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Rates of peat accumulation over the past 200 years in five *Sphagnum*-dominated peatlands in the United States *

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Abstract

Using ^{210}Pb-dating of peat cores, corroborated by pollen and acid-insoluble ash approaches, rates of vertical height growth, dry mass accumulation, and organic matter accumulation were determined for five *Sphagnum*-dominated peatland sites (one in Minnesota, one in Pennsylvania, one on the Maryland/West Virginia border, two in West Virginia), spanning a mean annual temperature range of 4.5 °C and differing in total annual precipitation by a factor of almost 2. Site differences in rates of vertical height growth and dry mass accumulation were documented, but both within-core and between-site differences in bulk density and ash concentrations of peat confound efforts to relate vertical height growth and dry mass accumulation to net organic matter accumulation. Taking bulk densities and ash concentrations into account, rates of net organic matter accumulation over the past 150–200 years were strikingly similar at four of the five sites, an unexpected result given the general trend that with decreasing latitude, peat deposits become older, thinner, and more highly decomposed. More comprehensive studies are needed in which net organic matter accumulation is determined at several locations within a single peatland, at several peatlands within a particular geographic/climatic region, and at peatland sites in different geographic/climatic regions. If additional studies confirm that recent (past 200 years) net organic matter accumulation is relatively insensitive to broad-scale regional climatic differences, boreal and subarctic peatlands may continue to function as a net sink for atmospheric CO_2 and a net source of atmospheric CH_4 with no change in rates of net organic matter accumulation, even under predicted scenarios of global climate change.

Introduction

Boreal and subarctic peatlands cover an estimated 346 million ha of the earth's land surface; their estimated 455 Pg of stored carbon represents approximately one third of the global soil carbon pool (Gorham, 1991). Most of these peatlands are located in regions that were covered with ice during the most recent glacial period, so the large quantity of carbon presently stored as peat is a testament to the role of peatland ecosystems as a long-term net sink for photosynthetically fixed atmospheric CO_2. Peatlands appear to continue to be a net sink for atmospheric CO_2, with estimates of present-day net carbon storage ranging from 0.076–0.3 Pg yr^{-1} (Miller 1981; Armentano & Verhoeven 1985, Gorham 1991). Contrastingly, peatlands may represent a substantial source of atmospheric CH_4, concentrations of which continue to increase at about 0.9% yr^{-1} (Houghton *et al.*, 1990). Globally, natural wetlands release an estimated 115 Tg of CH_4 to the atmosphere (range 100–200 Tg) and thus may con-

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tribute over 20% of the total annual CH_4 release to the atmosphere from all known sources (Houghton *et al.* 1990). Given the quantity of carbon stored as peat globally, the functional attributes of peatlands as present-day net sinks for atmospheric CO_2 and net sources of atmospheric CH_4, and given predictions that climatic warming will be most pronounced in northern latitudes (Grotch & MacCracken, 1991), how peatlands may respond functionally to predicted scenarios of global climate change is emerging as an important question (Post, 1990; Gorham, 1991).

While most of the world's peatlands are located in boreal and subarctic regions, numerous, relatively small, *Sphagnum*-dominated peatlands can be found along the axis of the Appalachian Mountains (USA) as far south as southern West Virginia and even into North Carolina (Cameron, 1968; 1970; McDonald, 1985). Vegetationally and biogeochemically, many of these wetlands are similar to their more extensive northern counterparts (Wieder *et al.* 1981; Wieder, 1985). The Appalachian peatlands are of Quaternary age (Arnold & Libby, 1951; Cameron, 1968; Maxwell & Davis, 1972; Spear & Miller, 1976; Watts, 1979), with most having initiated peat accumulation 9000–13 000 years ago. Further, it is likely that the Appalachian peat deposits have developed over thousands of years under climatic conditions that have been generally warmer than conditions in boreal and subarctic regions. We submit that descriptive, comparative studies of organic matter biogeochemistry between northern (cooler climate) and southern (warmer climate) peatland sites may provide insight into how boreal and subarctic peatlands may respond to projected future climate change. Based on this premise, we report here data on rates of vertical height growth, dry mass and organic matter accumulation over the past 150–200 years in five *Sphagnum*-dominated peatlands which span over 8 degrees of latitude and differ in present-day mean annual temperature by as much as 4.5 °C and in mean annual precipitation by almost a factor of 2. Cameron (1968) states that within the Appalachian region, with decreasing latitude peat deposits become fewer in number, smaller in areal extent, thinner, and more highly decomposed. Interpreting this observation as indicative of lower net long-term organic matter accumulation in more southern sites than in more northern sites, we expected to document site differences in recent rates of net organic matter accumulation that are related to site differences in present-day climatic conditions.

Study sites

Five *Sphagnum*-dominated peatlands were selected for study (Fig. 1). The northern-most site, Marcell S-2 Bog (47 °32′N, 93 °28′W; 420 m a.s.l.), is a 3.2 ha peatland surrounded by 6.5 ha of upland watershed (Verry & Timmons, 1982). The bog vegetation is dominated by a mature stand of black spruce (*Picea mariana*), with an understory of ericaceous shrubs and sedges. *Sphagnum* mosses cover the peat surface, with *S. magellanicum* dominating in the hummocks and *S. angustifolium* dominating in the hollows; the organic peat deposit reaches a maximum depth of about 8 m (Urban *et al.*, 1989). Although surface water chemical data are not available for Marcell S-2 Bog, streamwater draining perched bog watersheds in the Marcell Experimental Forest (including watershed S-2), has a pH of 3.9 and dissolved Ca^{2+}, Mg^{2+}, K^+, NH_4^+, NO_3^- and SO_4^{2-} concentrations of 60, 40, 32, 32,14, and 48μmol l^{-1}, respectively (Verry, 1975). Tamarack Swamp (41 °15′N, 75 °38′W; 590 m a.s.l.) is situated in the glaciated Pocono Plateau Section of the Appalachian Plateaus Physiographic Province of Pennsylvania (Fenneman, 1938), approximately 30 km north of the Late Wisconsinan glacial border. The 28 ha wetland is surrounded by 76 ha of forested upland. The bog vegetation is dominated by *Picea mariana*, *Larix laricina*, and *Acer rubrum* with an understory of ericaceous shrubs; *Sphagnum* species cover an average of 73% of the peat surface (the *Sphagna* have not been identified to species). Surface water chemistry is characterized by pH values of 4.2–4.5, and concentrations of dissolved Ca^{2+}, Mg^{2+}, K^+, $NH^+{}_4$, NO_3^- and SO_4^{2-} of 27, 15, 32, 28, 6, and 37 μmol l^{-1}, respectively (Sanguinetti, 1992). Tamarack Swamp appears to be a kettle bog, with a small open water pond surrounded by a floating *Sphagnum* mat. Cranesville Swamp (39 °26′N, 79 °31′W; 770 m a.s.l.), Big Run Bog (39 °07, 79 °35′W, 980 m a.s.l.), and Tub Run Bog (39 °07′N, 79 °33′W; 950 m a.s.l.) all are situated in the unglaciated Allegheny Mountain Section of the Appalachian Plateaus Physiographic Province (Fenneman, 1938). At 230 ha, Cranesville Swamp is by far the largest peatland studied. Much of the surrounding 920 ha watershed is used for agriculture and pasture land. Several distinct plant communities have been identified at Cranesville Swamp (Robinette, 1964). Sampling for this study occurred in an unforested shrubby community (mostly *Vaccinium myrtilloides* and *Pyrus melanocarpa*) with several sedge species and a continuous cover of *Sphagnum* (not identified to species). In this community, surface water pH is 4.4 and concentrations of dissolved Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+}, NO_3^{-} and SO_4^{2-} are 40, 17, 38, 5, 3, and 111 μmol l^{-1}, respectively; peat depths at Cranesville Swamp are typically less than 1 m (Lang & Topa, 1982). Big Run Bog is a 15 ha peatland surrounded by 276 ha of forested upland watershed. The vegetation at Big Run Bog has been described by Wieder *et al.* (1981) and Walbridge (1982). Sampling for this study occurred in an unforested, open area relatively free of shrubs, dominated by sedges and rushes and with a continuous cover of *Sphagnum*. The dominant *Sphagnum* in the area sampled were *S. fallax* and *S. magellanicum*; *S. girgensohnii*, *S. imbricatum* and *S. papillosum* also occur at Big Run Bog (Walbridge, 1982). In the community from which peat was extracted for the present study, surface water pH averages 3.9 and concentrations of dissolved Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+}, NO_3^{-} and SO_4^{2-} average 22, 8, 12, 9, 1, and 110 μmol l^{-1}, respectively; peat depth averages about 40 cm and the peat at the maximum depth of 225 cm was radiocarbon-dated to 13 080±420 yr bp (Wieder, 1985). Several boreal peatland plant species reach their southern limits in Cranesville Swamp, Big Run Bog, or in the other mountain peatlands in West Virginia (see Wieder *et al.*, 1981). Tub Run Bog is a 23 ha peatland bordered along its eastern edge by a 21 ha abandoned, unreclaimed Upper Freeport coal surface mine, which was active in the late 1940's and early 1950's. Abandoned underground mines extend into the coal seam to the east. Of the 297 ha mostly forested watershed surrounding Tub Run Bog, 122 ha was undermined; precipitation on this portion of the watershed percolates downward into the old mines and is diverted away from Tub Run Bog. Acid mine drainage, with pH values as low as 2.2 and elevated concentrations of Ca^{2+}, Mg^{2+}, dissolved Fe and SO_4^{2-}, is discharged into Tub Run Bog from the abandoned coal surface mine both chronically and in as pulsed loadings following rain events (Wieder & Lang, 1986). The vegetation at Tub Run Bog has been described by Walbridge (1982). Sampling for this study occurred in an unforested, open area relatively free of shrubs, dominated by sedges and rushes, with an almost continuous moss cover consisting mainly of *Sphagnum fallax* and *Polytrichum commune* (*Sphagnum fimbriatum*, *S. girgensohnii* and *S. imbricatum* also occur at Tub Run Bog). In this community, surface water has a pH of 4.3 with concentrations of dissolved Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+}, and NO_3^{-} of 67, 29, 15, 11, and 0 μmol l^{-1}, respectively (Walbridge, in press). The peat at Tub Run Bog typically is less than 40 cm deep and reaches a maximum depth of about 1 m.

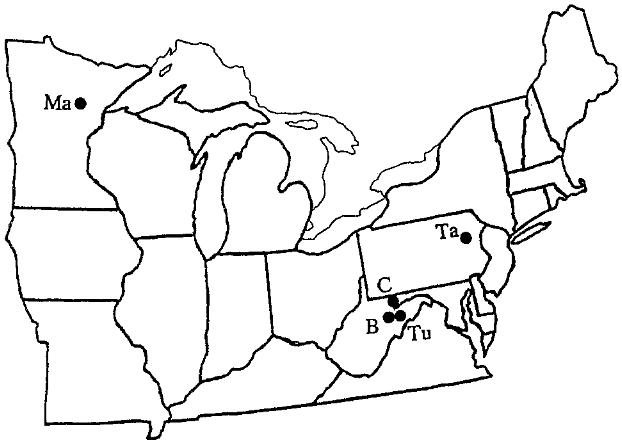

Fig. 1. Location of the study sites (Ma = Marcell S-2 Bog, Ta = Tamarack Swamp; C = Cranesville Swamp, B = Big Run Bog, Tu = Tub Run Bog).

Climatological data are available from stations (NOAA 1985) located near and at similar elevations to each of the peatland sites (Marcell S-2 Bog, 30 km from Grand Rapids, MN; Tamarack Swamp, 25 km from Freeland, PA; Cranesville Swamp, 20 km from Oakland, MD; Big Run Bog and Tub Run Bog, 30 km from Bayard, WV). In terms of temperature and precipitation regimes, Grand Rapids is quite different from the Appalachian stations (Fig. 2). Mean annual temperature at Grand Rapids is about 4 °C lower than at the other stations, mainly because of lower winter temperatures. Freezing temperatures (below 0 °C) have been recorded in all months of the year except June, July and August at Freeland, in all months except July and August at Grand Rapids, and in all months except July at Oakland and Bayard. Low temperature extremes may be exacerbated at Cranesville Swamp, Big Run Bog and Tub Run Bog because of their topographic positions in local frost-pockets (cf. Hough, 1945). Although the median duration of the frost-free season is shortest at Grand Rapids and Bayard and longest at Freeland, mean monthly temperatures from May through September are similar at all sites. At Grand Rapids, total annual precipitation is only about 56% of the mean annual precipitation at the Appalachian stations, and there is a distinct seasonality to precipitation which is much less evident at the Appalachian stations. Mean annual snowfall is much greater at Bayard (2441 cm) and Oakland (2083 mm) than at either Freeland (1364 mm) or Grand Rapids (1455 mm).

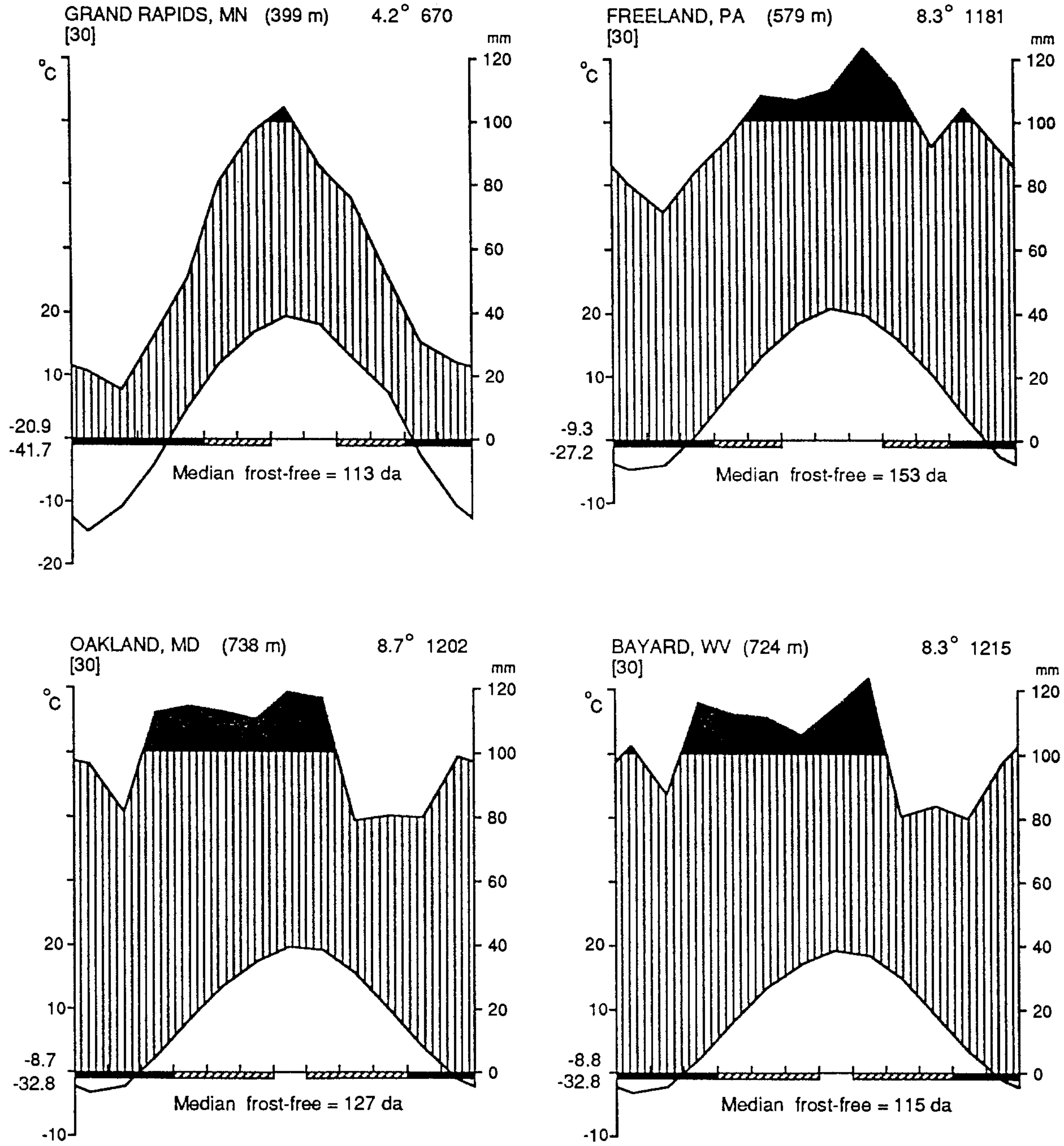

Fig. 2. Climate diagrams (after Walter 1985) for stations near Marcell S-2 Bog (Grand Rapids, MN; 47 °14′N, 93 °30′W), Tamarack Swamp (Freeland, PA; 41 °01′N, 75 °54′N), Cranesville Swamp (Oakland, MD; 39 °24′N, 79 °24′W), and Big Run Bog and Tub Run Bog (Bayard, WV; 39 °16′N, 79 °22′W). Diagrams show: along the top the station name, elevation, mean annual temperature (°C), total annual precipitation (mm), and number of years of record (in brackets); mean monthly temperature (left y-axis, line plotted below the vertical hatching) and mean monthly precipitation (right y-axis, line plotted above the vertical hatching) plotted as a function of month (x-axis from January through December) with monthly precipitation values greater than 100 mm shaded in black; to the left of the x-axis, mean monthly temperature for the coldest month and the record low temperature; solid bars below the x-axis indicate months with a mean daily minimum temperature below 0 °C and diagonally hatched bars indicate months in which an absolute minimum daily temperature below 0 °C has been recorded.

Materials and methods

Of the 2–3 peat cores collected from each of the five sites, one was selected for ^{210}Pb dating and further processing. All cores were collected from hollows or lawns in regions of the wetlands where hummock/hollow topography was poorly developed. Intact peat cores were collected in 10 cm diameter, 40 cm long sections of PVC pipe with sharpened bottom edges. To facilitate core collection, a circular incision was made in the fibrous surface peat prior to insertion of the PVC cylinder. If the cylinder was inserted with minimal compaction (less than 5 cm), the peat external to the core was excavated, the bottom of the cylinder was covered by hand, and the assembly was lifted from the peatland. Peat cores were extruded in the field, and sectioned into 2 cm depth intervals; each core section was placed into an airtight plastic bag, returned to the laboratory and frozen. Peat samples were freeze-dried, weighed, and ground to pass a 2 mm mesh using a Tecator Cyclotec sample mill.

A 0.5 g subsample from each core section was placed into a porcelain crucible and dry-ashed in a muffle furnace at 550 °C for 4 hrs; organic matter was calculated as loss on ignition. For Marcell S-2 Bog only, the crucibles containing the resulting ash then were placed into a sand bath to digest the ash in hot (135 °C) aqua regia (concentrated HCl and concentrated HNO_3, 3:1 v/v) for 1 h. The digested mixture was filtered through Whatman 42 filter paper and repeatedly rinsed. The filter paper with its remained residue the was placed in a muffle furnace at 550 °C for 4 h. The material remaining after this step is referred to as acid-insoluble ash (Urban *et al.*, 1989).

Peat profiles were ^{210}Pb dated using acid digestion of peat (W. R. Schell, pers. comm.). The constant rate of supply (CRS) model of Appleby & Oldfield (1978) was applied. A 3 g subsample from each peat core section, along with approximately 15 dpm of ^{208}Po as a chemical yield tracer, was digested using concentrated HCl, concentrated HNO_3, and H_2O_2. The Pb and Po isotopes were plated onto silver discs for activity measurement on an ORTEC 576 alpha spectrometer. In using ^{210}Pb to date the cores, each date has an error term which is comprised of both counting error and propagated error associated with fitting the CRS model to the data. The magnitude of the error term increases with depth (Schell, 1987). For this paper, depths for which the error term exceeded the estimated age (yrs) of the section were not included in the construction of core chronologies. Additionally, the dates obtained using ^{210}Pb methodology represent the average date for each 2 cm section. In calculating dry mass or organic matter accumulation rates (μ g cm^{-2} yr^{-1}), the dates for the top and the bottom of each 2 cm section were estimated by averaging the date for the section with those of the overlying and underlying sections, respectively. The difference between the estimated dates for the top and bottom of each section then represents the number of years over which the peat in a particular 2 cm section accumulated.

Subsamples from each section of the cores from Big Run Bog and Marcell S-2 Bog (0.1 g for depths $\geq$ 8 cm or 0.2 g for depths $\leq$ 6 cm) were digested for pollen analysis by the Faegri and Iversen method (Faegri *et al.*, 1989). At least 200 pollen grains per sample were counted at magnifications of 200 to 400×. We note that grinding of the samples in the Tecator Cyclotec sample mill appeared to cause some damage to large pollen grains, such as those of *Pinus*, *Picea*, and *Tsuga*.

Results and discussion

Corroboration of ^{210}Pb-based chronologies

Year/depth curves (Fig. 3) graphically illustrate ^{210}Pb-based chronologies for individual cores. In light of concerns about possible Pb mobility in peat deposits (cf. Urban *et al.*, 1990), we used pollen analyses of the peat deposits from Marcell S-2 Bog, MN and Big Run Big, WV to corroborate ^{210}Pb-based chronologies prior to making interpretations regarding rates of peat accumulation.

The most useful aspect of the pollen profiles from Marcell S-2 Bog (Fig. 4) is the increase of pollen of weeds and shrubs indicating the clearance of land by settlers. Pollen of Compositae (mostly *Ambrosia*-type) increase from less than 4% in the 24–26 cm interval (dated to 1846) to 25% at 20–22 cm (dated to 1905). Also in this interval, pollen of Chenopodiaceae (including Amaranthaceae) increases from 0 to 2.5%, trilete fern (including *Pteridium* and *Lycopodium*) spores increase from 0 to 1.5%, and *Alnus* pollen increases from 2% to greater than 11%; percentage of *Pinus* pollen reciprocally decreases (from 66 to 28%) within this interval. These changes can be attributed to the clearing of land for agriculture, which began in the southern and western end of Minnesota in the early 1860's (Fite, 1966). Local colonization in the vicinity of Marcell S-2 Bog occurred around 1895 (Urban *et al.*

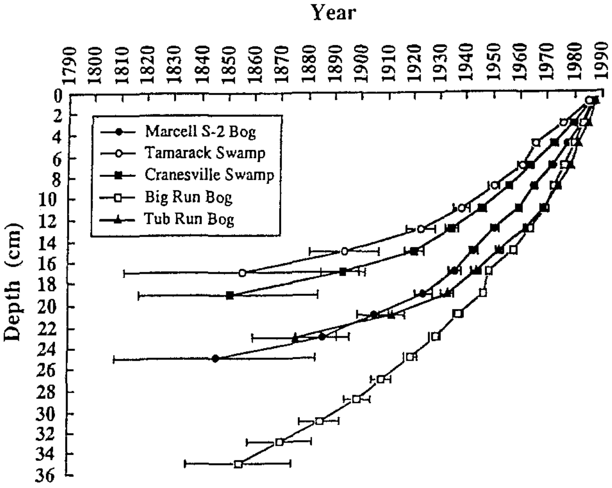

Fig. 3. Year/depth depiction of the ^{210}Pb-based chronologies. The horizontal bars associated with each data point represent error terms which are comprised of both ^{210}Pb counting error and propagated error associated with fitting the CRS model to the ^{210}Pb data.

1989). The timing of the settlement-related changes in the pollen record, as determined by ^{210}Pb dating of the peat profile, is thoroughly consistent with the known history of regional and local settlement of Minnesota.

The oldest ^{210}Pb date for the Big Run Bog peat profile (1816 at 35 cm) post-dates the settlement of large areas of the Appalachian Region which occurred from 1730 to 1790 (Salstrom, 1990). Destruction of the native virgin forests went along with settlement; in 1776, the first water-powered, up-and-down sawmill was established at St. George in Tucker County (Widner, 1965), less than 15 km from Big Run Bog. Increases in composite pollen and trilete fern spores in peat from the 43 to 35 cm depths would be consistent with settlement-associated clearing of the region.

Unlike Marcell S-2 Bog, Big Run Bog is situated in the heart of the Allegheny Mountains Region of the Mixed Mesophytic Region defined by Braun (1950), an area in which *Castanea dentata* formerly was abundant. We had insufficient peat for pollen analysis of all depth intervals, but note that percentages of *Castanea* pollen decrease from 1.5 to 1.2 to 0.0 in the 24–26 cm (1908), 20–22 cm (1937), and 12–14 cm (1965) sections, respectively. Blighted chestnut trees were first noticed in New York City in 1904. By 1910, the blight had extended southward into Pennsylvania; by 1925 virtually all of Pennsylvania's chestnut trees were dead (Fletcher, 1955). By 1930, 80–90% of the trees as far south as western North Carolina were infected (Keever, 1953). The timing of the decline of *Castanea*, as determined by ^{210}Pb dating of the peat profile, is consistent with the history of the progression of chestnut demise.

As a second independent approach for corroborating the ^{210}Pb dates at Marcell S-2 Bog, we used acid-insoluble ash (AIA), first proposed by Urban (1983) as a dating technique and subsequently applied to Marcell S-2 Bog (Urban *et al.*, 1989). The AIA dating technique assumes that the input of AIA from atmospheric deposition to the surface of a peat deposit has been constant and uniform over the past 200–300 years, and that atmospherically deposited AIA is immobile and chemically inert in the peat deposit (Urban, 1983). Urban's (1983) approach was to determine AIA input by multiplying the AIA concentration in the moss, surface litter and vascular plants by the current year's mass growth rate. Knowing the annual AIA input rate, measurement of the quantity of AIA in a given section of peat beneath a known surface area of a peatland allows for calculation of the number of years over which the peat in that section accumulated. For Marcell S-2 Bog, Urban (1983) estimated AIA input as 8.12 g m^{-2} yr^{-1}.

In using AIA as to corroborate ^{210}Pb dating, we determined that a significant linear relationship exists between the AIA content per peat core section and the number of years over which the peat in each section accumulated (Fig. 5A). However, the average rate of AIA input to Marcell S-2 Bog (the slope of the regression line divided by 78.54 cm^2, the core surface area) is only 5.35 g m^{-2} yr^{-1} considerably less than Urban's (1983) estimate. The ^{210}Pb dates and the AIA contents for each core section permit a reconstruction of historical changes in the rate of AIA deposition to Marcell S-2 Bog (Fig. 5B). This reconstruction indicates that the AIA input to the top 2-cm section of Marcell S-2 Bog is 8.00 g m^{-2} yr^{-1} virtually identical to Urban's estimate. While over the past 20 years (top 8 cm), mean AIA input has been relatively constant, averaging 8.38 g m^{-2} yr^{-1} AIA input has not been constant over the past 175 years. Prior to settlement of Minnesota AIA inputs were low, but elevated AIA inputs to Marcell S-2 Bog associated with initial local settlement in 1895, logging of the nearby uplands around Marcell S-2 Bog in the 1920's (Urban, 1983) and the widespread regional dust bowl conditions of the 1930's and to a lesser extent in the 1950's (Hurt, 1981) are clearly preserved in Marcell S-2 Bog. The timing of these historical changes in AIA input to Marcell S-2 Bog, as determined by ^{210}Pb dating of the peat, is consistent with the known history of the region. We interpret palynological corroboration of the ^{210}Pb-based chronologies at Marcell S-2 Bog and Big Run

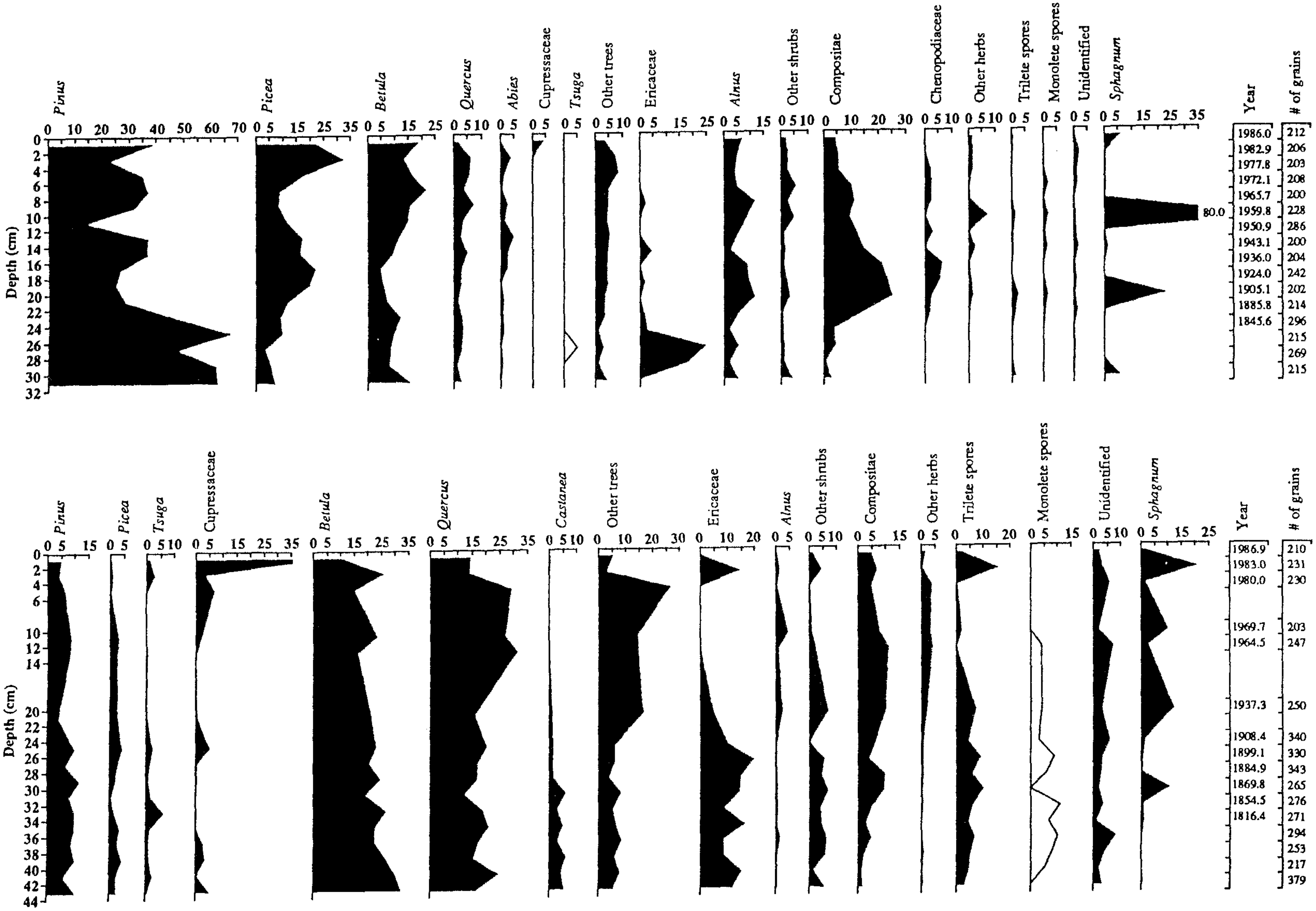

Fig. 4. Pollen diagrams for Marcell S-2 Bog, MN (top) and Big Run Bog, WV (bottom). Note that because of insufficient sample, pollen analysis was not performed on all depth intervals in the Big Run Bog profile. Compositae is predominantly *Ambrosia*-type, with minor contributions by Liguliflorae and other taxa; Chenopodiaceae includes Amaranthaceae; other trees is comprised of pollen from only hardwood species. Values are percent of total pollen, excluding *Sphagnum* spores from the denominator.

Bog, as well as AIA corroboration at Marcell S-2 Bog as indicating that the ^{210}Pb-based chronologies at the other three sites are valid as well.

Vertical height growth

Peat accumulates vertically, from the upward extension of *Sphagnum* plants and the addition of new organic material at the peat surface. Because depth serves as an analog for time in a peat deposit, a commonly used approach toward assessing long-term peat accumulation is to divide the depth of a peat layer by its age, as determined by radiocarbon dating. For boreal and subarctic peatlands, dating of basal peat yields long-term vertical height growth values that range from 0.1–0.8 mm yr^{-1} (see numerous references in Ovenden, 1990, Gorham, 1991); Gorham (1991) suggested that 0.5 mm yr^{-1} may be a conservative and reasonable estimate for boreal and subarctic peatlands in general. In contrast, long-term height growth rates for Buckle's Bog, MD, Cranberry Glades, WV and Big Run Bog, WV are only 0.15, 0.16, and 0.17 mm yr^{-1}, respectively (Maxwell & Davis, 1972; Arnold & Libby, 1951; Wieder, 1985). Generally lower values for long-term vertical height growth of temperate peatlands than for boreal and subarctic peatlands reflect both the relative thinness and relative old age of the temperate peat deposits (cf. Cameron, 1968).

Values for long-term vertical height growth of a peat deposit based on radiocarbon dated basal peat layers are considerably lower than values for annual vertical height increments of peat-forming *Sphagnum* living at the surface of peat deposits. For example, at Big Run Bog, *S. recurvum* (*S. fallax*) and *S. magellanicum* grew 6.3 and 7.5 cm in length during a single growing season (Wieder & Lang, 1983), compared to the long-term vertical height growth of 0.17 mm yr^{-1} determined from radiocarbon dating of the basal peat. Over a 3-year study period, *Sphagnum* in hummocks and hollows of perched and raised bogs in Minnesota grew 3.9–13.1 cm yr^{-1} (Grigal, 1985). Differences in estimates of height growth obtained by radiocarbon dating of basal peat layers versus measurement of current *Sphagnum* growth reflect ongoing decomposition and compaction within the peat column (cf. Clymo, 1984). Based on ^{210}Pb dating of peat cores, it is evident that apparent estimates of vertical height growth per year progressively decrease with depth (Table 1, Fig. 3), a pattern that was similarly documented in the most recent 150 years of development of a calcareous *Sphagnum* fen in Indiana (Cowles Bog) using ^{210}Pb dating (Cole *et al.* 1990), of Finnish peatlands using ^{210}Pb and moss increment dating (El-Dauoshy *et al.*, 1982), and of Swedish peatlands using the 'pine method' of dating (Ohlson & Dahlberg, 1991).

Based on radiocarbon dates of basal peat, we would have expected recently (roughly the past 200 years) deposited peat to exhibit considerably higher rates of vertical height growth at Marcell S-2 Bog than at our more southern temperate zone sites, yet such a pattern was not at all evident (Fig. 3). Site differences in vertical height growth determined from radiocarbon dated basal peat layers are not reflected in the more near-surface recently deposited peat. This disparity, along with the generally accepted view that the more recently deposited, less highly decomposed peat may be more likely to respond to future changes in local, regional, or global climate suggest that considerable caution must be exercised when using vertical height accumulation (based on radiocarbon dated peat layers) along with values for peat bulk density and organic matter content to assess both past and potential future changes in carbon storage in peatland ecosystems (Ovenden, 1990; Gorham, 1991).

Dry mass and organic matter accumulation

Site differences in the rate of accumulation of dry mass beneath a given area of peat surface (Fig. 6) do not mirror site differences in vertical height growth (Fig. 3), because of within-core and between-site differences in bulk density values (Fig. 7). More importantly, because dry mass accumulation does not take into consideration either within core or between-site differences in ash concentrations of peat (Fig. 7), patterns of dry mass accumulation may not accurately reflect patterns of organic matter accumulation over time. Ash concentrations of peat are affected by input of inorganic materials to the peat deposit, either through atmospheric deposition or runoff from upland areas of a peatland's watershed, and by degree of decomposition, with ash tending to be concentrated as the organic matter is progressively mineralized over time and released as CO_2 or CH_4. Also, loss of soluble organic compounds from peatlands results in an increase in the ash concentration of the residual peat. Ash concentrations were lowest at Marcell S-2 Bog (mean±standard error; 7.0±0.8% of dry mass), possibly reflecting low ash inputs and a relatively undecomposed peat throughout the 32 cm deep core. Ash concentrations were highest at Tub Run Bog (53.1±5.0%), probably reflecting anthropogenic disturbances to the upland watershed, notably

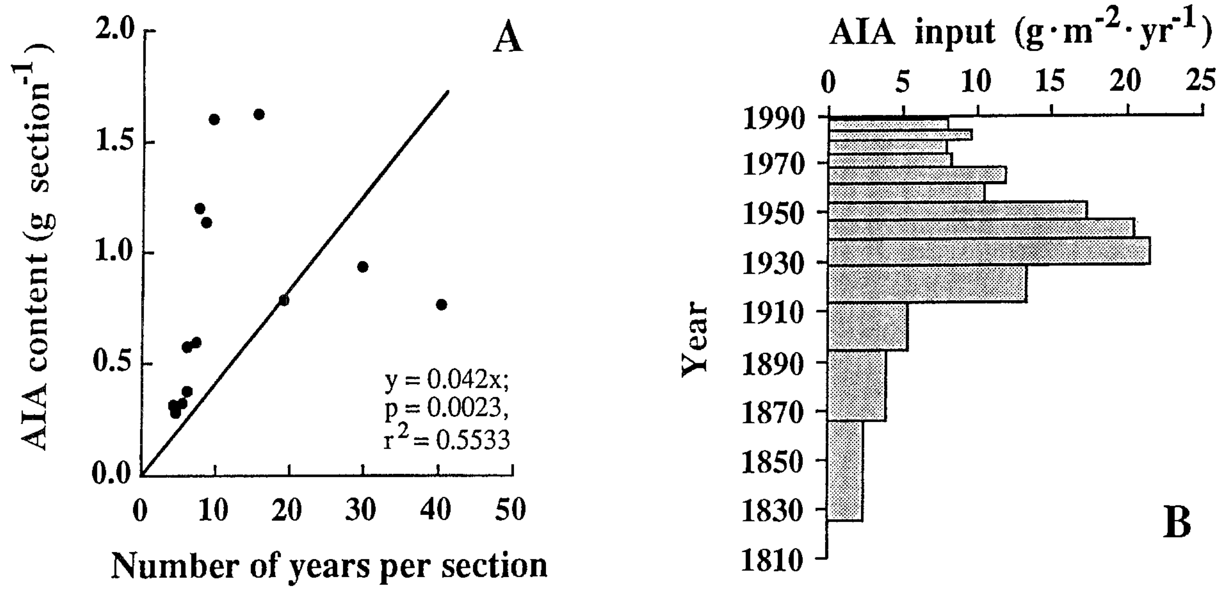

Fig. 5. Linear regression (with the stipulation that the fitted line pass through the origin) of AIA content of each 2 cm section of the Marcell S-2 Bog core versus the number of years over which the peat in each section accumulated, based on ^{210}Pb dating (A). Also shown are changes in the input of AIA to Marcell S-2 Bog over time (B); the height of each bar in the histogram corresponds to the number of years over which the peat in a particular 2 cm core section accumulated, with estimation of the dates for the top and bottom of each section described in text.

cutting of the forest in the late 1700's through the early 1900's (Thompson, 1974; Widner, 1965) and surface coal mining adjacent to the peatland in the 1940's and 1950's. At Tamarack Swamp, Cranesville Swamp, and Big Run Bog, ash concentrations averaged 20.7±2.1, 15.5±1.7, and 16.5±2.5%, respectively, and generally increased with depth, a pattern attributable at least in part to an increasing degree of decomposition of the peat with increasing depth.

By subtracting the inorganic ash fraction from the dry mass of each core section, curves representing the accumulation of organic matter beneath a given area of peat surface over time can be constructed (Fig. 8). These curves indicate that the rate of organic matter accumulation has been strikingly similar at four of the five sites (except Tub Run Bog), especially over the past 50 years. Among these four sites, rates of organic matter accumulation in the top 2 cm and over the past 50 or 100 years were within 8, 12, and 17% of each other, respectively (Table 1). Although differences between sites appear to increase deeper in the peat columns (Fig. 8), so do the error terms associated with date estimates (Fig. 3). We conclude that these four sites have not differed with regard to rates of organic matter accumulation over the past 100 years. The generally higher rate of organic matter accumulation at Tub Run Bog may be attributable to the considerably higher ash content, attendant higher soil fertility, and possibly higher net primary production, as compared to the other sites.

Conclusions

Palynological analysis of peat profiles from Marcell S-2 Bog and Big Run Bog, along with AIA analyses of peat from Marcell S-2 Bog, corroborated the ^{210}Pb dating for these two sites, leading us to conclude that ^{210}Pb dating produced a valid and accurate chronology of peat accumulation at all five sites. Although site differences in rates of vertical height growth and dry mass accumulation were documented, both within-core and between-site differences in bulk density and ash concentrations of peat confound efforts to estimate rates of net organic matter accumulation from the straightforward approach of determining vertical height growth and applying a single bulk density value to all depths within a particular peat deposit. Taking bulk densities and ash concentrations into account, rates of net organic matter accumulation over the past 150–200

Table 1. Vertical height growth and net rates of organic matter accumulation in the five peatland sites over the time period represented by the top 2 cm section of peat, over approximately the past 50 years, and over approximately the past 100 years. Values for the 50 and 100 year intervals are based on the total quantity of organic matter above the bottom of the peat section which was dated most closely to 1939 and 1889, respectively

Interval Site	Years per interval	Vertical height accumulation (mm yr^{-1})	Organic matter beneath the peat surface (mg cm^{-2})	Organic matter accumulation (mg cm^{-2} yr^{-1})
Top 2 cm section				
Marcell S-2 Bog	4.6	4.3	104	22.6
Tamarack Swamp	8.5	2.4	199	23.4
Cranesville Swamp	6.2	3.2	152	24.5
Big Run Bog	4.1	4.9	93	22.7
Tub Run Bog	2.6	7.7	100	38.5
Past 50 years				
Marcell S-2 Bog	49.5	3.2	1009	20.4
Tamarack Swamp	44.5	2.2	950	21.3
Cranesville Swamp	48.5	2.5	951	19.6
Big Run Bog	47.3	4.2	903	19.1
Tub Run Bog	50.5	3.6	1290	25.5
Past 100 years				
Marcell S-2 Bog	93.6	2.4	1477	15.8
Tamarack Swamp	114.1	1.4	1544	13.5
Cranesville Swamp	116.8	1.9	1789	15.3
Big Run Bog	97.0	3.1	1424	14.7
Tub Run Bog	95.3	2.3	1694	17.8

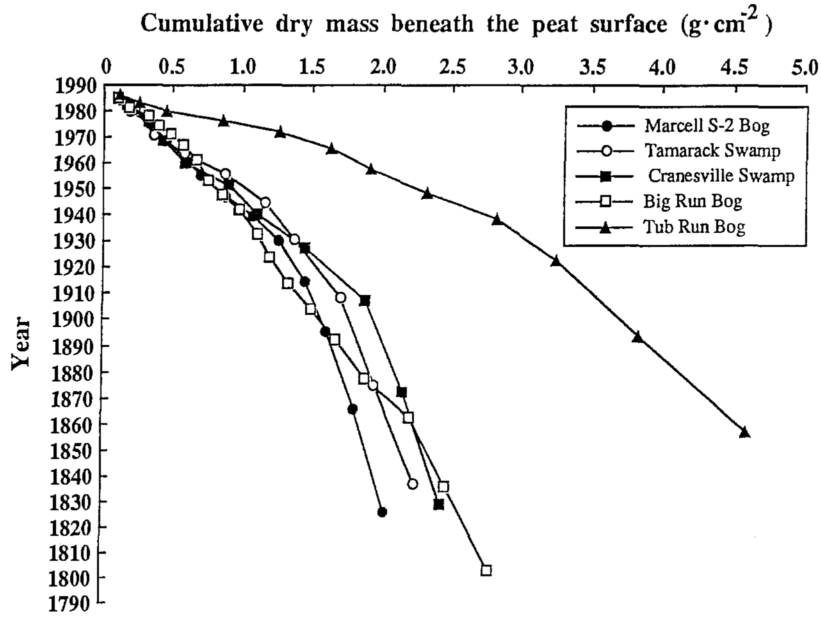

Fig. 6. Cumulative dry mass beneath the peat surface as a function of year (at the bottom of each 2 cm section), for each of the five sites.

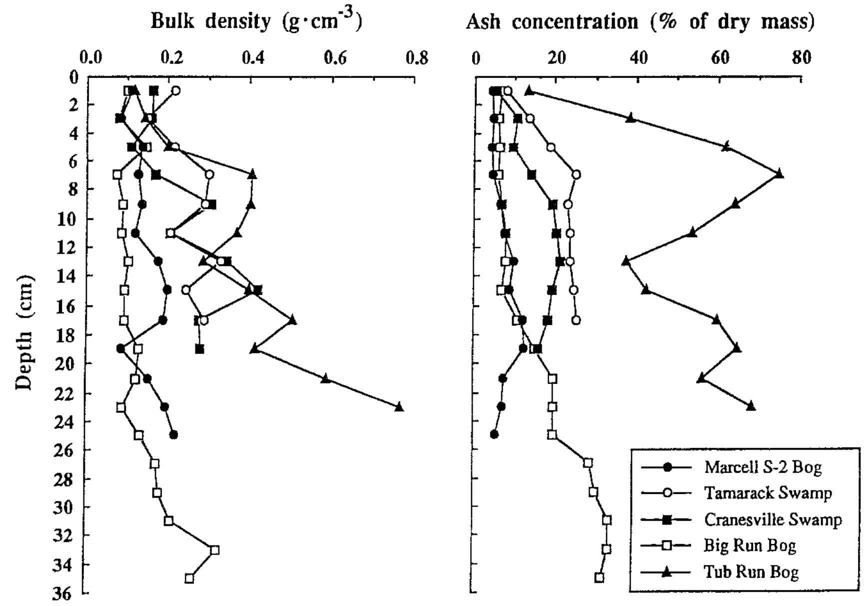

Fig. 7. Bulk density and ash concentration as a function of depth in each of the five sites.

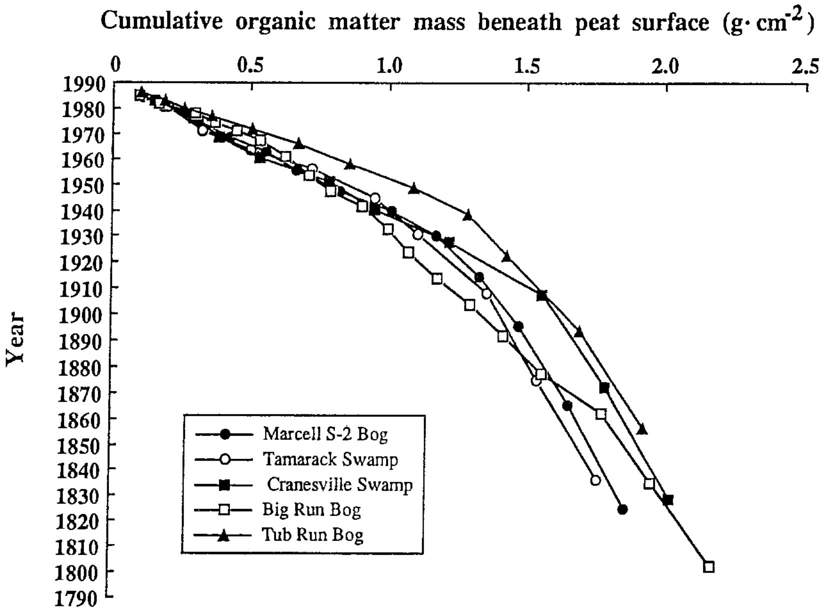

Fig. 8. Cumulative organic matter mass beneath the peat surface as a function of year (at the bottom of each 2 cm section), for each of the five sites.

years were strikingly similar at all sites except Tub Run Bog, even though these four sites span over 8 degrees of latitude, differ in present-day mean annual temperature by as much as 4.5 °C, and differ in mean annual precipitation by almost a factor of 2. Higher rates of net organic matter accumulation at Tub Run Bog may be related to a higher ash content of the peat, higher soil fertility, and higher net primary production.

Similarity in net organic matter accumulation between the four other sites over the past 150–200 years is surprising in light of the general trend that with decreasing latitude, peat deposits become older, thinner, and more highly decomposed, i.e., with decreasing latitude, peatlands have exhibited lower rates of net organic matter accumulation over thousands of years. The apparent disparity between recent (past 150–200 years) and long-term rates of peat accumulation suggests that the long-term differences associated with latitude either are the result of climatic conditions that prevailed more than 200 years ago, or are the result of present-day site differences in organic matter dynamics at depths below the 200-year level.

Prudence precludes a generalization of the findings reported here for five sites to peatlands globally. Additional studies are needed in which net organic matter accumulation is determined at: 1) several locations within a single peatland (notably in hummocks vs. hollows, and in different plant communities), 2) several peatlands within a particular geographic/climatic region, and 3) peatland sites which span geographic/climatic ranges. If additional studies confirm that recent (past 200 years) net organic matter accumulation is relatively insensitive to broad-scale regional climatic differences, boreal and subarctic peatlands may continue to function as a net sink for atmospheric CO_2 and a net source of atmospheric CH_4 with no change in rates of net organic matter accumulation, even under predicted scenarios of global climate change.

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