Peatlands of Continental North America

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Abstract

Peatlands in the USA and Canada are estimated to cover about 1.86 million km^2, most of which is located in the boreal zone with a continental climate and constitutes about 40–45% of the world's 4 million km^2 of peatland. Deep peat deposits (2–5 m) in boreal peatlands hold large stores of both carbon and nitrogen, estimated at about 33% of the global soil carbon and 10% of the world's soil nitrogen. The accumulation of carbon in peat is extremely sensitive to environmental disturbances. Changes in precipitation and temperature regimes related to climate change could act to decrease the accumulation rate, thus causing peatlands to turn from a carbon sink to a carbon source to the atmosphere. Peatlands provide a number of important ecological services, including not only significant carbon and nitrogen stores but also wildlife habitat, water filtration, and are home for a number of rare and endangered species and have been utilized and considered as culturally significant by native Americans for centuries.

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Introduction

The boreal zone of North America is a mosaic of peatlands, lakes, and upland forests all adapted to exist in a climate characterized by long, cold winters and short, cool summers. Precipitation falls mostly as snow in the winter and through localized thunderstorms during the summer. Peatlands, consisting of minerogenous fens and ombrogenous bogs, are an important sink of both carbon and nitrogen, and in boreal western Canada occupy from 30% to 40% of provincial landscapes. Two of the world's largest wetlands occur in continental North America, both dominated by bogs and fens. The Hudson Bay Lowland in Quebec, Ontario, and Manitoba is the second largest peatland area in the world, while the peatlands of the Mackenzie River watershed in Alberta, Northwest Territories, and the Yukon are generally considered the third largest peatland complex (Vitt et al. 2005). It is estimated that the USA and Canada together have about 1.86 million km^2 of peatland area most of which is located in the boreal zone with a continental climate (Wieder and Vitt 2006). This is about 40–45% of the world's 4 million km^2 of peatland. Peat is the undecomposed remains of organic matter. In boreal peatlands, cold anaerobic conditions allow deep deposits (2–5 m) of peat to develop over thousands of years. These deposits hold large stores of both carbon and nitrogen, estimated at about 33% of the global soil carbon and 10% of the world's soil nitrogen (Loisel et al. 2014). Peat deposits are formed in place and hold a permanent, long-term record of the development of individual peatlands and can form significant proxies for past climate (Vitt and Wieder 2008).

Major differences exist between peatlands of northern North America and those of Siberia and Fennoscandia (Gore 1983). Although many of the ground and field layer species are similar between the New and Old World, tree and shrub species are different. For example, the dominant shrub of Eurasian bogs is *Calluna vulgaris*, whereas in North America it is *Ledum groenlandicum*. The occurrence of a tree *Picea mariana* able to tolerate the ever growing peat surface by layering of the lower branches creates peatlands that have a dense tree layer. Although *Pinus sylvestris* occurs in European and Asian bogs, it never forms dense canopies, and the bogs of Eurasia are open and have only scattered individuals of trees, similar to the scattered individuals of *Picea mariana* as it occurs in the more maritime regions of eastern Canada. Secondly, the peat depths of Siberian peatlands are much greater than those of Canada, especially those of western and northern Canada. As a result, the carbon store of Siberian peatlands tends to be greater than that of Canadian peatlands (MacDonald et al. 2006). Thirdly, the climate of western Canada is drier and more arid than eastern Canada and Eurasia. The combination of a dense, well-developed tree layer and drier climate provides for higher fire frequencies. The high incidence of fire in western Canada results in more peat lost to fire and less carbon stored in the peat deposit. This higher frequency of wildfire coupled with a more severe early Holocene climate in western Canada have prohibited peat from forming deposits in western Canada that are as deep as those elsewhere.

Historical Development

Peatlands in continental North America began to initiate soon after the retreat of glaciers, some 12,000–15,000 years ago, by primary peat formation directly on wet, mineral soils. Also, the retreating glaciers stagnated leaving isolated blocks of ice scattered on the landscape that were soon covered by eroding mineral soil. When these blocks of ice melted there remained depressions with steep sides, and these "kettle holes" soon filled with water. Surrounding these depressions, wetland vegetation developed and over time the water-filled basins were filled in by decomposing peaty materials, thus forming a peatland vegetative cover from terrestrialization. Both primary peat formation and terrestrialization were common processes in the early Holocene, and the former continues to be a common initiation process in the Hudson Bay Lowland today as isostatic rebound provides new unvegetated surfaces. However, the modern landscape of Canada and Alaska is largely the result of a third peatland initiation process that is termed paludification or the swamping of previously dry mineral soils with upland vegetation. Most of the peatland-dominated landscape of the boreal region of the continent has an ever-increasing cover of peatland landforms (Halsey et al. 1998). This paludified landscape began to develop relatively late in the Holocene in western Canada, whereas it began earlier in the east. Thus in general, peatlands are older in eastern Canada and younger in the west (Glaser and Janssens 1986). Rates of paludification, especially in the dry western portion of Canada, were cyclic, with several episodes of paludification (Campbell et al. 2000). These paludification events appear to be climate-related with higher rates of paludification associated with wetter, cooler climatic periods.

Bogs and Fens

Bogs, here defined as ombrogenous or exclusively rain-fed peatlands, are characterized by low pH's (3.0–4.5), calcium pore water concentrations of less than 5 mg/L, and a set of common species. Bogs of western and central Canada and Alaska are dominated by a tree layer of *Picea mariana*, a well-developed shrub layer usually dominated by *Ledum groenlandicum*, an herb layer of *Rubus chamaemorus*, and a ground layer of *Sphagnum fuscum, S. magellanicum*, and *S. angustifolium*. In eastern Canada, trees are smaller, more scattered, and the bogs have a more open appearance. In the east, shrubs also include species of *Kalmia* and *Andromeda*, and the ground layer consists of additional species of *Sphagnum* such as *S. capillifolium* and *S. cuspidatum*. Except for *Eriophorum vaginatum,* sedges (species of *Carex*, *Scirpus*, and *Eriophorum*) are infrequent in bogs. Throughout the more northern portions of the boreal zone and southern subarctic, permafrost is common in bogs, forming continuously frozen peat plateaus with intermittent unfrozen pockets (collapse scars), while farther south in the northern and mid-boreal zones bogs and occasionally fens have intermittent permafrost or frost mounds, some of which have recently melted forming wet internal lawns (Vitt et al. 1994).

Fens are minerogenous peatlands strongly influenced by the chemistry of the inflowing surface and ground waters. Poor fens are acidic, oligotrophic ecosystems having pH's between 4.5 and 5.5 along with relatively low concentrations of base cations. These fens are dominated by species of *Sphagnum* (e.g., *S. angustifolium, S. fallax, S. majus, S. jensenii, S. riparium*, and/or *S. magellanicum*). True mosses are only present as infrequent members of the *Sphagnum*-dominated ground layer. In western Canada, poor fens form on low drainage divides and at higher elevations where the inflowing waters have small amounts of base cations. In general, poor fens become more frequent eastward and become the dominant fen type on the acidic Canadian Shield region of eastern Canada. Rich fens are circum-neutral to alkaline mesotrophic ecosystems with pH's between 5.5 and 8.5 and highly variable base cation concentrations. Two types of rich fens occur – at the lower pH's (5.5–7.0) with lower concentrations of base cations moderate-rich fens have some *Sphagnum* (e.g., *S. warnstorfii* and *S. teres*) and abundant sedges (e.g., *Carix aquatilis* and *C. lasiocarpa*), while at the higher pH's (7.0–8.5) extreme-rich fens occur where sites are influenced by calcareous inflowing waters. These alkaline, extreme-rich fens are dominated by true mosses, often called brown mosses (e.g., species of *Calliergon, Hamatocaulis*, and *Tomentypnum*), abundant sedges, and may contain deposits of marl. Extreme-rich fens are most frequent along the eastern foothill of the Canadian Rockies and northward into the subarctic plain of the western NWT. Although most boreal peatlands are species poor and have rather constant flora, rich fens are home to a large variety of plant species (Vitt and Chee 1990).

Peatland Landscapes

Fens in continental areas are variable in size and form. Both poor fens and rich fens can occupy basins influenced by stagnant waters (topogenous fens) and these basin fens often have continuous peatland vegetation cover, but this plant cover can be variable, both in structure and species. In wet basins, the fens are sedge dominated, whereas in drier basins *Larix laricina* and shrubby *Betula* and/or *Salix* species characterize the sites. Other basins, especially in eastern Canada are steep sided with open water surrounded by floating and grounded mats of fen vegetation. These "kettle-hole" fens vary depending on the chemistry of the associated water body and can be *Sphagnum*-dominated poor fens or calcareous, brown moss-dominated rich fens (Vitt and Slack 1975). Basin fens are most common in the southern boreal zone and on the Canadian Shield, whereas northward where relatively flat landscapes and late melting of the winter ice provide hydrological conditions favoring the formation of large peatland complexes. The fens of these northern complexes are often patterned into a series of ridges (strings) and pools (flarks) perpendicular to the overland water flow. These patterned fens are influenced by soligenous (overland) flowing water and also by the underlying mineral topography that provides areas of water stagnation. The presence of stagnant water allows succession to more oligotrophic fens that gradually become ombrotrophic and develop into bog islands and peninsulas (Glaser et al. 1981).

Threats and Future Challenges

Permafrost thaw in bogs of the northern boreal region appears to be related to climatic changes over the past 200 or so years as climate warmed following the Little Ice Age. When frost mounds thaw in bogs, the surface collapses, the thawed area becomes very wet, and the trees and shrubs die. The collapsed area is colonized by sedges and mesotrophic species of *Sphagnum* and plant production increases. As these internal lawns succeed back to a drier hummocky bog surface, plant production is greater than decomposition and carbon is stored in the newly deposited peat, providing a short-term net carbon sink resulting from the permafrost thaw (Turetsky et al. 2002a). This reaction of boreal permafrost thaw happening in bogs of the boreal zone is quite different from the reactions of permafrost thaw in mineral soils of the arctic.

Although there is increasing disturbance in boreal peatlands from oil and gas exploration and production, reservoir creation, and peat harvesting, the overall impact of these activities is much less than the impacts from natural disturbance from wildfire (Turetsky et al. 2002b). In comparison, in the more populated areas of eastern Canada, the large-scale drainage of peatlands from agriculture and urbanization is a lesser concern in the west.

Peatlands are an important carbon store. Whereas the amount of carbon stored in peat is large, the amount of carbon currently added to the peat column on an annual basis is very small (generally estimated as 19–24 gC m^{-2} $years^{-1}$ – Loisel et al. 2014). As a result, the accumulation of carbon in peat is extremely sensitive to environmental disturbances. Especially concerning are changes in precipitation and temperature regimes related to climate change, which could act to decrease the accumulation rate thus causing peatlands to turn from a carbon sink to a carbon source to the atmosphere. In boreal North America, peatlands occupy a significant portion of the landscape and provide a number of important ecological services, including not only significant carbon and nitrogen stores but also wildlife habitat, water filtration, and are home for a number of rare and endangered species including the woodland caribou *Rangifer tarandus caribou*. Native Americans have utilized these places for centuries and consider them as culturally significant. Community succession is a slow process, and in peatlands the fen to bog successional series is well documented and forms an important part of boreal ecology, and this is especially true for western Canada where the climate is dry and wildfire is such an important natural disturbance (Vile et al. 2011). Bogs, with their unique ombrotrophic status, also are subject to disturbances, especially fire, and their importance in providing a long-term but climate-sensitive carbon stock should not be underestimated (Wieder et al. 2008).

References

Campbell ID, Campbell C, Yu Z, Vitt DH, Apps MJ. Millennial-scale rhythms in peatlands in the western interior of Canada and in the global carbon cycle. Quatern Res. 2000;54:155–8.

Glaser PH, Janssens JA. Raised bogs in eastern North America: transitions in landforms and gross stratigraphy. Can J Bot. 1986;64:395–415.

Glaser PH, Wheeler GA, Gorham E, Wright Jr HE. The patterned peatlands of the Red Lake peatland, northern Minnesota: vegetation, water chemistry, and landforms. J Ecol. 1981;69:575–99.

Gore AJP, editor. Mires – swamp, bog, fen and moor, Ecosystems of the world 4B – regional studies. Amsterdam: Elsevier; 1983.

Halsey LA, Vitt DH, Bauer IE. Peatland initiation during the Holocene in continental western Canada. Clim Change. 1998;40:315–42.

Loisel J, Yu Z, Beilman DW, et al. A database and synthesis of northern peatland soil properties and Holocene carbon and nitrogen accumulation. Holocene. 2014;24:1028–42.

MacDonald GM, Beilman DW, Kremenetski KV, Sheng YW, Smith LC, Velichko AA. Rapid early development of circumarctic peatlands and atmospheric CH_4 and CO_2 variations. Science. 2006;314:285–8.

Turetsky MR, Wieder RK, Vitt DH. Boreal peatland C fluxes under varying permafrost regimes. Soil Biol Biochem. 2002a;34:907–12.

Turetsky MR, Wieder RK, Halsey L, Vitt DH. Current disturbance and the diminishing peatland carbon sink. Geophys Res Lett. 2002b;29(11). https://doi.org/10.1029/2001GLO14000.

Vile MA, Scott KD, Brault E, Wieder RK, Vitt DH. Living on the edge: the effects of drought on Canada's western boreal forest. In: Tuba Z, Slack NG, Stark LR, editors. Bryophyte ecology and climate change. Cambridge, UK: Cambridge University Press; 2011. p. 277–97.

Vitt DH, Chee W-L. The relationships of vegetation to surface water chemistry and peat chemistry in fens of Alberta, Canada. Vegetatio. 1990;89:87–106.

Vitt DH, Slack NG. An analysis of the vegetation of *Sphagnum*-dominated kettle-hole bogs in relation to environmental gradients. Can J Bot. 1975;53:332–59.

Vitt DH, Wieder RK. The structure and function of bryophyte-dominated peatlands. In: Goffinet B, Shaw AJ, editors. Bryophyte biology. 2nd ed. Cambridge, UK: Cambridge University Press; 2008. p. 357–92.

Vitt DH, Halsey LA, Zoltai SC. The bog landforms of continental western Canada, relative to climate and permafrost patterns. Arct Alp Res. 1994;26:1–13.

Vitt DH, Halsey LA, Nicholson BJ. The Mackenzie River basin wetland complex. In: Fraser LH, Keddy PA, editors. The world's largest wetlands: ecology and conservation. Cambridge, UK: Cambridge University Press; 2005. p. 218–54.

Wieder RK, Vitt DH, editors. Boreal peatland ecosystems. Berlin/Heidelberg/New York: Springer; 2006.

Wieder RW, Scott KD, Kamminga K, Vile MA, Vitt DH, Bone T, Xu B, Benscoter BW, Bhatti JS. Post-fire carbon balance in boreal bogs of Alberta, Canada. Glob Chang Biol. 2008. https://doi.org/10.1111/j.1365-2486.2008.01756.x.

Yu Z, Beilman DW, Jones MC. Sensitivity of northern peatland carbon dynamics to Holocene climate change. In: Baird AJ, Belyea LR, Comas X, Reeve AS, Slater LD, editors. Carbon cycling in northern peatlands. Washington, DC: American Geophysical Union; 2009. p. 55–69.