

Organic Matter Accumulation and Community Change at the Peatland–Upland Interface: Inferences from ^{14}C and ^{210}Pb Dated Profiles

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ABSTRACT

Peatland-margin habitats with organic matter accumulation of 40–150 cm make up a significant but poorly quantified portion of Canada's boreal forest region. Spanning the transition between non-wetland forest and fen proper, these ecosystems represent a zone of complex environmental and vegetation change, yet little is known about their ecological function or development. We here use vegetation and macrofossil analysis, traditional ^{14}C , bomb-spike ^{14}C , and ^{210}Pb dating to investigate the development, organic matter accumulation, and recent vegetation history of peat margin communities at two sites in central Saskatchewan, Canada. Although similar in general shape, bomb-spike ^{14}C and ^{210}Pb chronologies show limited agreement in three of the four profiles examined, with ^{210}Pb generally producing younger ages than ^{14}C . Peat initiation and long-term organic matter accumulation at the Old Black Spruce (OBS) transect were probably

driven mainly by the dynamics of *Sphagnum*, whereas at the Sandhill Fen (SF) transect, they were controlled by water level fluctuations in the neighboring fen. Bryophyte macrofossils suggest a recent drying of the vegetation surface at both sites, most likely triggered by regional drought in the late 1950s and 1960s. At OBS, the shift from *Sphagnum*- to feather moss-dominated communities continued in the 1990s, possibly reflecting effects of direct disturbance on local drainage patterns. Overall, our results suggest that community composition and C dynamics of peat-margin swamps respond dynamically to climatic and hydrologic fluctuations. However, uncertainties regarding the reliability of different chronologies limit our ability to link observed community changes to specific causal events.

Key words: peatland margins; climate change; C accumulation; ^{210}Pb ; ^{14}C ; bryophyte macrofossils.

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INTRODUCTION

In the vast boreal forest regions of continental North America, soil drainage is a main determinant of soil carbon (C) storage (Rapalee and others 1998), and extensive peatlands have developed on

cold, waterlogged terrain that limits organic matter decay. In Canada alone, peatlands cover 1,237,000 km², or 13.6% of the land area and store an estimated 153.7 Gt of C (Tarnocai 1998), with another approximately 64 Gt C in boreal (non-peat) forest soils (Apps and others 1993).

The transition from non-wetland forest to peatland is a complex gradient that involves changes in organic layer depth, soil temperature, water tables, and several vegetation-related variables (see for example, Hartshorn and others 2003; Bhatti and others 2006). Especially in areas of little or no topography, this transition is often gradual, with large areas of dense (> 30% cover) *Picea mariana* or *P. mariana/Larix laricina* forest on shallow (40–150 cm organic layer depth) organic soils. Communities of this type have been variously described as “mire margin forest”, “forested mire”, “moist forest”, or “swamp” in different national classifications (See Locky and others (2005) for a recent review), and their transitional nature was recognized early on especially in Scandinavia (Cajander 1913; Korpela and Rainikainen 1996a, b). Under the Canadian System of Wetland Classification, they are classified as swamps, where “swamp” is a wetland influenced by minerotrophic groundwater that is dominated by tall woody vegetation (Warner and Rubec 1997).

Peat margin swamps (a subform of the swamp wetland class) occupy sloping terrain situated between peatland and upland (=non-wetland) mineral ground; dry treed swamps grade into upland forest, whereas wet treed swamps grade into treed fen (Warner and Rubec 1997; Locky and others 2005). In many cases, the boundaries between these different community types are dynamic, and given suitable hydrotopographic conditions, swamps and their adjoining fens can spread outward into adjacent uplands (Heinselman 1970; Foster 1984; Warner and Rubec 1997; Bauer and others 2003). Conversely, decreased water levels result in increased tree productivity and may lead to a contraction of wetland boundaries (Hartshorn and others 2003).

Few North American studies have examined the development, C cycling, and C accumulation dynamics of communities that occupy the transition zone between upland and fen. Work has mostly focused on either ‘true’ peatlands (bogs or fens) or on upland systems, and studies that consider multiple ecosystem types and drainage classes (for example, Harden and others 1997; Trumbore and Harden 1997) have often been spatially extensive. Here, we use a more localized, transect-based approach to examine peatland-margin

communities at two fen sites in central Saskatchewan. Beyond examining patterns of peat initiation and C accumulation, our aim is to see if traditional paleoecological methods can be used to reconstruct recent (twentieth century) patterns of community change in peatland-margin environments.

Because of their ecotonal nature, peat margin ecosystems are likely to be highly sensitive to climate change (Hartshorn and others 2003). However, they also have complex hydrological connections with both neighboring wetlands and surrounding uplands, and these may buffer or obscure any direct linkage between climate, water levels, and vegetation dynamics. Moreover, the woody, often highly decomposed nature of peat deposited in peatland-margin environments means they are not an obvious environment for paleoenvironmental reconstruction, and the effectiveness of many standard dating tools has not been tested in this type of environment.

We collected organic matter (OM) profiles from locations that span the transition from upland to fen to investigate the key questions: (a) When did peat first initiate at different points along the peatland–upland transition? (b) What were the initial community types present, and can they provide insights into mechanisms that triggered OM accumulation at different locations? (c) How do ²¹⁰Pb and (bomb) ¹⁴C chronologies compare for surficial organic layer profiles? (d) What are long-term and recent (apparent) rates of peat and C accumulation at different points along the peatland–upland transition? and (e) Is there any evidence for recent (twentieth century) community changes, and if so, can these be linked to the known climatic history of the region?

MATERIALS AND METHODS

Study Sites

Cores for this study were collected at two sites located in the BERMS (Boreal Ecosystem Research and Monitoring sites) area of central Saskatchewan, which was formerly the BOREAS (BOReal Ecosystem-Atmosphere Study) southern study area (Figure 1). The climate of the region is cold and continental, with a mean annual temperature of 0.4°C and approximately 470 mm annual precipitation at the nearest long-term weather station (Waskesiu Lake; Environment Canada 2004). Water chemistry parameters at both sites fall into the published range for rich fens (Vitt and Chee 1990), with average pH values of 8.0 and 7.2,

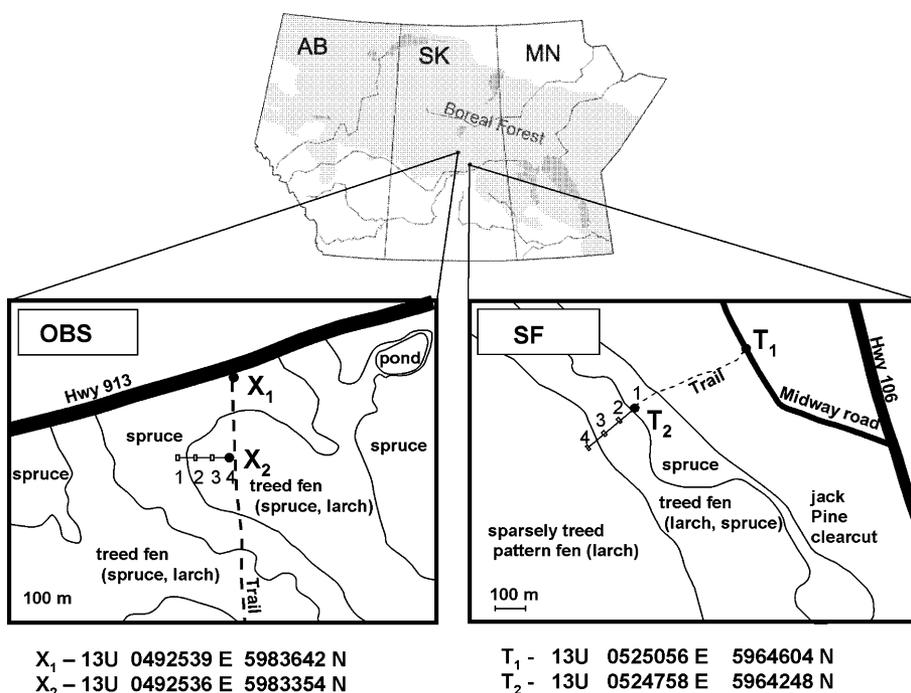


Figure 1. Location of study sites in continental western Canada, and layout of study transects at the OBS and SF sites.

Boundaries plotted on detailed site maps are based on a combination of field notes, published maps, air photos, and satellite images. Co-ordinates shown are UTM.

conductivity of $288 \mu\text{S cm}^{-1}$ and $153 \mu\text{S cm}^{-1}$, and Ca concentrations of 34.8 mg l^{-1} and 17.2 mg l^{-1} at the Old Black Spruce (OBS) and Sandhill Fen (SF) sites, respectively. (Values are averages based on $n = 110$ (OBS) and $n = 120$ (SF) samples taken between May and October 2004.)

The peatland basin at OBS ($53^\circ 59' 54'' \text{ N}$, $105^\circ 06' 55'' \text{ W}$) is located close to the top of the local drainage path. In spite of having water chemistry akin to extreme-rich fens, its vegetation includes many taxa normally associated with poor fens or bogs, making this site a 'mixed mire' sensu du Rietz (1949). *Picea mariana* is the dominant tree in both the fen and adjoining uplands, with some individuals of *Larix laricina* scattered throughout. Parent material underlying the site is glacial till of Pleistocene origin, most likely 100–200 m in thickness. Tills in this region of SK are generally calcareous and undifferentiated, containing a mixture of gravel, sand, silt, and clay (Anderson and Ellis 1976; Simpson 1997).

The SF site ($53^\circ 49' 34'' \text{ N}$, $104^\circ 37' 30'' \text{ W}$) is a patterned rich fen, with alternating peat ridges (strings) and wet depressions (flarks). The dominant tree species in the part of the fen examined is *L. laricina*, which gradually gives place to *P. mariana* in the adjoining upland. The site is situated on a glacial outwash plain (Simpson 1997), and medium-fine sands underlie the fen peat to an unknown depth.

Transect and Plot Setup

At each site, a permanent transect (150–200 m in length) was set up across the transition from upland (or upland edge) into the peatland (Figure 1). Four equidistant stations were established along this transect, with organic matter depths of 40–50 cm at station 1 (upland edge) and approximately 150 cm at station 4 (peatland). At each station, a systematic grid of 24 plots ($2 \times 1 \text{ m}^2$) was laid out, with two groups of 12 plots at either side of a central area used for environmental measurements. Instrumentation for the continuous monitoring of water tables was installed in October 2002, with further (manual) wells added throughout the plot grid in 2003. Stand characteristics, carbon stocks, and changes in environmental parameters along both study transects are described in detail by Bhatti and others (2006).

Collection and Analysis of Vegetation Data

At each transect station, 6 of the 24 systematically placed plots were randomly selected and used for bryophyte sampling, and another 6 for sampling of vascular vegetation. Percent cover of all bryophyte taxa was measured using a pinframe placed over one half ($1 \times 1 \text{ m}^2$) of each bryophyte plot; percent cover for vascular taxa was estimated visually for the entire $2 \times 1 \text{ m}^2$ area of vascular vegetation

plots. All vegetation data presented here were collected in July or August 2003. To identify taxa characteristic of specific transect locations, species indicator values were calculated using the method of Dufrêne and Legendre (1997), which takes into account both relative abundance (percent cover) and relative frequency (or constancy). The significance of indicator values was tested using Monte Carlo Permutation. Nomenclature follows Moss (1983) for vascular plants, Anderson (1990) for *Sphagnum*, and Anderson and others (1990) for other bryophytes.

Tree canopy cover above vegetation plots was measured by hemispherical photography, either in July (bryophyte plots) or September (vascular plots) 2003. A digital camera with a Nikon fisheye converter lens (FC-E8 0.21×) was mounted on a tripod leveled above each plot, and a picture of the canopy was taken. Canopy closure was later determined from digital images using Gap Light Analyzer version 2.0 (Frazer and others 1999).

Core Collection

Three peat cores were collected from each transect station in October 2002. Two of these cores (“²¹⁰Pb cores”) were surficial (60–80 cm depth) and were taken by driving a 10-cm diameter piece of sharpened PVC pipe into the peat. Pipes were capped in the field and used to transport cores back to the lab. The third core (“full core”) included the entire organic matter profile (50–170 cm depending on location) and was taken using a 5-cm diameter modified Macaulay peat sampler. Core sections were stored in half-sections of PVC pipe and wrapped in plastic film. On return to the lab, all cores were frozen until further processing.

Sample Processing and Analysis

Full Cores

Samples of 2-cm length (19.6 cm³) were removed from full cores at 5-cm intervals. The wet weight of each sample was determined before and after removal of a small subsample for archival purposes, and a correction factor was calculated to account for the proportion of mass removed. The remainder of the sample was dried to stable weight at 65°C, and dry weight and bulk density were calculated after correcting for mass lost in subsampling. Each sample was then ground to a fine powder and split for organic matter (OM), organic C, total C and N determination. The OM content of each sample was calculated by subtracting ash from total dry weight, with ash concentration determined by combusting

subsamples at 550°C for 4 h. Organic C and total C/N were measured by dry combustion on LECO CR12 and LECO CNS analyzers, with burning temperatures of 842° and 1100°, respectively.

The base (peat/mineral interface) of each core was defined as the point where organic C content dropped below 17%, a cut-off used in the Canadian System of Soil Classification (Soil Classification Working Group 1998) to distinguish organic and mineral horizons. A 1-cm sample (‘basal peat’) was removed from just above this interface, and its botanical composition was scored using a simplified version of Barber and others’ (1994) quadrat count method. Small (3–5 cm³) subsamples were washed over a 125 µm sieve and dispersed on a petri plate, and the proportion made up by different macrofossil components was determined as the average of 10 quadrat counts, using a dissecting microscope with 10 × 10 grid eyepiece graticule at low power. In one core (SF station 4), none of the samples analyzed had less than 17% organic C, but a sharp increase in ash content (15–46% sample weight) between the two lowest samples (144–145 cm and 149–150 cm), together with sand observed at the core base (154 cm) during coring, suggested that the peat/mineral interface was located between 150 and 154 cm depth. In this core, a sample from 151 to 152 cm was designated and analyzed as the basal sample.

After botanical scoring, selected macrofossil remains (wood, bark, or *Sphagnum*) were removed from basal samples for ¹⁴C analysis. Pretreatment was based on Shotyk and others (2003) and D. Beilman (personal communication); samples were placed in screw-cap test tubes and successively heated at 65° C for 10–20 min with 1 N HCl, 1 N NaOH (twice), and 1 N HCl. After each treatment, samples were centrifuged, and the solution decanted. After the final treatment, samples were transferred to screw-cap plastic vials using 0.01 N HCl, with a small volume (less than 1 ml) left in the vials for shipping. Prior to radiocarbon analysis, samples were combusted and then reduced to graphite using the hydrogen-reduction method (Vogel and others 1984). Radiocarbon values are reported as fraction Modern (F¹⁴C) and Δ¹⁴C (Stuiver and Polach 1977; Reimer and others 2004b). All ¹⁴C determinations were done at the Center for Accelerator Mass Spectrometry (CAMS) at Lawrence Livermore National Laboratory, with an average precision of 4‰.

Samples remaining after ¹⁴C analysis were separately analyzed for δ¹³C to correct for effects of mass-dependent fractionation. They were dried at 70°C, finely ground by hand, and analyzed as

described by Preston and others (2006). Basal radiocarbon dates were calibrated using CALIB rev. 5.0 (Stuiver and Reimer 1993) and the INTCAL04 dataset (Reimer and others 2004a).

²¹⁰Pb Cores

Cores for ²¹⁰Pb analysis were thawed just enough to allow for removal from the PVC and sectioned into 2-cm intervals on a band saw. Each of the resulting samples was cut in half, and one half-sample was dried at 65°C, weighed, and used for ²¹⁰Pb analysis. The other half-sample remained frozen and was later sub-sampled for OM and (in selected cores) macrofossils and ¹⁴C analysis. In the upper core sections, the first half-sample often had insufficient mass for ²¹⁰Pb analysis, and if this was the case, material left over after other analyses was added to the ²¹⁰Pb sample. Organic matter analysis involved ashing samples at 550°C for 4 h, as described for full profiles.

Samples for ²¹⁰Pb determination were acid-digested with concentrated HCl, HNO₃, and H₂O₂ after addition of ²⁰⁹Po as a chemical yield tracer. The material was then plated onto silver discs, and activity was measured using alpha spectrometry. Within a given core, the age of each sample was calculated from the total ²¹⁰Pb inventory using the constant rate of supply (CRS) model (Appleby and Oldfield 1978; Brenner and others 2004).

To allow for corroboration of ²¹⁰Pb chronologies (Turetsky and others 2004), the upper 10 samples of selected cores (OBS stations 1 and 3; SF stations 2 and 4) were also analyzed for ¹⁴C. Prior to removal of material for dating, the botanical composition of each sample was scored using the

quadrat count method described above. Remains subsequently selected for ¹⁴C analysis were bryophyte fragments and/or *Larix* needles, and it is assumed that these reflect atmospheric ¹⁴C concentrations in the year the sample was at the surface. Post-modern ¹⁴C dates were converted to years AD using CALIBomb and the calibration data of Levin and Kromer (2004). CALIBomb incorporates ¹⁴C produced during atmospheric nuclear weapons testing (the “bomb spike”, see Hua and Barbetti 2004) into the date estimate (Reimer and Reimer 2004; see also Reimer and others 2004b). Calibration of pre-1950 ¹⁴C dates invariably produced several possible dates and large sigma ranges, and these dates were excluded from further analysis.

RESULTS

Community Change Along Transects

In 2004, median water tables at the OBS transect ranged from 45.0 to 25.5 cm below the surface, with driest conditions at station 1 (upland edge), wettest conditions at station 2, and intermediate values at stations 3 and 4 (Table 1). Tree canopy closure ranged from 91.3 to 64.5%, with decreasing values (opening up of the canopy) from station 1 to station 3, followed by a slight increase at station 4 (Table 1).

The feather moss *Pleurozium schreberii* was common at all points along the OBS transect. Species with significant indicator values for OBS station 1 (upland edge) are *Hylocomium splendens* and *Carex vaginata*, and these are replaced by *Equisetum sylvaticum*, *Carex disperma*, *Smilacina trifolia*, *Orthilia*

Table 1. Water Table Depth, Tree Canopy Cover, Organic Matter Stocks, and Organic Matter Accumulation Rates in Transitional Forest Sites

Site/ station	2004 median water table (cm below surface)	Tree canopy cover (%)	OM depth (cm)	Total OM mass (kg m ⁻²)	Total C mass (kg m ⁻²)	Organic C mass (kg m ⁻²)	Total profile age (years)	Long-term OM accumulation rate (g m ⁻² a ⁻¹)	50-year OM accumulation rate (g m ⁻² a ⁻¹)
OBS 1	45.0	91.3 (0.5)	48	47.9	30.5	28.6	815	58.8	140.6
OBS 2	25.5	84.1 (3.8)	73	72.6	41.9	39.3	1755	41.4	123.9
OBS 3	31.9	64.5 (8.9)	124	117.6	68.2	62.6	1525	77.1	105.7
OBS 4	27.2	71.5 (8.6)	164	190.9	109.7	102.9	3930	48.6	144.5*
SF 1	22.0	83.5 (2.6)	44	60.2	36.0	32.8	912	66.0	148.1
SF 2	14.5	80.0 (2.1)	114	139.4	84.2	77.5	3825	36.4	150.7
SF 3	3.5	69.8 (8.9)	132	173.4	104.6	97.4	3835	45.2	147.1
SF 4	-2.3	46.4 (19.2)	152	190.4	115.0	107.5	3440	55.3	155.6

* 188.4 in replicate 1 alone (see text).

OM Organic matter, OBS Old Black Spruce, SF Sandhill Fen.

At each site, stations represent a gradient from upland margin (Station 1) to peatland (Station 4). Total profile ages are based on calibrated ¹⁴C dates and quoted relative to the time of coring (2002). Fifty-year OM accumulation rates are based on ²¹⁰Pb and represent the average of two profiles examined at each station.

secunda, *Salix myrtillofolia*, and *Ledum groenlandicum* at station 2. Although not a significant indicator, *Tomenthyllum nitens* reached its greatest prominence (both relative abundance and relative frequency) at station 2, and was found in microsites close to the water table at other stations. OBS stations 3 and 4 were similar to each other in their overall complement of species, with common peatland taxa such as *Dicranum undulatum*, *Drosera rotundifolia*, *Sphagnum fuscum*, *Kalmia polifolia*, *Rubus chamaemorus*, and *Vaccinium vitis-idaea* common in both. Taxa with significant indicator values at OBS station 3 were *Oxycoccus microcarpus*, *Carex aquatilis*, *Geocaulon lividum*, and the lichens *Cladina mitis* and *Cladina stygia*. *Andromeda polifolia* and *Peltigera aphthosa* had significant indicator values at OBS station 4.

The SF transect was wetter on average than that at OBS, with a steady rise in water table ('wetting up') from the upland edge toward the peatland (Table 1). Tree canopy closure ranged from 83.5 to 46.5%, showing a steady decline from station 1 to station 4.

Species with significant indicator values at SF station 1 are *Pleurozium schreberi*, *Ledum groenlandicum*, and *Carex disperma*, whereas *Smilacina trifolia* and *Sphagnum angustifolium/warnstorffii* (these taxa could not be reliably separated in the field) are significant indicators at SF station 2. Several other taxa (for example, *Carex aquatilis*, *Vaccinium vitis-idaea*, *Hylocomium splendens*) are equally prominent at both stations. *Potentilla palustris* and *Betula pumila* have significant indicator values at SF station 3, where they occur with taxa such as *Hypnum pratense*, *Salix candida*, and *Leptodictyum riparium*. *Hamatocaulis vernicosus*, *Campylium stellatum*, *Andromeda polifolia*, and *Menyanthes trifoliata* are significant indicators for station 4, whereas *Aulacomnium palustre* is common throughout the SF transect.

Full Core Profiles

Peat Properties and C Stocks

The average bulk density of samples from the SF site (0.15 g cm^{-3}) was slightly higher than at OBS (0.12 g cm^{-3}), and OM concentrations at both sites were generally high (80–95% of total dry weight, except immediately above the peat/mineral interface). Total peat C content was $51.9 \pm 4.3\%$ (mean \pm SD) at the SF site, and slightly lower ($49.5 \pm 2.7\%$) at OBS. Organic C (C_O) only made up approximately 93% of total C (C_T) at both sites, indicating a significant presence of inorganic C (~7% of total C, or ~3.5% of total dry mass) in peat profiles. Total C storage along the transects examined ranged from 30.5 to 109.7 kg m^{-2} at OBS and from 36.0 to 115.0 kg m^{-2} at the SF site (Table 1).

Basal Ages and Long-Term OM Accumulation Rates

Basal peat ages at OBS are 760 cal. years BP at the upland edge and 3880 cal. years BP at station 4 (Table 2). At the two intervening stations, peat accumulation began at about 1500–1700 cal. years BP, with the older of the two dates at the station closer to the upland (OBS 2). Long-term rates of OM accumulation ranged from 41.4 to $77.1 \text{ g m}^{-2} \text{ a}^{-1}$ and showed no clear trend along the transect (Table 1).

At SF station 1 (upland edge), peat accumulation began about 860 cal. years BP, and the other three stations showed no clear trend in age (Table 2). All had basal ages between 3390 and 3790 cal. years BP, with the youngest date (3390 cal. years BP) at SF 4 (peatland). Measured long-term rates of OM accumulation at this site are highest ($66.0 \text{ g m}^{-2} \text{ a}^{-1}$) at SF 1 and lowest ($36.4 \text{ g m}^{-2} \text{ a}^{-1}$) at SF 2. From

Table 2. Basal Peat ^{14}C Samples and Dates

Site/ station	Depth (cm)	CAMS #	$\delta^{13}\text{C}$	^{14}C age (years BP)	Error	Cal. age (years BP)	2 σ range	Material dated
OBS 1	47–48	110544	–27.86	855	35	763	688–903	Wood
OBS 2	72–73	110545	–26.10	1780	30	1703	1616–1810	Wood, charcoal
OBS 3	123–124	110546	–30.34	1595	35	1473	1402–1551	<i>Sphagnum</i> cf. <i>fuscum</i>
OBS 4	163–164	110548	–25.22	3575	35	3878	3728–3977	Wood
SF 1	43–44	110539	–26.05	965	35	860	791–937	Wood, bark, conifer epidermis
SF 2	113–114	110540	–26.01	3500	35	3773	3689–3869	Wood
SF 3	131–132	110541	–26.49	3515	35	3783	3696–3880	Wood
SF 4	151–152	110542	–26.37	3160	35	3388	3276–3456	Wood, bark, conifer epidermis

OBS Old Black Spruce, SF Sandhill Fen.

At each site, stations represent a gradient from upland margin (Station 1) to peatland (Station 4).

there, they gradually increase toward the peatland (Table 1).

Macrofossil Composition of Basal Peat

Irrespective of position along the upland–peatland gradient, basal peat samples were woody at both sites, with more than 20% herbaceous contributions at most stations (Figure 2). At OBS station 3, *Sphagnum* remains accounted for approximately 50% of the recognizable material. Other bryophytes (*Drepanocladus s.l.*) made up approximately 20% of the basal sample at SF 4 (peatland). Conifer needles (*Larix* and *Picea*) were present in basal samples at both sites and reached their highest abundance at the peatland end of both transects. Charcoal was present at the base of seven of the eight cores examined and accounted for approximately 10% of basal material at OBS stations 1 and 2 and at SF stations 2 and 3.

^{210}Pb Cores

^{210}Pb Profiles and Recent OM Accumulation Rates

Overall efficiency of the digestion and counting procedure (recovery of the ^{209}Po chemical yield

tracer) was $1.23 \pm 0.04\%$ ($n = 234$). Total residual ^{210}Pb inventories ranged from 7.1 to 21.4 pCi cm^{-2} , corresponding to ^{210}Pb fluxes of 0.22–0.67 pCi $\text{cm}^{-2} \text{y}^{-1}$, values that are consistent with those reported in other studies (Appleby and Oldfield 1978; Turetsky and others 2007).

Because ^{210}Pb cores were slightly compressed during coring, all accumulation rates are expressed here on a mass basis. Plots of cumulative OM mass versus ^{210}Pb -derived age (Figure 3) generally show reasonable agreement between replicate cores, especially over the last 50 years. During this period, average ^{210}Pb -derived OM accumulation rates were higher at the SF site ($150 \text{ g m}^{-2} \text{ a}^{-1}$) than at OBS ($129 \text{ g m}^{-2} \text{ a}^{-1}$), and fastest rates were measured at the peatland end of both transects ($156 \text{ g m}^{-2} \text{ a}^{-1}$ at SF 4 and $145 \text{ g m}^{-2} \text{ a}^{-1}$ at OBS 4; Table 1). Within-site variability was generally low, although station OBS 3 showed very slow recent accumulation rates ($106 \text{ g m}^{-2} \text{ a}^{-1}$) compared to adjacent stations.

Bomb-Spike ^{14}C Analysis

Bomb ^{14}C dates are listed in Table 3. Cumulative mass/age relationships for cores dated by both ^{210}Pb and bomb-spike ^{14}C (Figure 4) often show what appears to be a systematic offset between the two methods, with ^{210}Pb showing an apparent tendency to yield younger dates than ^{14}C . ^{14}C analysis produced no clear trend in age in the upper four samples at SF 4, with samples from the 4 to 6 and 6 to 8 cm sections in particular yielding younger ages than expected, based on both comparison with ^{210}Pb and the overlying ^{14}C sample. At station SF 2, peat below 8 cm depth consisted mainly of woody roots that were unsuited to ^{14}C analysis, and moss remains used for dating produced pairs of possible ages with one recent (1986–1990) and one about 1960. Given lack of consistency with overlying dates and the general paucity of moss remains in these horizons, these dates were excluded from further analysis.

Macrofossil Composition of Surficial Profiles

Macrofossil profiles for cores dated by both ^{210}Pb and ^{14}C are shown in Figure 5. At OBS station 1, the surficial feather moss layer was underlain by peat made up mostly of woody roots, and *Picea* needles became increasingly abundant in upper parts of the profile. *Aulacomnium palustre* and *Sphagnum warnstorffii* were the only bryophytes present in lower core sections analyzed, and were replaced by feather mosses (*Hylocomium splendens* and *Pleurozium schreberi*) either in the mid-1980s (^{210}Pb) or in the 1970s (^{14}C).

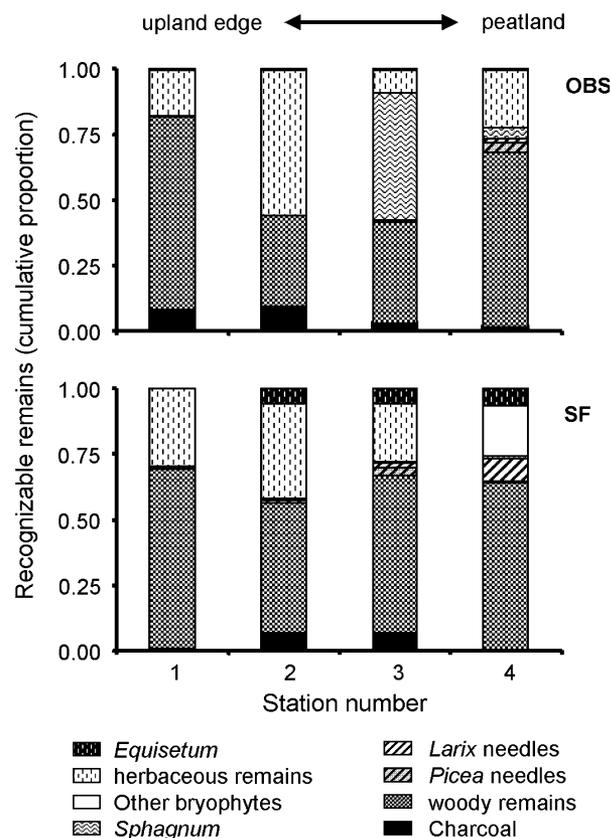


Figure 2. Macrofossil composition of basal ^{14}C samples at OBS and SF transects.

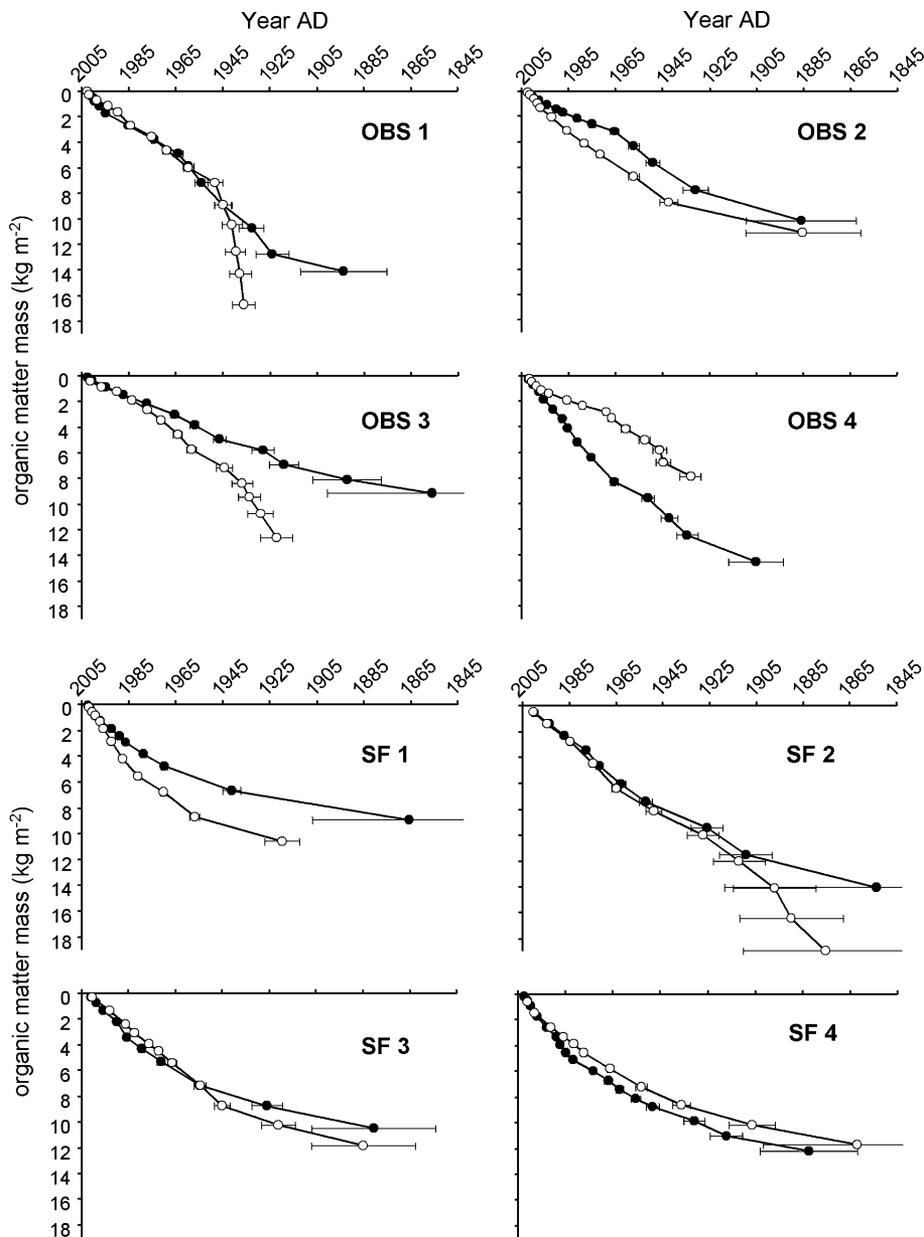


Figure 3. Cumulative mass/ ^{210}Pb age profiles for surficial cores ($n = 2$ per station) from the OBS and SF sites. Because the uncertainty associated with ^{210}Pb dates increases with depth, only dates younger than 1850 are shown.

The core from OBS station 3 consisted mostly of *Sphagnum fuscum* peat, with varying amounts of ericaceous and other woody roots at different depths. Feather mosses first appear in peat deposited in the late 1970s (^{210}Pb) or late 1960s/early 1970s (^{14}C) and are a dominant component of samples younger than about 1995. *Picea* and *Larix* needles also became important after this time, and the surface sample contained over 50% *Cladina* lichens.

The core from SF station 2 consisted mostly of woody roots, mixed with varying amounts of other woody and herbaceous remains. Feather mosses first appeared in peat deposited either after 1960

(^{210}Pb) or in the mid-1950s (^{14}C), and they became dominant in samples younger than about 1993 (both methods).

At SF 4, the bulk of the core was made up of herbaceous remains, with increasing proportions of woody roots and *Larix* needles toward the surface. The only bryophytes present in lower core sections were *Drepanocladus aduncus* and *Scorpidium scorpioides*, and both disappeared in the mid- to late 1950s (both methods). *Bryum* sp. and *Hamatocaulis vernicosus* first appeared in the mid- (^{210}Pb) or late (^{14}C) 1990s, and *D. aduncus* re-appeared close to the present surface.

Table 3. Bomb ^{14}C Dates and Calibration

Core	Sample depth (cm)	CAMS #	$\delta^{13}\text{C}$	F^{14}C	$\pm\text{Error F}^{14}\text{C}$	$\Delta^{14}\text{C}$	$\pm\text{Error } \Delta^{14}\text{C}$	Material dated	Cal. age (year AD)	2σ range
OBS 1 R1	0–2	110529	–32.29	1.0996	0.0040	92.4	4.0	<i>P. schreberi</i> ; <i>H. splendens</i>	1998.7	1995.3–2001.5
									1954.6	1953.7–1955.5
	2–4	110530	–31.83	1.1048	0.0050	97.6	5.0	<i>P. schreberi</i> ; <i>H. splendens</i>	1997.7	1993.8–2001.0
									1954.6	1953.7–1955.5
	4–6	110531	–32.67	1.1111	0.0040	103.9	4.0	<i>P. schreberi</i> ; <i>H. splendens</i>	1996.8	1993.8–2000.1
									1954.6	1953.7–1955.5
	6–8	110532	–32.72	1.1209	0.0040	113.6	4.0	<i>P. schreberi</i> ; <i>H. splendens</i>	1994.9	1991.8–1998.8
									1954.6	1953.7–1955.5
	8–10	110533	–31.91	1.1414	0.0041	134.0	4.1	<i>H. splendens</i> ; <i>P. schreberi</i>	1991.9	1990.2–1993.8
									1956.4	1955.5–1957.3
	10–12	110534	–31.74	1.1700	0.0043	162.3	4.3	<i>H. splendens</i>	1988.7	1985.9–1990.6
									1956.4	1955.5–1957.3
	12–14	110535	–33.69	1.2502	0.0041	242.1	4.1	Moss (<i>H. splendens</i>) stems	1982.3	1980.3–1983.7
	14–16	110536	–29.0	1.2393	0.0045	231.3	4.5	<i>A. palustre</i>	1961.4	1959.3–1962.0
	16–18	110537	–30.34	1.1408	0.0042	133.4	4.2	<i>A. palustre</i> ; <i>Sphagnum</i>	1961.4	1959.3–1961.9
	18–20	110538	–30.55	1.0930	0.0050	85.9	5.0	<i>A. palustre</i> ; <i>S. warnstorffii</i>	1956.4	1955.5–1957.3
OBS 3 R2	0–2	105995	–31.74	1.1021	0.0040	94.9	4.0	<i>P. schreberi</i>	2000.1	1995.3–2002.6
									1953.7	1951.8–1955.5
	2–4	105996	–31.76	1.1029	0.0040	95.7	4.0	<i>P. schreberi</i>	1998.3	1995.3–2001.0
									1954.6	1953.7–1955.5
	4–6	105997	–28.02	1.2077	0.0044	199.8	4.4	<i>S. fuscum</i> ; <i>P. schreberi</i>	1997.8	1995.3–2001.0
									1954.6	1953.7–1955.5
	6–8	105998	–30.57	1.2550	0.0056	246.8	5.6	<i>S. fuscum</i> ; <i>P. schreberi</i>	1984.8	1983.5–1986.6
									1960.8	1959.2–1961.8
	8–10	105999	–28.27	1.5003	0.0055	490.6	5.5	<i>S. fuscum</i>	1981.5	1980.1–1983.3
									1959.7	1959.3–1962.0
	10–12	106000	–28.06	1.0703	0.0040	63.3	4.0	<i>S. fuscum</i>	1971.4	1970.8–1972.4
									1963.2	1960.2–1963.2
								2003.3	2001.1–2004.0	
								1952.8	1951.8–1953.7	

Table 3. continued

Core	Sample depth (cm)	CAMS #	$\delta^{13}\text{C}$	F^{14}C	$\pm\text{Error F}^{14}\text{C}$	$\Delta^{14}\text{C}$	$\pm\text{Error } \Delta^{14}\text{C}$	Material dated	Cal. age (year AD)	2 σ range
SF 2 R2	0–2	105985	–28.10	1.0838	0.0039	76.8	3.9	<i>Larix</i> needles	2001.5	1998.0–2003.8
									1953.7	1951.8–1955.5
	2–4	105986	–31.79	1.1325	0.0052	125.2	5.2	<i>P. schreberi</i>	1993.2	1990.7–1996.7
									1955.5	1953.7–1957.3
	4–6	105987	–31.51	1.4083	0.0051	399.2	5.1	<i>P. schreberi</i> ; <i>Larix</i> needles	1974.3	1973.3–1974.8
								1962.8	1962.4–1963.0	
SF 4 R2	6–8	105988	–30.01	1.3624	0.0075	353.5	7.5	<i>Larix</i> needles; <i>P. schreberi</i>	1975.9	1974.9–1979.2
									1962.3	1962.2–1962.4
	8–10	105989	–29.44	1.1026	0.0040	95.4	4.0	Moss stems and leaves	1997.9	1995.3–2000.9
									1954.6	1953.7–1955.5
	0–2	105993	–30.51	1.1036	0.0043	96.4	4.3	'Brown moss'; <i>Larix</i> needles	1997.7	1995.2–2000.9
								1954.6	1953.7–1955.5	
	2–4	105994	–29.24	1.1049	0.0054	97.7	5.4	'Brown moss'	1997.7	1993.8–2001.0
								1954.6	1953.7–1955.5	
	4–6	110640	–27.0*	1.0989	0.0046	91.8	4.6	'Brown moss'	1998.7	1995.3–2001.8
								1954.6	1953.7–1955.5	
	6–8	110522	–27.0*	1.0973	0.0046	90.1	4.6	<i>Larix</i> needles; 'brown moss'	1998.9	1995.3–2001.8
								1954.6	1953.7–1955.5	
	10–12	110523	–27.0*	1.3223	0.0057	313.7	5.7	'brown moss'; <i>Larix</i> needle	1978.3	1976.9–1979.6
								1962.2	1962.2–1962.2	
	12–14	110524	–27.0*	1.5069	0.0058	497.1	5.8	<i>Larix</i> needles	1971.4	1970.8–1972.0
								1963.2	1963.2–1963.2	
	14–16	110525	–27.0*	1.0263	0.0043	19.6	4.3	'Brown moss'; <i>Larix</i> needles	1950.9	1950.0–1951.8

Dates and σ ranges shown in bold are those plotted in Figure 5.

* Indicate $\delta^{13}\text{C}$ values that were estimated rather than measured. The value of –27 assigned to such samples is based on Olsson (1986) for peat. Material category 'brown moss' includes *Hamatocaulis vermicosus*, *Scorpidium scorpioides*, *Drepanocladus aduncus*, and *Bryum* sp.

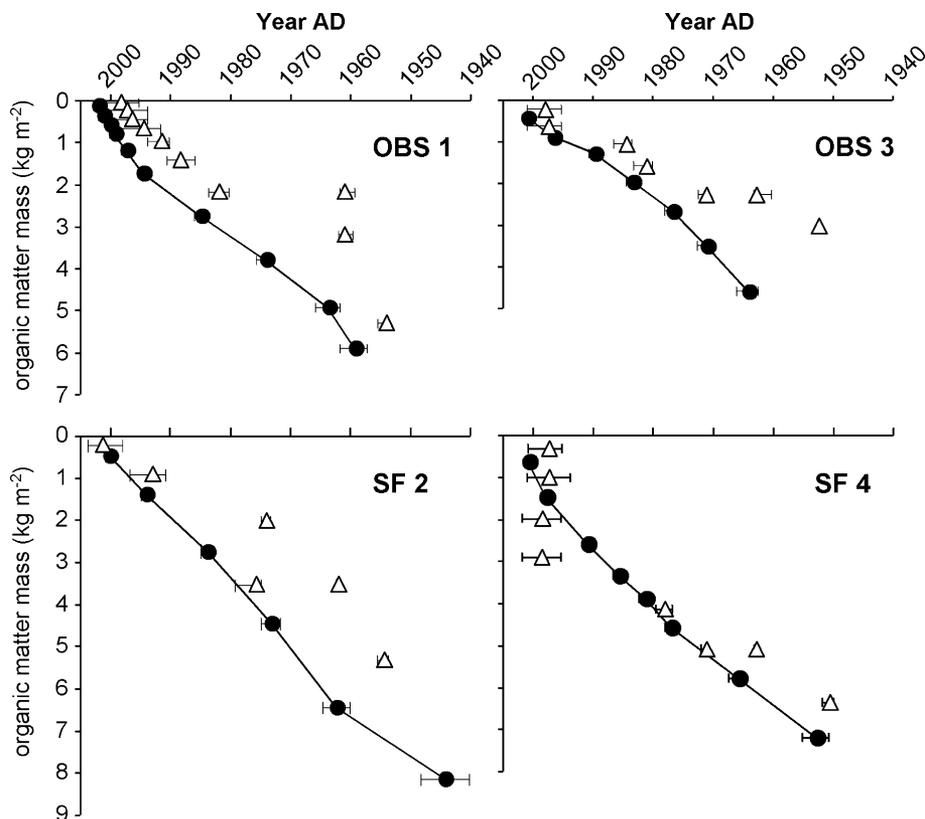


Figure 4. Cumulative mass/age relationships for cores dated by both ^{210}Pb (filled circles and solid lines) and bomb-spike ^{14}C (open triangles).

DISCUSSION

Environmental Gradients and Species Response

With its dense black spruce canopy, sparse vascular understory, and abundance of feather mosses, OBS station 1 resembles boreal black spruce forest of a type often found on mineral soil. Vegetation here is strikingly dissimilar to that at station 2, which supports a mix of species with both upland- and peatland affinities. This station is the wettest on the OBS transect, and presence of species such as *Tomentypnum nitens* points toward a direct influence of base-rich mineral groundwater. OBS stations 3 and 4 are drier and similar to each other in their overall species complement, with most taxa present characteristic of bog or poor fen. However, presence of taxa such as *Sphagnum warnstorffii* in microsites close to the water table still reflects the base-rich nature of local groundwater.

SF station 1 (upland edge) resembles OBS station 2 in water table depth, canopy cover, and presence of indicators such as *Carex disperma* and *Ledum groenlandicum*. Other taxa are shared with OBS station 1 (*Hylocomium splendens*), OBS station 3 (*Carex aquatilis*), or are absent from OBS altogether,

suggesting between-site differences in environmental controls that are more complex than could be measured in this study.

Although similar to SF 1 in terms of canopy closure, station SF 2 is slightly wetter, has deeper peat, and shows a shift in several dominant species, a pattern that continues all the way along the SF transect. Starting at station SF 3, trees are gradually replaced by shrubs, and fen bryophytes occur in suitable microhabitats. Station 4 straddles a string/flark boundary in the fen proper (Figure 1), and the indicators *Hamatocaulis vernicosus* and *Campylium stellatum* are mosses characteristic of rich fen environments.

Overall, our results indicate that although peat depth, canopy closure, and water table depth all change along the upland–peatland transition, these changes are not closely linked within a site, and associated vegetation responses are complex. At OBS, Station 2 represents a wet, lag-like boundary between black spruce/feather moss forest (station 1) and black spruce/*Sphagnum* “mixed mire” (stations 3 and 4). At the SF site, water table and canopy gradients are longer, with a more gradual transition from treed swamp (stations 1 and 2) to shrubby swamp (station 3) to fen proper (station 4).

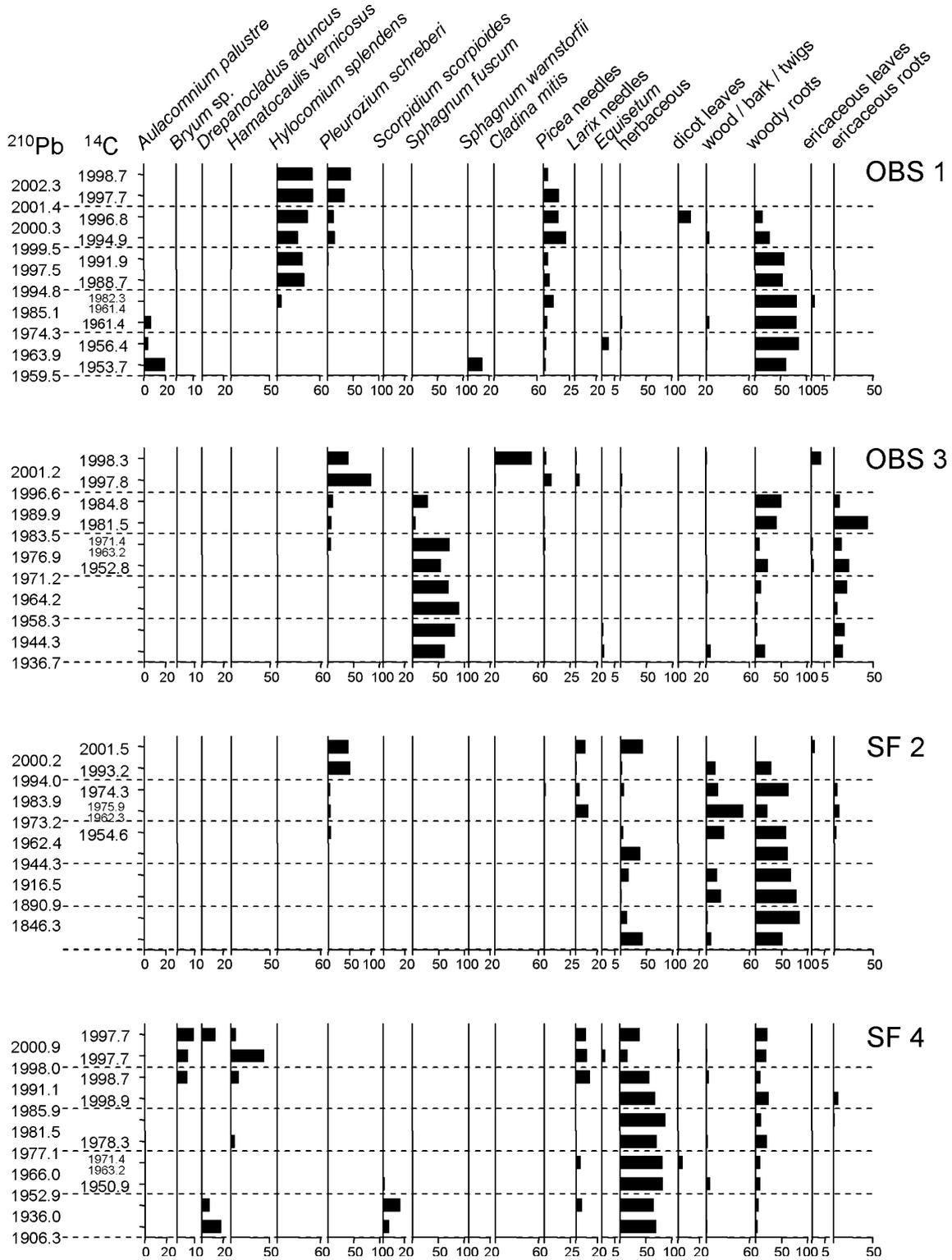


Figure 5. Macrofossil composition of surficial profiles dated by bomb-spike ¹⁴C.

Peat Initiation and Basal Peat-Forming Communities

Basal peat ages at both sites span the period about 3800–800 cal. BP, with youngest dates at the upland edge and lack of a monotonous trend (increasing age) into the peatland. At all points analyzed, peat initiation was by paludification, with high abundance of woody remains in basal samples.

At OBS, *Sphagnum* is present in basal samples from stations 3 and 4, and much of the peat at this site is made up of *Sphagnum* remains. Peat accumulation in the lower parts of the OBS transect most likely began when *Sphagnum* invaded non-peatland forest sites. Once *Sphagnum* becomes established, its physiological and biochemical properties can lower soil temperatures, pH, and nutrient availability, leading to rapid exclusion of other taxa and accumulation of thick organic horizons (van Breemen 1995). The high-pH, high-alkalinity nature of local groundwater, however, would have excluded *Sphagnum* from wetter microsites, which may explain its absence from basal deposits at OBS station 2.

At the SF site, *Sphagnum* is largely absent from basal deposits, and the woody/herbaceous nature of basal peat suggests that paludification was a result of flooding brought on by rising water levels in the adjacent fen. The rapid increase in peat depth between stations SF 1 and SF 2 suggests a sharp drop in mineral terrain between these two stations, with SF 1 perched at the edge of a basin that contains stations 2–4. This change in elevation may have had marked effects on long-term hydrological patterns, especially given the sandy nature of mineral material underlying the site. Similar basal ages at stations SF 2 to SF 4 suggest that wide tracts of forest were paludified between about 3300 and 3800 cal. BP, a time that corresponds to the main period of climate-induced paludification in central Saskatchewan (Halsey and others 1998).

Charcoal makes up a significant portion of basal deposits at both sites, and the effect of fire on community trajectories and carbon accumulation at peatland–upland boundaries is likely to be complex. Many paludified sites contain charcoal in their basal deposits (for example, Korhola 1992; Bauer and others 2003), and removal of trees by fire may lead to lowered evapotranspiration and a temporary rise in local water tables, thus providing conditions suitable for invasion of peatland taxa. Charcoal, however, is ubiquitous in boreal soils (for example, Trumbore and Harden 1997), and its presence alone is no proof that peatland initiation

was a direct result of fire. In fact, fire can play an important role in maintaining black spruce–feather moss systems by periodically removing bryophyte mats and soil organic layers (Foster 1984; Fenton and others 2005), thus preventing the lateral spread of *Sphagnum*.

Correspondence of ^{210}Pb and Bomb ^{14}C Chronologies

Although ^{210}Pb - and ^{14}C -derived mass/age plots are similar in shape (Figure 4), ^{210}Pb has an apparent tendency to produce younger dates than ^{14}C in three of the four profiles examined by both methods. Inability to distinguish between the two possible dates closest to the peak of the post-bomb atmospheric ^{14}C curve leads to a certain degree of ambiguity in three of the four profiles examined (Figure 4), and bomb ^{14}C results show no apparent difference in age between the upper four samples at SF 4. Differences between the two dating methods and their relative reliability in peat margin forest sites clearly require further investigation.

Bomb ^{14}C is a relatively new approach to high-resolution peat dating, and studies that have used the method generally reported encouraging results (Trumbore and Harden 1997; Goodsite and others 2001; Garnett and Stevenson 2004). However, the post-bomb atmospheric distribution of ^{14}C has not been uniform across the globe, and whether or not calibration data are representative of local conditions can usually not be tested (Garnett and Stevenson 2004; Reimer and others 2004b). Calibration data used in this study (Levin and Kromer 2004) are from central Europe, and were chosen because they included the year in which samples were taken.

Given rapid changes in post-bomb atmospheric ^{14}C signals and the high (~ 1 year) temporal resolution of the method, bomb ^{14}C is further sensitive to any C relocation within peat profiles, and results may be affected by uptake of C from non-atmospheric sources. Although such reservoir effects are best known in the context of marine samples (see for example, Hughen and others 2004), re-fixation of respired CO_2 by surface *Sphagnum* has been demonstrated in peatlands (Turetsky and Wieder 1999), and under some conditions, respired C may be centuries old (Winston and others 1997; Hirsch and others 2003). Kilian and others (1995, 2000) observed a reservoir effect of 100–250 ^{14}C years in samples containing ericaceous roots and attributed this to (indirect) uptake of C from methane produced deep within the profile. Although no roots were dated in this study, foreign C may have been introduced into samples by fungi, which are impossible to remove from tissues during sample

preparation. Similarly, old (^{14}C -dead) C could be introduced in the form of carbonates, although any carbonates adhering to remains should have been removed by ^{14}C pre-treatments.

Unlike ^{14}C , which dates organic material directly, ^{210}Pb is based on the influx of aerially deposited (unsupported) ^{210}Pb that is added at the peat surface and slowly decays as it is buried in the growing profile. A key assumption is post-depositional immobility of ^{210}Pb , and criticism of the method has mostly related to this assumption (see Turetsky and others 2004 for a review). ^{210}Pb is widely accepted as a reliable dating method in ombrotrophic, *Sphagnum*-dominated deposits where Pb is rapidly immobilized by cation exchange (Vile and others 1999; Turetsky and others 2004). In non-*Sphagnum* environments, factors immobilizing ^{210}Pb are poorly known, and downward leaching of ^{210}Pb could partially explain the pattern of younger ^{210}Pb -derived ages compared to ^{14}C .

Contradicting this notion of ^{210}Pb mobility, we generally observed low and constant ^{210}Pb activity at depths below 24 cm, corresponding to supported ^{210}Pb activities that averaged 35 and 19 mBq/g. One exception to this is one of the cores from OBS 4, where the lowest sample analyzed (36–40 cm) had ^{210}Pb activities of 100 mBq/g, suggesting overestimation of supported ^{210}Pb (and underestimation of residual unsupported ^{210}Pb) to the extent that our dates for this one core are suspect. Removal of this core from the dataset leads to an adjusted 50-year accumulation rate at OBS 4 of $188.4 \text{ g m}^{-2} \text{ a}^{-1}$ (Table 1).

Cores at OBS 4 were taken in *Sphagnum fuscum* hummocks, and of all profiles analyzed, are most likely to meet normal criteria of (hummock-level) ombrotrophy and immobilization of ^{210}Pb . In contrast, agreement between ^{14}C and ^{210}Pb results appears best at SF 4, a brown-moss/herbaceous-rich fen. Several workers have reported leaching of Pb in and below the zone of water table fluctuation, even in *Sphagnum*-dominated peats (for example, Belyea and Warner 1994; but see Vile and others 1999 for a different view), and few studies have applied ^{210}Pb as a dating tool in calcareous fen environments. Those that have (Cole and others 1990; Goodsite and others 2001) generally selected acidic (or *Sphagnum*-dominated) microsites for analysis. In results obtained here, the ^{210}Pb inventory in SF 4 cores is similar to that at other sites, suggesting that ^{210}Pb retention is no less efficient in rich fens than it is in other environments.

As a final consideration, peat is a mixture of different botanical constituents, and material laid down within a given year can be of varying ages.

This phenomenon is well known in the context of wiggle-match dating (for example, Kilian and others 2000), and its potential to influence ^{14}C results is high especially in surficial core sections where the period examined is short and changes in ambient ^{14}C have been rapid. Rather than analyze bulk samples, we attempted to minimize confounding effects of material type by restricting our analysis to bryophyte remains and *Larix* needles, that is, materials that can be reasonably expected to reflect atmospheric ^{14}C concentrations in the year they were deposited at the surface. In most cores examined, however, roots make up a significant portion of the peat, which means that at any point in time, material is added *below* the level used as a reference for dating. Both ^{14}C (using remains selected here) and ^{210}Pb assume that material produced in the current year is deposited strictly at the soil surface, and the methods should thus be consistent in the way they assign dates to specific soil layers. However, neither of them can account for belowground addition of roots, which means 50-year OM accumulation rates are minimum estimates.

Recent and Long-Term OM Accumulation Rates

At the SF site, 50-year OM accumulation rates based on ^{210}Pb are similar ($147\text{--}156 \text{ g m}^{-2} \text{ a}^{-1}$) at all points along the transect, and long-term rates increase steadily from stations SF 2 to SF 4. The fast long-term rates of OM accumulation observed at station SF 1 are at least in part a dating artifact, reflecting the shallow (and young) nature of organic deposits at this site (Clymo and others 1998). At OBS, 50-year rates are more variable ($106\text{--}145$ or $188 \text{ g m}^{-2} \text{ a}^{-1}$), and long-term OM accumulation rates show no obvious pattern. Station 3 in particular seems an anomaly, with the fastest long-term ($77 \text{ g m}^{-2} \text{ a}^{-1}$) yet slowest short-term ($105 \text{ g m}^{-2} \text{ a}^{-1}$) rates of OM accumulation. After OBS 1 (upland edge), this site is the driest of the four stations examined, and slow recent OM accumulation rates paired with an abundance of lichens at the present surface suggest that conditions may currently be too dry for net OM accumulation.

Recent (50-year) ^{210}Pb -based rates of OM accumulation observed here are consistent with values reported from other peatland sites in North America (Turetsky and others 2000). Although high accumulation rates at upland-edge stations may seem surprising, values measured are consistent with 45–65-year values modeled by Rapalee and others (1998) for moderately to poorly drained black-spruce–feather-moss and black-spruce–*Sphagnum*

systems in northern Manitoba. Below the surficial moss layer, peat at upland-edge stations is largely composed of woody (root) remains, and tree biomass (and presumably productivity) declines sharply across the upland to peatland transition (Bhatti and others 2006). Trumbore and Harden (1997) measured long (>100-year) soil C turnover times in upland black spruce sites and attributed them to input of woody material to detrital layers. Thus, the 'classic' peatland model where organic matter inputs occur only at the surface is not applicable in these upland-edge forest sites.

In spite of rapid initial rates, upland-edge regions cannot maintain fast OM accumulation in the long term, reflecting more deeply aerated soil profiles and probably higher losses due to fire. The severity of fire-induced C losses in boreal landscapes is largely controlled by soil drainage (Harden and others 1997; Rapalee and others 1998), which means several key parameters relevant to C production and retention change concurrently across the peatland–upland interface.

At the upland edge, most of the OM initially produced is lost to either decay or fire, and transfer of charred remains to deeper soil layers is a key determinant of long-term carbon storage (Harden and others 2000; Kane and others 2007). At the fen end of transects, rapid transfer of material below the permanent water table leads to more of the initial biomass being ultimately laid down as peat, with high water tables protecting OM from both microbial decay and fire.

At the SF site, increasing rates of long-term OM accumulation from SF 2 to SF 4 are inversely related to 2004 median water tables (Table 1), suggesting that in this part of the transect, long-term peat accumulation is directly or indirectly linked to water table position. More so than OBS where decay-resistant *Sphagnum* litter (Johnson and Damman 1993) is an important part of peat profiles, higher-quality herb and bryophyte litters produced at the SF site probably require high water tables to be preserved as peat (Bauer 2004).

Twentieth Century Community Change and Sensitivity of Peat-Margin Environments to Climate

Patterns of bryophyte replacement at OBS 1, OBS 3, and SF 4 all suggest that peatland margins have dried in the recent past, but lack of agreement between ^{210}Pb and ^{14}C chronologies and limited temporal resolution of the record limit our ability to temporally constrain such changes. Using the ^{14}C chronology, the disappearance of *Scorpidium*

scorpioides (a species of wet, calcareous habitats) at SF 4, replacement of *Sphagnum warnstorffii* and *Aulacomnium palustre* with feather moss at OBS 1, and appearance of *Pleurozium schreberi* at OBS 3 all date to the late 1950s to early 1970s, a period of extended drought in the region (Figure 6). Highway 106, which passes the SF site, was gravelled during the same period. However, given its location relative to the study transect and the fact that the entire site is located on sand (Simpson 1997), even effects of roadbed construction (date unknown) on hydrology should have been minimal.

Conditions for much of the 1970s and 1980s were wetter than the long-term average (Figure 6), and rich fen bryophytes (*Drepanocladus aduncus* and *Hamatocaulis vernicosus*) re-appear in the SF 4 record in the 1990s. At OBS, there is no evidence for a reversal of the apparent surface-drying trend, with feather moss completely replacing the original *S. fuscum* in the Station 3 core by the late 1990s. Based on field observations, recent replacement of *Sphagnum* with feather moss is a widespread

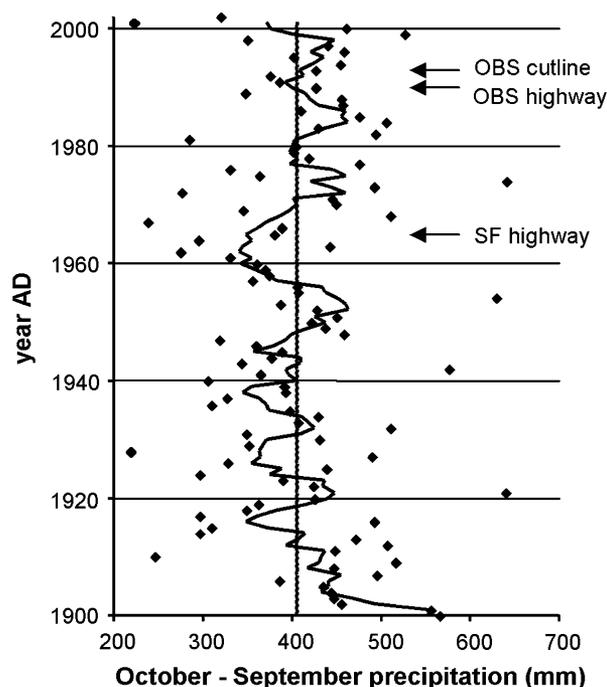


Figure 6. Twentieth century precipitation record from Prince Albert, SK (53° 13' N, 105° 40' W). The solid black line is a 5-year running mean; the vertical line marks the 1900–2002 average (406.7 mm). Arrows and notes on the right denote the timing of potential anthropogenic disturbance events. OBS cutline: construction of BOREAS cutline and boardwalk (1993); OBS highway: construction on Highway 913 at OBS (1990); SF highway: construction on Highway 106 at SF.

phenomenon at this site and may be part of natural vegetation succession. Alternatively, structural upgrading of Highway 913 may have isolated the peatland from runoff originating in uplands to the north and north-west, and construction of a broad cutline for tower access during BOREAS (in 1993) may have improved local drainage.

Vegetation at the peatland end of the OBS transect is predominantly rain-fed, as evidenced by the dominance of poor fen/bog taxa in spite of extreme-rich fen water chemistry. The physiographic position of the OBS peatland (at the top of a local drainage path) is one that should be highly conducive to ombrotrophication (Glaser and others 1997), but bogs are not a common landscape feature in this region. The study area is located close to the southern limit of peatland distribution (Halsey and others 1998), and links between climate, vegetation, and patterns of C accumulation should be fairly direct at OBS. The SF peatland, on the other hand, is a larger, flow-through system that may share complex hydrological links with surrounding uplands. In this type of environment, direct effects of climate change may be harder to observe, but our results suggest that this site, too, has responded flexibly to past environmental change.

CONCLUSION

Carbon dynamics at the peatland–upland interface are determined by a complex of environmental drivers that change sharply across the transition. Although inter-related, these drivers may not change in direct parallel, nor are they constant in time, and the result is a complex ecotone that responds flexibly to environmental change. Although long-term trends (such as peatland expansion) are well-documented in the paleoecological literature, processes underlying such trends are hard to observe in real time, and standard methods of paleoecological analysis are hard to apply at the interface between peatland and upland systems. The often poor preservation of environmental proxies, below-ground input of roots, and uncertainties regarding the reliability of standard dating tools all limit our ability to obtain high-resolution chronologies and link apparent changes to specific causal events. Although our results allow for general conclusions about mechanisms of peat initiation and C accumulation patterns at our study sites, more general questions about C dynamics or resilience of the peatland/upland interface will require spatially more expensive studies using different approaches.

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