\delta^{13}C$ values for the two bogs are plotted in Figure 2 as function of time, assuming a constant growth rate in each bog defined by the surface and the depth for the detected activity maximum corresponding to year 1964.

TABLE 1. Carbon Isotopic Composition in *Sphagnum fuscum* Separated from Peat at Different Depths from Lakkasuo and Korvinsuo Bogs

Depth (cm)	$\Delta^{14}C$ ‰	$\delta^{13}C$ (‰ PDB)
Lakkasuo (acid-treated fraction)		
0.0–2.5	--	−28.5
2.5–5.0	149.1 ± 8.7	−28.5
5.0–7.5	--	−26.8
12.5–15.0	341.1 ± 9.7	−27.5
15.0–17.5	445.2 ± 10.1	−27.6
17.5–18.7	501.7 ± 10.9	−27.5
18.7–20.0	564.0 ± 11.1	−25.8
20.0–21.2	317.1 ± 8.9	−25.7
21.2–22.5	180.8 ± 8.4	−25.7
23.7–25.0	98.9 ± 7.9	−25.2
25.0–26.2	--	−25.5
25.0–27.5	−12.2 ± 8.6	--
27.5–30.0	−37.8 ± 8.2	−26.1
30.0–32.5	−19.6 ± 8.2	−26.6
32.5–35.0	−24.8 ± 7.3	−26.3
35.0–37.5	−44.8 ± 8.2	−25.7
37.5–40.0	−33.2 ± 5.7	−26.1
40.0–42.5	−22.2 ± 7.2	−26.9
42.5–45.0	−25.6 ± 6.1	−27.1
45.0–47.5	−8.9 ± 9.0	−27.2
47.5–50.0	−28.4 ± 9.4	−28.0
50.0–52.5	--	−28.3
52.5–55.0	7.3 ± 9.3	--
60.0–62.5	--	−28.1
Korvinsuo (cellulose fraction)		
0.0–0.5	128.2 ± 7.0	−25.7
5.0–5.5	164.3 ± 7.1	−26.4
10.0–10.5	177.0 ± 7.5	−26.2
14.0–14.5	209.7 ± 8.3	−26.5
18.0–18.5	248.6 ± 7.9	−25.6
20.0–20.5	294.2 ± 7.6	−26.1
22.5–23.0	--	−26.0
25.0–25.5	372.0 ± 9.2	--
26.2–26.7	444.4 ± 9.0	−26.9
28.5–29.0	598.0 ± 10.0	−25.6
29.5–30.0	660.0 ± 13.0	−25.6
32.0–32.5	624.0 ± 10.0	−24.8
35.0–35.5	84.0 ± 9.3	−24.6
39.5–40.0	−21.6 ± 7.9	−25.5
42.0–42.5	−9.8 ± 8.0	--

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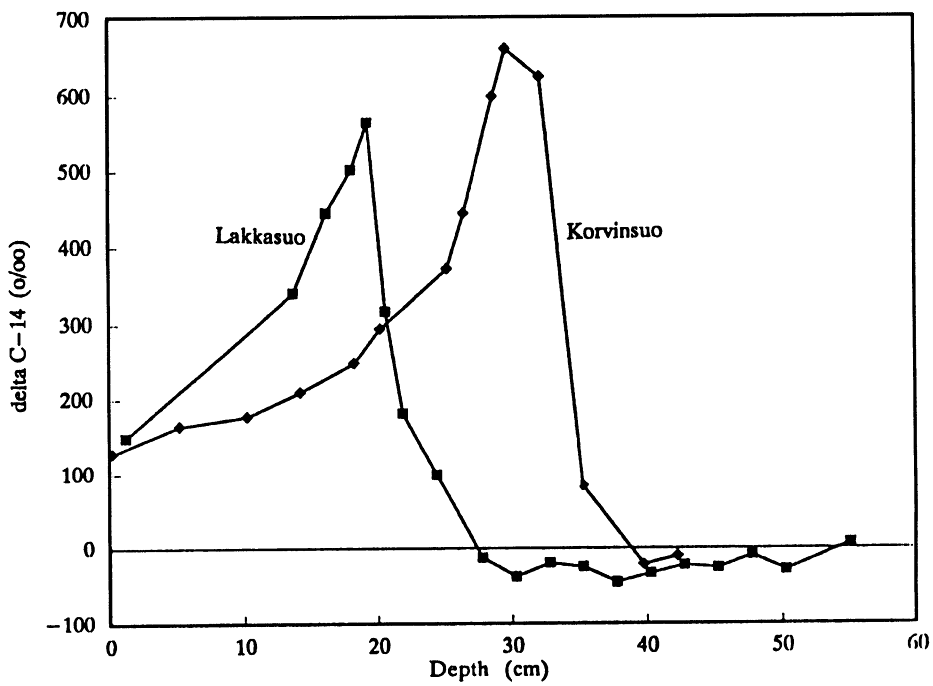

Fig. 1. $\Delta^{14}C$ *vs.* peat depth in Korvinsuo and Lakkasuo bogs

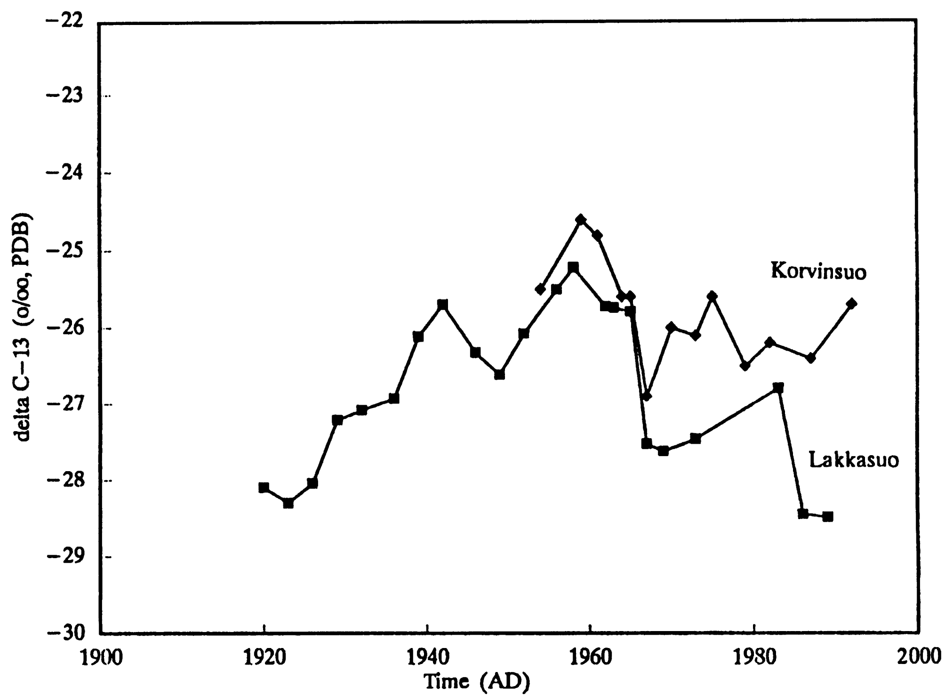

Fig. 2. $\delta^{13}C$ values *vs.* time for *Sphagnum fuscum* from Korvinsuo and Lakkasuo bogs. The time scale is constructed assuming a constant growth rate in each bog defined by the surface and the depth for the detected activity maximum corresponding to year 1964.

Discussion

The ^{14}C activities measured in the peat samples from bogs K and L are compared with the clean air yearly mean ^{14}C values reported by Levin *et al.* (1985). These values agree with the ^{14}C activity of annual plant material from corresponding years as observed by Levin *et al.* (1985) and Tauber (1967). Olsson and Possnert (1992) obtained ^{14}C activities from tree rings of an oak from the suburb of Uppsala in good agreement with these values if one takes into account the 1-yr shift due to storage of carbon in the tree before being fixed in the early wood cellulose of the tree-ring. The growing season for *Sphagnum fuscum* in the study sites presented in this paper extend from May to September (Lindholm 1990), and therefore, annual moss-increments can be compared to tree rings.

The maximum ^{14}C activity observed in the peat is lower than the atmospheric annual mean ^{14}C maximum of 841‰ as given by Levin *et al.* (1985) for the year 1964. For bog K, where the samples are taken to represent annual periods, the ratio between the peat and the atmospheric maxima is 0.71. As the samples from bog L represent 3–5 yr, we compared the peat maximum value with a 5-yr running mean for the atmospheric $\Delta^{14}C$ values. The ratio for the peat to atmospheric maximum is 0.77. The lower activity in the peat is due to the influence of low-activity CO_2 emitted from decomposition of peat at deeper levels of the bog in the total CO_2 taken up by the plants at time of growth. The amount of emitted CO_2 needed to decrease the peat ^{14}C activity to the observed levels depends on the ^{14}C activity of the emitted CO_2. Table 2 gives examples of calculated percentages of emitted CO_2 required to give the measured activity when different $\Delta^{14}C$ values for the emissions are assumed.

TABLE 2. Examples of the Amount of Emitted CO_2 Required to Give the Measured Activity of the Peat from Bogs K and L at the Bomb Peak Maximum when Different Activity for the Emitted CO_2 is Assumed

$\Delta^{14}C$ Activity (‰)	Amount of emitted CO_2 (%)	
	Bog K	Bog L
0	21.5	22.6
−100	19.2	19.9
−300	15.9	16.0
−500	13.5	13.4

The topmost sample from bog K, consisting of peat grown *ca.* 1992, had a $\Delta^{14}C$ value of +128 ± 14‰. For the topmost sample from bog L grown 1985–1988, the corresponding value was +149 ± 9‰. Using the numbers from Table 2 and an atmospheric $\Delta^{14}C$ value of +150‰, a mixing of 13.5% emitted CO_2 with a $\Delta^{14}C$ value of −500‰ would give a $\Delta^{14}C$ value of +60‰, whereas an emission of 21.5% with a $\Delta^{14}C$ value of 0‰ would lead to a $\Delta^{14}C$ value of +120‰ for the peat. Thus, it is reasonable to conclude that the mean $\Delta^{14}C$ value of the emitted CO_2 cannot be much below 0‰. Only for the period of the bomb peak maximum is the difference between the ^{14}C activity of emitted and atmospheric CO_2 large enough to directly influence the ^{14}C activity of peat growing during that period. The ^{14}C activities in the topmost samples from the two bogs are very similar. This also indicates that the much older bottom layers of bog K have no observable influence on the mean ^{14}C activity of the emitted CO_2.

The $\delta^{13}C$ of the moss depends on the isotopic composition of the uptake CO_2 and fractionation during assimilation. The availability of water plays a more important role than temperature conditions on the assimilation rate of *Sphagnum fuscum* (Lindholm 1990). The CO_2 emissions influence both

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the isotopic composition and the concentration of CO_2 in the surface air, and changes in emission rates are therefore reflected in the $\delta^{13}C$ in the moss plants.

The $\delta^{13}C$ values plotted in Figure 2 show great fluctuations within a range of 3‰. These variations overlie the decrease of *ca.* 1‰ in atmospheric $\delta^{13}C$ values for the period 1960–1990. Strong fluctuations are also observed for deeper levels studied in bog L. For the time period in question, records of temperature and amount of precipitation are available from meteorological stations nearby. The pronounced decrease in $\delta^{13}C$ values observed in the curves for both bogs after 1965 may be related to the relatively low precipitation during several successive summer seasons in 1964–1969, leading to lowering of the water table in the bogs and to higher emissions. Direct measurements of CO_2 emissions show variations from year to year within a factor of two, and these variations correlate with the height of the water table in the bog (Silvola *et al.* 1994). Due to complex interconnections between the different parameters influencing the plant $\delta^{13}C$, the variations observed in this study are, however, difficult to interpret further from the limited data available at this stage.

Conclusion

The ^{14}C activity observed in the surface peat from the two bogs shows a pattern similar to that of the ^{14}C activity of atmospheric CO_2 for the last few decades. The ^{14}C activity of the peat is, however, systematically lower due to the input of depleted CO_2 emitted from decomposing layers of the bog. A comparison between ^{14}C activity maxima of peat and atmospheric CO_2 suggests that the emitted CO_2 amounted to 20% of the total CO_2 taken up by the growing *Sphagnum fuscum* plants at the time of the atmospheric bomb peak maximum. The mean ^{14}C activity of the emitted CO_2 is close to 100 pMC, *i.e.*, the main source for the emitted CO_2 is the uppermost layers of the bog. Variations in CO_2 emission rates influence the isotopic composition and the concentration of CO_2 in the surface air, and can be observed as variations in $\delta^{13}C$ in moss plants.

References

Alm, J., Tolonen, K. and Vasander, H. 1993 Determination of recent apparent carbon accumulation in peat using dated fire horizons. *Suo* 43: 191–194.

Aravena, R., Warner, B. G., Charman, D. J., Belyea, L. R., Mathur, S. P. and Dinel, H. 1993 Carbon isotopic composition of deep carbon gases in an ombrogenous peatland, northwestern Ontario, Canada. *Radiocarbon* 35(2): 271–276.

Dörr, H. and Münnich, K. O. 1980 Carbon-14 and carbon-13 in soil CO_2. *In* Stuiver, M. and Kra, R. S., eds., Proceedings of the 10th International ^{14}C Conference. *Radiocarbon* 22(3): 909–918.

____1986 Annual variations of the ^{14}C content of soil CO_2. *In* Stuiver, M. and Kra, R., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28(2A): 338–345.

Grootes, P. M., Farwell, G. W., Schmidt, F. H., Leach, D. D. and Stuiver, M. 1989 Importance of biospheric CO_2 in a subcanopy atmosphere deduced from ^{14}C AMS measurements. *In* Long, A., Kra, R. S. and Srdoč, D., eds, Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 475–480.

Laine, J., Päivänen, J., Schneider, H. and Vasander, H. 1986 *Site Types at Lakkasuo Mire Complex: Field Guide* 8. Helsinki, University of Helsinki, Publications Department of Peatland Forestry: 1–35.

Levin, I., Kromer, B., Schoch-Fischer, H., Bruns, M., Münnich, M., Berdau, D., Vogel, J. C. and Münnich, K. O. 1985 25 years of tropospheric ^{14}C observations in Central Europe. *Radiocarbon* 27(1): 1–19.

Lindholm, T. 1990 Growth dynamics of the peat moss *Sphagnum fuscum* on hummocks on a raised bog in southern Finland. *Annales Botanici Fennici* 27: 67–78.

Olsson, I. U. and Possnert, G. 1992 ^{14}C activity in different sections and chemical fractions of oak tree rings, AD 1938–1981. *In* Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 757–767.

Pakarinen, P. and Tolonen, K. 1977 On the growth rate and dating of surface peat. *Suo* 28: 1–24.

Silvola, J., Alm, J., Ahlholm, U., Nykänen, H., and Martikainen, P. J. 1994 CO_2 fluxes in peatlands under varying temperature and moisture conditions. *In* Kanninen, M. and Heikinheimo, P., eds., *The Finnish Research Programme on Climate Change, Second Progress Report.* Helsinki, Publications of the Academy of Finland 1/94: 273–276.

Svensson, B. H. and Sundh, I. 1993 Factors affecting methane production in peat soils. *Suo* 43(4–5): 183–190.

Tauber, H. 1967 Copenhagen radiocarbon measurements VIII. Geographic variations in atmospheric ^{14}C activity. *Radiocarbon* 9: 246–256.

Tolonen, K. 1967 Über die Entwicklung der Moore im finnischen Nordkarelien. *Annales Botanici Fennici* 4: 219–416.

Tolonen, K., Davis, R. B. and Widoff, L. 1988 Peat accumulation rates in selected Maine peat deposits. *Maine Geological Survey, Department of Conservation Bulletin* 33: 1–99.

Tolonen, K., Possnert, G., Jungner, H., Sonninen, E. and Alm, J. 1992 High resolution ^{14}C dating of surface peat using the AMS technique. *Suo* 42(4–5): 271–275.

White, J. W. C., Ciais, P., Figge, R. A., Kenny, R. and Markgraf, V. 1994 A high-resolution record of atmospheric CO_2 content from carbon isotopes in peat. *Nature* 367: 153–156.