

Chapter 3

Latitudinal Trends in Organic Carbon Accumulation in Temperate Freshwater Peatlands

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Abstract The 30-year rate of organic carbon (C) accumulation, based on cesium-137 (¹³⁷Cs), was measured in 15 freshwater peatlands across a latitudinal gradient from southern Florida (26°N) to northern Minnesota (47°N) to identify relationships between climate (temperature) and C accumulation. Organic C accumulation was inversely related to mean annual air temperature (MAAT, °C) in acidic peatlands (pH < 5) (C, g m⁻² year⁻¹ = 199 - 7.94 × MAAT; $r^2 = 0.64$, $p \leq 0.01$), with greatest accumulation in the coldest climate. There was a weak but non-significant relationship between C accumulation and MAAT in circumneutral peatlands (pH > 5) ($r^2 = 0.41$, $p \leq 0.17$). A regression model that incorporated both temperature and precipitation (rain factor, f = mean annual precipitation in cm/MAAT) was no more effective in predicting organic C accumulation than one with temperature alone ($r^2 = 0.57$ for acidic peatlands, $r^2 = 0.36$ for circumneutral peatlands). Across all sites, circumneutral peatlands sequestered less C (49 ± 11 g m⁻² year⁻¹) than acidic peatlands (88 ± 20 g m⁻² year⁻¹) regardless of temperature. Our findings suggest that, like terrestrial ecosystems, organic C accumulation in freshwater peatlands is linked to climate through the effects of temperature though local factors such as pH, hydroperiod and nutrient enrichment; other factors also should be considered when assessing the potential of freshwater wetlands to sequester C.

Keywords Cesium-137 (¹³⁷Cs), climate change, Histosol, precipitation, temperature

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3.1 Introduction

Histosols, peat-accumulating wetland soils, occupy 1.3% of the total land area but store 21–29% of the world's soil organic carbon (C) (Eswaran *et al.*, 1993, 1995; Batjes, 1996). Anaerobic conditions resulting from inundation and soil saturation lead to incomplete decomposition of plant detritus and accumulation of C as soil organic matter (Ponnamperuma, 1972); accumulation of organic matter in the soil over time results in the formation of soils with significant accumulation of peat.

In terrestrial ecosystems, accumulation of litter and soil organic C is determined primarily by climate, especially temperature (Post *et al.*, 1982; Burke *et al.*, 1989; Raich & Schlesinger, 1992; Schimel *et al.*, 1994; Couteaux *et al.*, 1995) with greater accumulation in cooler and moister climates than warmer, drier climates (Schlesinger, 1990; Vogt *et al.*, 1986; Chadwick *et al.*, 1994). The importance of climate to organic C accumulation in peatlands has not been determined, although the fact that 50% of peatlands are in northern latitudes (Matthews & Fung, 1987; Aselmann & Crutzen, 1989; Franzen, 1994) suggests that peat accumulation is regulated, in part, by temperature.

Long-term rates of soil organic C accumulation, based on cesium-137 (^{137}Cs), were measured in 15 freshwater peatlands across a latitudinal gradient from southern Florida (26°N) to northern Minnesota (47°N) to identify whether, like terrestrial soils, trends exist in organic C accumulation that are linked to climate.

3.2 Methods

Soil cores were collected from 15 temperate peatlands of the eastern continental USA between 26°N (south Florida) and 47°N (Minnesota). Peatlands represented a range of latitudes and vegetation types (bog, fen, marsh, forest) and were sampled between 1994 and 2000 (Table 3.1). Our sampling sites included large temperate peatlands such as the Great Dismal Swamp (VA), Okefenokee Swamp (GA) and the Everglades (FL) in the southern USA and bogs and fens in the northern USA (MN, MI). Mean annual air temperature (MAAT) of the locations ranged from 3.9°C to 23.9°C and was strongly related to latitude ($r^2 = 0.98$).

One to three undisturbed peatlands were sampled at each location. Within each peatland, one to three cores, each 30–50 cm in length, were collected using a piston corer 8.5 cm in diameter. A total of 31 cores were collected. Our sampling criteria was based on wetlands that were underlain by organic soils (i.e. Histosols or histic epipedons) greater than 30 cm thick and containing >12% organic C (USDA, 1999), and with no obvious evidence of recent natural disturbances (fire) and human disturbances like ditches, levees or logging.

Cores were sectioned into 2 cm depth increments and analyzed for ^{137}Cs , bulk density, organic C and pH. Cesium-137 was measured by gamma spectrometry of the 661.62 keV photopeak (Craft & Richardson, 1998). The ^{137}Cs maximum in each

Table 3.1 Sampling location, predominant vegetation, climate attributes, peat characteristics and organic C accumulation of freshwater peatlands

State	Vegetation	Latitude (°N)	MAAT ^a (°C)	pH ^b	Accretion ^c (mm year ⁻¹)	Bulk density (g cm ⁻³) ^d	Organic C (%) ^d	Accumulation (g C m ⁻² year ⁻¹)
MN (1,1) ^e	Bog	47.0	3.0	3.5	10.3	0.04	42.8	198 —
MI (1,1)	Cedar ^f	46.0	5.0	5.5	1.5	0.15	42.1	95 —
MI (1,1)	Bog	45.6	5.0	4.0	6.4	0.05	44.7	132 —
MI (2,1)	Fen	45.4	5.0	6.0	0.9	0.09	44.1	38 (28–47) ^g
IN (2,2–3)	Marsh	41.5	10.0	5.6	1.5	0.15	29.8	61 (15–109)
NJ (2,1–2)	AWC ^h	40.0	12.0	4.0	1.8	0.12	47.4	97 (67–136)
VA (1,3)	AWC ^h	36.6	5.0	3.8	1.6	0.14	47.8	105 (90–142)
NC (1,3)	AWC ^h	35.8	16.0	3.9	3.5	0.05	47.0	90 (66–109)
NC (1,1)	Pocosin ⁱ	34.8	17.0	3.8	0.3	0.08	48.3	13 —
GA (3,1)	Cypress	31.3	18.0	5.5	0.7	0.32	16.5	36 (15–56)
GA (1,2)	Marsh ^j	30.8	20.0	4.0	0.8	0.07	47.6	24 (9–39)
FL (1,2)	AWC ^h	30.2	19.0	3.9	0.3	0.13	48.4	17 (16–18)
FL (1,1)	Cypress	29.6	19.0	3.9	2.1	0.12	48.6	122 —
FL (1,1)	Fen ^k	26.5	23.0	5.5	0.8	0.05	51.0	19 19
FL (2,1)	Fen ^l	25.7	23.0	6.0	1.0	0.12	46.0	46 (37–56)

^a Mean annual air temperature (MAAT) was determined from 1960 to 2000 data from the nearest NOAA National Weather Service reporting station (<http://www.ncdc.noaa.gov>).

^b Soil pH (0–10 cm depth) was measured in 10:1 distilled water to soil solution ratio using a hydrogen ion electrode.

^c ¹³⁷Cs accretion rate.

^d Averaged over 0–10 cm depth.

^e Number of peatlands sampled, number of cores collected within each peatland.

^f Northern cedar swamp forest.

^g Range of organic C accumulation.

^h Atlantic white cedar forest (Pine Barrens NJ, Dismal Swamp VA, Alligator River NC, Apalachicola FL).

ⁱ Evergreen shrub bog.

^j Okefenokee swamp (Only one interpretable ¹³⁷Cs profile was obtained).

^k Everglades (Loxahatchee peat and Everglades peat, respectively).

core, corresponding to the 1964 period of maximum deposition of ¹³⁷Cs from above-ground nuclear weapons testing, was used to determine the 30-year rate of vertical accretion (Ritchie & McHenry, 1990). Accretion was calculated using the midpoint of the increment containing the ¹³⁷Cs peak (e.g. 5 cm if the peak was located in the 4–6 cm depth increment). Only cores that contained interpretable ¹³⁷Cs profiles, such as shown in Fig. 3.1, were used in the statistical analyses.

Cesium-137 is a powerful marker because it is strongly adsorbed onto clay and organic particles, its uptake by vegetation is low and its diffusion is usually limited (Ritchie & McHenry, 1990). Even when diffusion does occur, such movement likely will not change the position of the ¹³⁷Cs peak (Ritchie & McHenry, 1990). Cesium-137 is more mobile under acidic than circumneutral conditions (Appleby *et al.*, 1991), so that, in some acidic peat, it is not effective for determining vertical accretion (Oldfield *et al.*, 1995). Our ombrotrophic peat cores, however, have well-defined

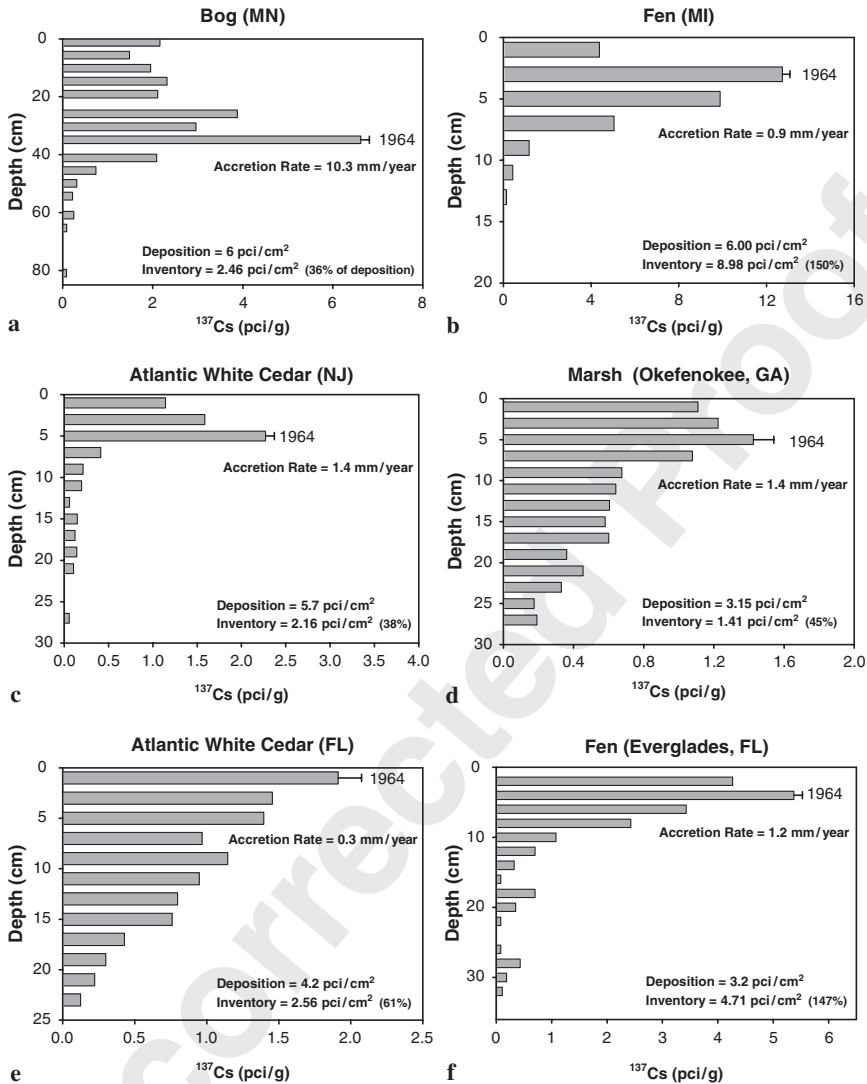


Fig. 3.1 ¹³⁷Cs profiles, cumulative atmospheric deposition of ¹³⁷Cs and ¹³⁷Cs inventories (0–30 cm depth) in peat cores collected from (a) bog in Minnesota, (b) fen in Michigan, (c) Atlantic white cedar forest in New Jersey, (d) Okefenokee marsh in Georgia, (e) Atlantic white cedar forest in Florida, and (f) Everglades fen in Florida

peaks with inventories comparable to atmospheric deposition (see Figs. 3.1a–f) suggesting that ¹³⁷Cs is a relatively immobile and reliable marker horizon in our acidic peat soils.

Cumulative atmospheric deposition of ¹³⁷Cs and ¹³⁷Cs inventories in peat (0–30 cm depth) were calculated for representative cores collected from bogs (MN), fens (MI,

FL Everglades) marshes (GA Okefenokee), and Atlantic white cedar forests (NJ, FL). For each core, atmospheric deposition of ^{137}Cs was extrapolated from cumulative ^{137}Cs deposition (1953–1972) at Chicago, Illinois (MN Bog, MI fen), Upper Hudson River, New York (NJ AWC), and Columbia, South Carolina (GA Okefenokee marsh, FL AWC and Everglades) (Gustafson *et al.*, 1965; Eisenbud, 1973; McHenry & Ritchie, 1975) using the relationship between ^{137}Cs deposition and latitude (Davis, 1963). Calculation of ^{137}Cs inventories revealed that our peat soils contained 36% (MN bog) to 150% (MI fen) of the cumulative atmospheric deposition of ^{137}Cs (Fig. 3.1a–f). Cesium-137 inventories in acidic peatlands were smaller as compared to circumneutral peatlands. Relative to atmospheric inputs, higher latitude peatlands contained proportionally less ^{137}Cs than peatlands at lower latitudes.

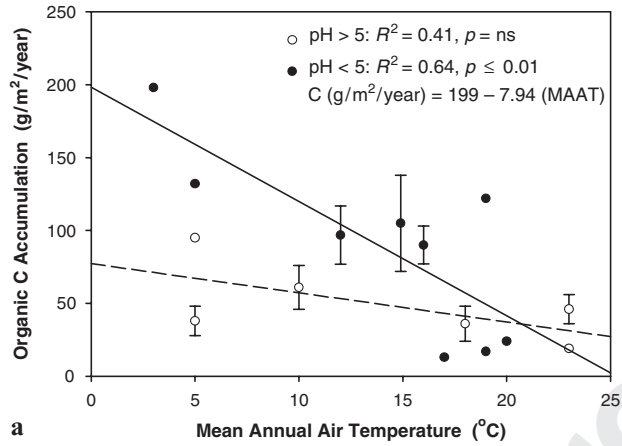
Bulk density was measured by weighing depth increments that were dried at 70°C. Depth increments were ground and analyzed for organic C by dry combustion (Perkin-Elmer CHN analyzer). Organic C accumulation was calculated using ^{137}Cs -based accretion rates and bulk density and C content averaged across depth increments above and including the ^{137}Cs marker layer.

3.3 Results and Discussion

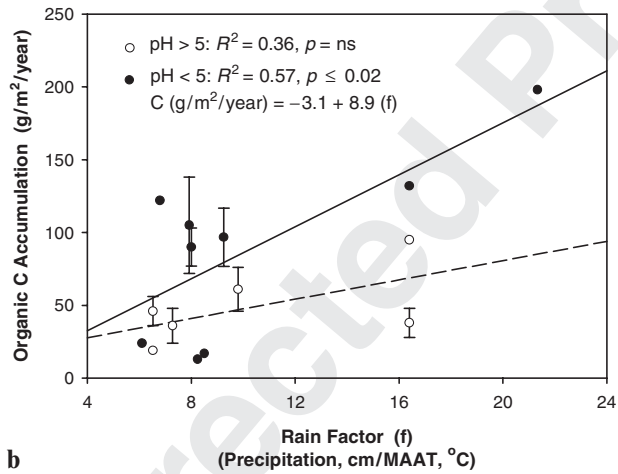
Organic C accumulation of temperate freshwater peatlands increased with increasing latitude ($r^2 = 0.35$, $p \leq 0.02$) and decreasing MAAT ($r^2 = 0.38$, $p \leq 0.02$). An even stronger relationship emerged when peatlands were separated on the basis of pH. Organic C accumulation of acidic (pH < 5) peatlands increased with latitude ($r^2 = 0.55$, $p \leq 0.03$) and with decreasing MAAT (Fig. 3.2a). Organic C accumulation of circumneutral (pH > 5) peatlands exhibited a weak but non-significant relationship with latitude and MAAT (Fig. 3.2a). A regression model based on separate slopes for acidic and circumneutral peatlands explained more variation ($r^2 = 0.67$) than the model that included all peatlands ($r^2 = 0.38$). Similar to temperature, peatland C accumulation increased with rain factor, f ($f = \text{mean annual precipitation}/\text{mean annual temperature}$; Lang cited in Eggelsmann 1976), for acidic peatlands but not for circumneutral peatlands (Fig. 3.2b). However, temperature alone explained more variation in peatland C accumulation than rain factor.

Organic C accumulation in soil represents the balance between net primary production (NPP), which adds C to the soil, and decomposition, which converts litter and soil organic matter to CO_2 . Accumulation of C in soil is affected more by decomposition rate than by NPP (Cebrian & Duarte, 1995; Schlesinger, 1997), and temperature is a primary factor controlling the rate of decomposition in terrestrial (Raich & Schlesinger, 1992; Couteaux *et al.*, 1995; Kirschbaum, 1995) and peatland soils (Updegraff *et al.*, 2001). Our findings support the idea that, like terrestrial soils, C accumulation in freshwater peatlands is controlled primarily by temperature, not precipitation.

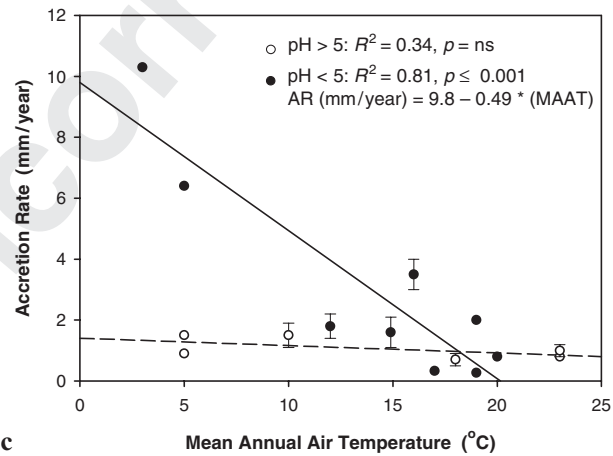
Variation in peatland C accumulation was driven mostly by differences in accretion rate rather than by differences in soil bulk density and organic C content (Table 3.1).



a



b



c

Fig. 3.2 (a) Relationship between organic C accumulation and MAAT of acidic (pH < 5) versus circumneutral (pH > 5) peatlands. (b) Relationship between organic C accumulation and rain factor (f) of acidic (pH < 5) versus circumneutral (pH > 5) peatlands. (c) Relationship between accretion rate and MAAT of acidic (pH < 5) versus circumneutral (pH > 5) peatlands. Bars denote one standard error for locations where multiple cores were collected and analyzed

Accretion rate (in mm/year) was inversely related to MAAT across all sites ($r^2 = 0.36$). And, like organic C accumulation, accretion was more strongly related to MAAT in acidic versus circumneutral peatlands (Fig. 3.2c). Rain factor explained comparable amounts of variation in accretion rates in acidic peatlands ($r^2 = 0.89$, $p < 0.001$) but not in circumneutral peatlands ($r^2 = 0.21$).

Mean organic C accumulation ($86 \pm 21 \text{ g C m}^{-2} \text{ year}^{-1}$) was two times greater in acidic than circumneutral peatlands ($49 \pm 11 \text{ g C m}^{-2} \text{ year}^{-1}$) in spite of very low C accumulation ($<20 \text{ g C m}^{-2} \text{ year}^{-1}$) in several acidic peatlands in the southeastern USA (NC, GA, FL). Optimum pH for most bacteria is in the range of pH 6–8 (Atlas & Bartha, 1987) and, as a result, decomposition of organic matter proceeds faster in circumneutral than acidic wetland soils (Schlesinger, 1990). Enhanced organic C accumulation in acidic peatlands may be attributed to lower decomposition and C mineralisation caused, in part, by low pH (DeLaune *et al.*, 1981; Benner *et al.*, 1985; Farrish & Grigal, 1988; Bridgham *et al.*, 1991, 1998; Updegraff *et al.*, 1995; Verhoeven & Toth, 1995). There was no consistent difference in surface soil (0–10 cm) bulk density or organic C concentration (%) with latitude or pH (Table 3.1).

In conclusion, organic C accumulation in temperate freshwater peatlands is controlled both by climate through the effects of temperature and local factors such as pH. While predicting future rates of C sequestration by freshwater peatlands one should consider the varying effects of global (i.e. temperature) and local (i.e. pH) factors on organic C accumulation.

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