Dissolved organic carbon in a northern boreal landscape

T. R. Moore

Department of Geography and Centre for Climate and Global Change Research, McGill University, Montreal, Québec, Canada

Received 7 February 2003; revised 13 June 2003; accepted 29 July 2003; published 4 December 2003.

[1] I examined concentrations and fluxes of dissolved organic carbon (DOC) in precipitation, upland forest throughfall, stemflow and soil water, peatland pore water, beaver ponds, and streams from May to September 1994 in the BOREAS Northern Study Area, near Thompson, Manitoba, Canada. Concentrations of DOC in precipitation were large (8 mg L^{-1}) compared to other boreal locations, possibly associated with a high incidence of local forest fires. DOC concentrations increased in throughfall, stemflow, and soil organic horizons and decreased in subsoil pore water, associated with DOC sorption. Pore water of fens and bogs contained large DOC concentrations (seasonal average 20 to 40 mg L^{-1}), similar to that observed in beaver ponds (seasonal average 19 to 38 mg L^{-1}). Streams draining three small (30 to 420 km^2) catchments contained DOC concentrations generally from 15 to 30 mg L^{-1}, with a negative correlation with discharge. For the May to September period, it was estimated that precipitation imported ~2 g DOC m^{-2}, increasing to 3 to 6 g DOC m^{-2} with passage through forest vegetation and organic horizons. DOC export in streams was estimated to be ~3 g DOC m^{-2}, controlled mainly by contributions from wetlands and beaver ponds before reaching streams. Although DOC concentrations are large, compared to other landscapes, the hydrologic pathways and the paucity of mineral subsoils for DOC sorption, and the small runoff (average 125 mm, May to September 1994 to 1996) in this continental climate (precipitation 535 mm yr^{-1}) environment results in a small export of DOC from the land surface to water bodies. *INDEX TERMS:* 1055 Geochemistry: Organic geochemistry; 1610 Global Change: Atmosphere (0315, 0325); 1615 Global Change: Biogeochemical processes (4805); 1655 Global Change: Water cycles (1836); *KEYWORDS:* dissolved organic carbon, forests, peatlands, beaver ponds, boreal

Citation: Moore, T. R., Dissolved organic carbon in a northern boreal landscape, *Global Biogeochem. Cycles*, *17*(4), 1109, doi:10.1029/2003GB002050, 2003.

1. Introduction

[2] Dissolved organic carbon (DOC) is a mixture of compounds ranging from short-chain to high molecular weight humic compounds. It is contained in precipitation, is released from plant tissues and decomposing soil organic matter, is adsorbed in mineral soil horizons, and is eventually exported from terrestrial ecosystems as mineralized carbon dioxide or in stream and rivers. *Willey et al.* [2000] estimated that global terrestrial DOC deposition in precipitation to be 0.34 Gt yr^{-1}. *Ludwig et al.* [1996] and *Aitkenhead and McDowell* [2000] estimated DOC export from rivers to the ocean to be between 0.2 and 0.4 Gt yr^{-1}, of which one quarter is derived from tundra and taiga regions, which include boreal forests and wetlands.

[3] DOC export from temperate and boreal terrestrial catchments generally ranges from 1 to 50 g m^{-2} yr^{-1}, with the largest export from catchments with a high runoff or with a high proportion of wetlands within the catchment [e.g., *Hope et al.*, 1994; *Aitkenhead and McDowell*, 2000]. *Aitkenhead and McDowell* [2000] calculated mean DOC export for catchments: taiga 0.7, cool conifer 4.2, heath/moorland 5.6, boreal/peat 6.3, and peatlands 8.5 g m^{-2} yr^{-1}. Although this export is a small component of the C budget of an ecosystem, greater internal cycling of DOC occurs within terrestrial ecosystems: Fluxes of DOC from the forest floor and organic soil horizons range between 10 and 85 g DOC m^{-2} yr^{-1}, and the subsoil fluxes range from 2 to 40 g DOC m^{-2} yr^{-1} [*Neff and Asner*, 2001]. Much of this difference is emitted as CO_2 through DOC mineralization within the soil profile. Moreover, the transport of DOC within and from ecosystems can influence soil formation and weathering, and the loss of N, P and other nutrients.

[4] *Kalbitz et al.* [2000] have reviewed the controls on the dynamics of DOC in soils, and *Neff and Asner* [2001] have proposed a model for the movement of DOC in terrestrial ecosystems. These involve the rates of production of DOC by the vegetation and the organic soil, the transport into the soil profile, the adsorption by mineral soil horizons, and eventual export from the system. Although there are several studies of DOC dynamics within individual ecosystems, such as forests and wetlands [e.g., *McDowell and Likens*, 1988; *Dalva and Moore*, 1991], few studies have examined

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Table 1. Characteristics and Location of the Sites of Measurement of DOC

Site	Location (Latitude °N, Longitude °W)	Characteristics	Measurements
		Precipitation	
Fen	55.92, 98.42	collector above tower hut	[DOC] and flux in precipitation
Jack Pine	55.93, 98.60	in sand pit	
		Uplands	
Jack Pine	55.93, 98.62	jack pine-lichen woodland, sand	[DOC] and flux in throughfall, stemflow, soil water, and seepage
Aspen	55.91, 98.50	aspen stand, clay	
Black Spruce	55.91, 98.50	young black spruce stand, clay	
		Peatlands	
Fen	55.92, 98.42	mixed shrub and herb cover with brown mosses	[DOC] in pore water from peat profiles
Collapse Fen	55.92, 98.41	dominated by sedges and *Sphagnum* mosses	
Collapse Bog	55.92, 98.40	dominated by shrubs and *Sphagnum* mosses	
		Beaver Ponds	
Jack Pine (JP)	55.95, 98.60	string of small ponds	[DOC] in water leaving or entering a sequence of ponds
Black Spruce (BS)	55.91, 98.50		
Gillam Road (GR)	55.92, 97.67	pond with well-defined inlet and outlet	
Gillam Side-road (GSR)	55.91, 97.66	string of small ponds	
Tower	55.85, 98.01	pond for CO_2 and CH_4 flux studies	
		Streams	
Sapochi River	55.91, 98.49	drainage basin area ~420 km^2	[DOC] in water and discharge from BOREAS HYD09
East Basin	55.92, 98.53	drainage basin area ~30 km^2	
West Basin	55.92, 98.38	drainage basin area ~30 km^2	

DOC in a varied landscape [*McClain et al.*, 1997], and its relevance in the overall C budget.

[5] The BOREAS project was established to develop information on the C budget of boreal landscapes, using detailed studies of sites in northern Manitoba (the Northern Study Area) and central Saskatchewan (the Southern Study Area), encompassing upland forests and wetlands [*Sellers et al.*, 1997]. The objectives of this study were to establish the sources, sinks, and fluxes of DOC within a northern boreal landscape, ranging from precipitation, upland forests, peatlands, beaver ponds, and streams and to define the relevance of DOC to the overall C budget of the system.

2. Area, Materials and Methods

2.1. Area

[6] The study area is located between Nelson House and Thompson, in northern Manitoba, between 55.5°N to 56.8°N and 97.5°W and 98.7°W. The mean annual temperature and precipitation are -3.4°C and 536 mm yr^{-1}, respectively, with May to September means of 11.1°C and 343 mm yr^{-1}. Most of the BOREAS Northern Study Area is underlain by poorly drained clay, with bedrock outcrops and well-drained sandy glacial till and kame deposits. *Rapalee et al.* [1998] recognized broad land cover types, based on landform, depth of organic matter accumulation and vegetation cover: (1) well-drained, upland sandy soils (Eluviated Dystric Brunisols, Cryochrepts) covered by jack pine (*Pinus banksiana*) and lichens [*Moore et al.*, 2000; H. Veldhuis, personal communication, 1996]; (2) moderately well-drained, upland clayey soils (Orthic Gray Luvisols, Cryoboralfs) covered by a mixture of black spruce (*Picea mariana*) and aspen (*Populus tremuloides*) [*Savage et al.*, 1997; H. Veldhuis, personal communication]; (3) imperfectly and poorly drained clayey soils (Gleyed Gray Luvisols and Luvic Gleysols, Cryoboralfs) covered by black spruce (*P. mariana*) and *Sphagnum* and other mosses on the forest floor [*Harden et al.*, 1997]; (4) peatlands ranging from palsas to peat plateau bogs, with a core of permafrost, to collapse features resulting from the thawing of permafrost [*Bubier et al.*, 1995; *Lafleur et al.*, 1997]. Where linked to the regional groundwater table, collapse fens develop, dominated by sedges and brown mosses, and where the collapse is isolated from the regional groundwater table, bogs occur, dominated by *Sphagnum* mosses and ericaceous shrubs; soils in these peatlands are mainly Typic Fibrisols (Cryofibrists), with Organic Cryosols (Cryoboralfs and Cryohemists) in areas with permafrost (H. Veldhuis, personal communication); and (5) beaver ponds with central open water surrounded by aquatic, sedge and shrub vegetation [*Roulet et al.*, 1997].

[7] In a 733 km^2 section of the BOREAS Northern Study Area, *Rapalee et al.* [1998] noted that landscape coverage was: jack pine 6%, moderately well drained spruce and aspen 21%, imperfectly and poorly drained spruce 32%, palsa 14%, fen 18%, bog 1%, and other (including open water) 8%. Beaver ponds cover between 1 and 3% of the area (N. T. Roulet, personal communication, 1996).

2.2. Materials and Methods

[8] Samples for DOC analysis were collected at weekly intervals mid-May to mid-September 1994 at sites described in Table 1. Bulk precipitation was collected in a 15-cm funnel with glass wool in the neck of the funnel to reduce particulate contamination, the glass wool being changed every 2 weeks. Throughfall was sampled in 15-cm-diameter funnels placed beneath the canopy, and stemflow was collected by wrapping tubing around stems leading into a collection bottle, with glass wool to reduce particulate

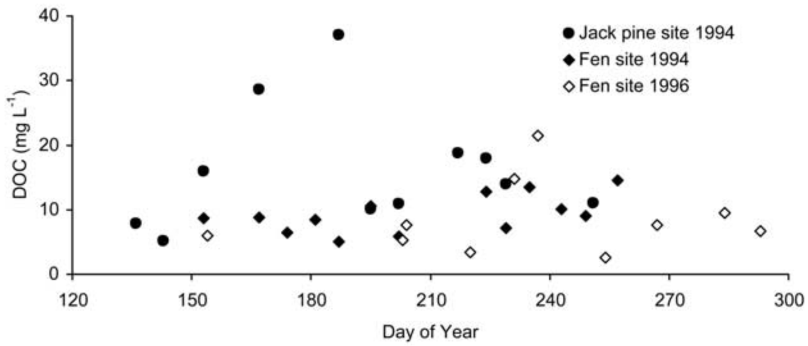

Figure 1. Concentration of DOC in precipitation collected in the open at the jack pine and fen sites.

contamination. Volumes were corrected to effective depth of throughfall and stemflow at each site. Soil water was sampled by zero tension lysimeters, similar to those used by *Jordan* [1968], installed at the base of the forest floor and in the upper part of the mineral soil. Seepage of water to the soil surface along slopes was collected at sites with clay subsoil. Peat pore water was collected at depths of 20, 50, and 90 cm from triplicate sets of piezometers at each site. Surface water was collected from three chains of beaver ponds as well as a well-defined inflow and outflow at one individual one beaver pond. Runoff DOC was determined on samples collected from the Sapochi River (drainage basin area ~420 km^2) and the East and West Basins (drainage basin areas ~30 km^2) draining the areas to the south of the Thompson-Nelson House road, as well as the stream draining the fen. At the three stream sites, BOREAS personnel measured discharge.

[9] Upon collection, the samples were filtered through Whatman GF/C paper and stored at 4°C until analyzed for DOC concentration by a Shimadzu 5050 Analyzer.

[10] Because of the dry summer, little water was collected from the subsoil lysimeters or from seepages, which dried up. To assess the ability of subsoils to adsorb DOC leached down the profile by soil water, soil samples from two sandy Brunisol profiles from the jack pine site and two clayey Luvisol profiles from the aspen site were collected. They were treated with solutions varying in their DOC concentration at 0, 10, 20, 30, 40, and 50 mg L^{-1}, prepared by soaking the forest floor and organic horizons from the aspen and jack pine sites. The DOC solutions were treated over night in a 10:1 ratio (solution: soil mass ratio) with air-dried soil samples. The null point of DOC (DOC_{np}) was calculated, the concentration at which the solution neither lost nor gained DOC, and indicates the relative strength of DOC adsorption by the soil [*Moore et al.*, 1992].

[11] Runoff from the three streams was collated from BOREAS data and a WATFLOOD model was run for the mid-May to mid-September 1994 to 1996 to estimate the monthly runoff (T. Whidden, personal communication, 2002).

3. Results

[12] Comparison with the 30-year mean from May to September revealed that 1994 was about 2°C warmer than average and received about 36% less precipitation than normal [*Savage et al.*, 1997]. In particular, August and September were dry months, with only 30% of the long-term precipitation. In 1996, it was also warmer than normal and precipitation was 15% less than the long-term average [*Joiner et al.*, 1999]. Although restricted to the May to September period, these 5 months represent most of the biological activity and runoff in this cold, continental climate.

3.1. Precipitation

[13] DOC concentration in precipitation in 1994 ranged from 5 to 37 mg L^{-1}, with the precipitation at the jack pine site generally being larger than that collected at the fen site (Figure 1). Concentrations at the jack pine site generally rose to a mid-summer peak, though those at the fen site concentration showed an increase in autumn. Precipitation was collected at the fen site in 1996 and showed similar concentrations (Figure 1). Seasonal deposition of DOC at the fen and jack pine sites in 1994 was 1.6 and 2.8 g m^{-2} (Table 2).

3.2. Uplands

[14] DOC concentrations in throughfall ranged from 13 to 20 mg L^{-1} with equivalents of 180 to 204 mm, resulting in deposition of 2.3 to 4.0 g m^{-2} (Table 2). Although DOC

Table 2. Depths, DOC Concentrations and Fluxes in Precipitation at the Jack Pine and Fen Sites, and in Throughfall and Stemflow at the Jack Pine, Aspen, and Spruce Sites and Concentrations of DOC in Forest Floor Soil Solutions and Seepage From the Mineral Soil, Collected From Mid-May to Mid-September 1994[a]

	Fen	Jack Pine	Aspen	Spruce
Precipitation, mm	208	215	–	–
Precipitation, mg L^{-1}	8.8 (2.9)	18.6 (13.5)	–	–
Precipitation deposition, g m^{-2}	1.6	2.8	–	–
Throughfall, mm	–	204	190	180
Throughfall, mg L^{-1}	–	19.9 (7.2)	20.4 (13.6)	12.5 (4.3)
Throughfall deposition, g m^{-2}	–	4.0	3.2	2.3
Stemflow, mm	–	2	19	2
Stemflow, mg L^{-1}	–	64.2 (26.0)	36.6 (19.1)	59.4 (25.1)
Stemflow deposition, g m^{-2}	–	0.6	0.7	0.2
Forest floor, mg L^{-1}	–	40.6 (17.9)	19.1 (9.5)	20.8 (10.8)
Subsoil seepage, mg L^{-1}	–	7.1 (1.8)	26.4 (11.7)	27.7 (10.3)

[a]Figures in parentheses indicate standard deviation of the concentrations.

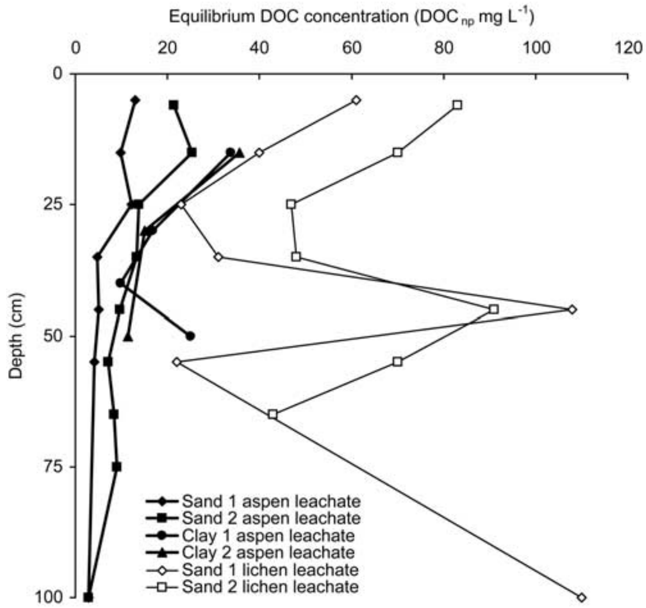

Figure 2. Variation in the DOC null point (DOC_{np}, concentration at which there is neither gain nor loss of C by the soil) from the DOC sorption experiments. The two sandy soils were collected from the jack pine site, and the two clayey soils were collected from beneath stands of aspen. Two extracts of the forest floor were used: one from the aspen site, derived from decomposing aspen leaves and humus, and the other from the jack pine site, comprising lichen and pine litter.

concentrations in stemflow were large (37 to 64 mg L^{-1}), the small volumes of stemflow resulted in a small deposition (0.2 to 0.7 g m^{-2}). Average concentrations of DOC in the soil water leachate collected at the base of the forest floor at the three forested sites ranged from 19 to 41 mg L^{-1}, and if the depth of water leaving the forest floor was about 150 mm [*Moore et al.*, 2000], this would result in a transfer of 3 to 6 g m^{-2} of DOC from the forest floor to the mineral subsoil. Seepage areas at the jack pine, aspen, and spruce sites produced water with DOC concentrations averaging 7, 26, and 28 mg L^{-1}, the latter two being water transmitted across the organic-mineral interface of the clayey soil.

[15] The ability of the sandy and clayey soils from the jack pine and aspen sites to sorb DOC varied (Figure 2). Using the DOC extract from the aspen site leaves and humus, the DOC null point (DOC_{np}) declined with depth in the four soil profiles, from 10 to 35 mg L^{-1} at a depth of 15 cm to generally <15 mg L^{-1} at a depth of 45 cm and lower. In general, the DOC_{np} concentrations of the two sandy soils were smaller than those for the two clayey soils. Treatment of the soil samples with the lichen-pine extract produced larger DOC_{np} concentrations for the sandy profiles, with greater variability with depth.

3.3. Peatlands

[16] Pore water collected from depths of 20, 50, and 90 cm at the tower fen, collapse fen, and collapse bog sites contained average DOC concentrations of between 19 and 38 mg L^{-1}, with the concentrations in the general sequence collapse bog > collapse fen > tower fen (Figure 3). Concentrations of DOC in the open-water moats, or lags, surrounding the peatlands ranged from 20 to 48 mg L^{-1}. The stream draining the tower fen contained DOC concentrations generally ranging from 15 to 20 mg L^{-1}, similar to that in the fen pore water.

3.4. Beaver Ponds

[17] DOC concentration in beaver ponds ranged from 14 to 63 mg L^{-1}, with an overall average of 24 mg L^{-1} (Figure 4). In sequences of beaver ponds, there was little overall variation within each linked sequence, though the Gillam Side Road sequence average of 28 mg L^{-1} was larger than in the other two sequences, where the averages were 20 and 22 mg L^{-1}. One beaver pond (Gillam Road) had a well-defined inflow and outflow and sampling at 10 dates showed that there was little consistent difference between inflow and outflow. There was, on average, slightly more (3 mg L^{-1}) DOC in the outflow than the inflow, though in five of the samplings the inflow DOC concentration was larger than in the outflow.

3.5. Streams

[18] DOC concentrations over the 2 years in the Sapochi River and the adjacent East and West Basin streams generally ranged from 10 to 30 mg L^{-1}, with averages (standard deviation in parentheses) of 19.0 (3.1), 18.8 (6.8), and 21.8 (8.1) mg L^{-1}, respectively. DOC concentrations generally increased in the summer but although

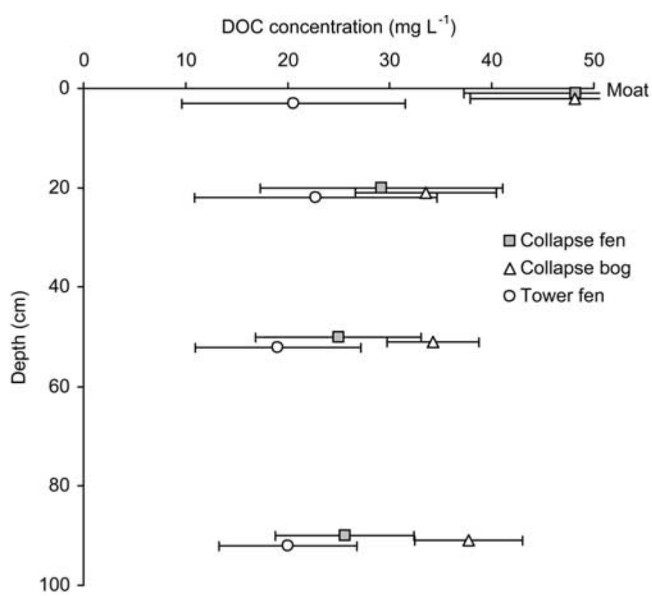

Figure 3. Concentration of DOC with depth in the pore water from the tower fen, the collapse fen, and the collapse bog. Each value represents the mean of three samples from each depth over the sampling period from early June to mid-September, with the standard deviation indicated by the error bars. The uppermost samples represent the moat at the edge of the sites.

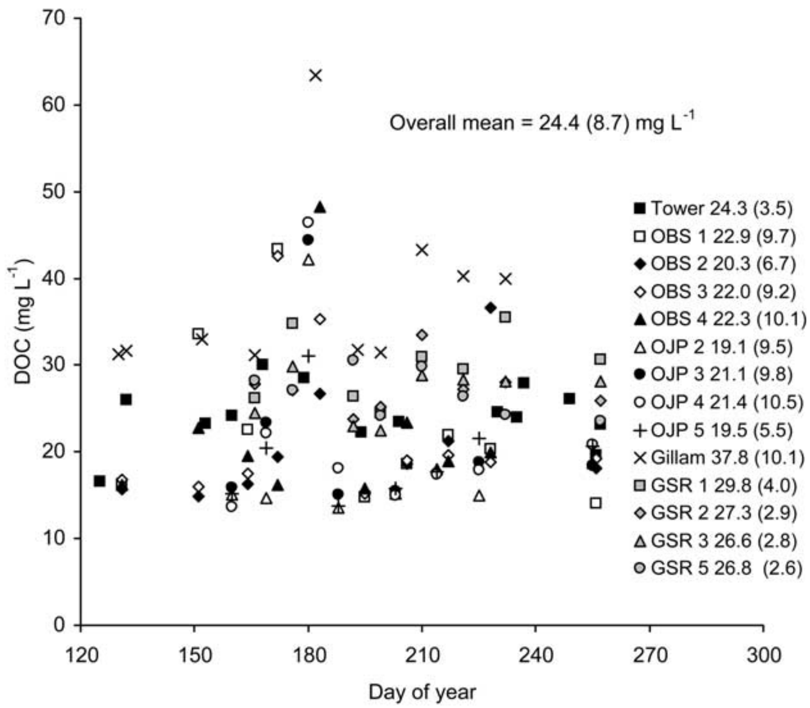

Figure 4. Seasonal variation in concentration of DOC in beaver ponds. Figures in the legend indicate the mean and standard deviation (in parentheses) of concentration in each pond.

there was a ten-fold range of discharge over the sampling period, from spring snowmelt to summer low flow, there were weak relationships between discharge and DOC concentration in the three streams, both for 1994 and for the combined 1994 and 1996 measurements (Figure 5). The estimated monthly runoff from 1994 to 1996 revealed the importance of June and July to the annual runoff and that the estimated annual runoff varied from 94 to 176 mm

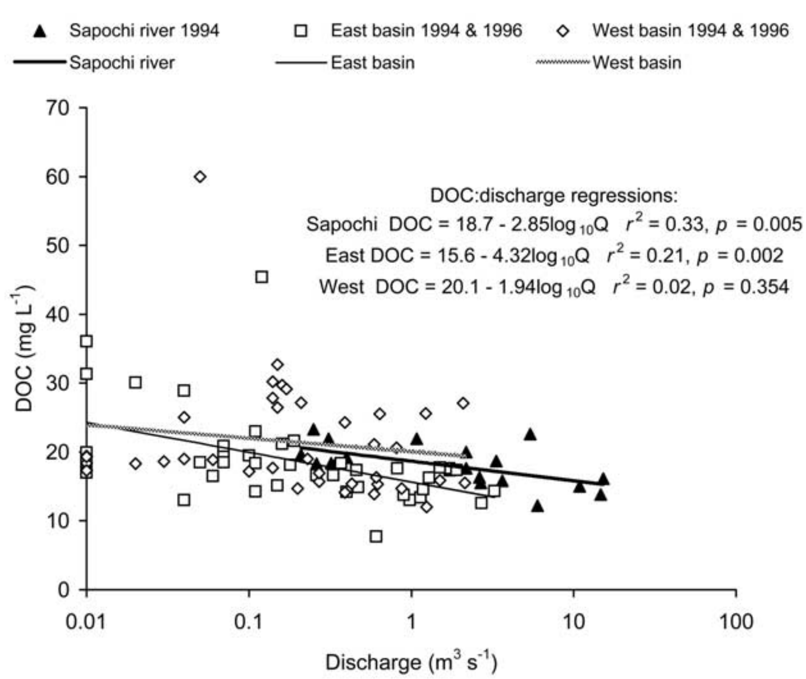

Figure 5. The relationship between discharge and DOC concentration in the Sapochi River (1994) and the East and West Basin (1994 and 1996) streams.

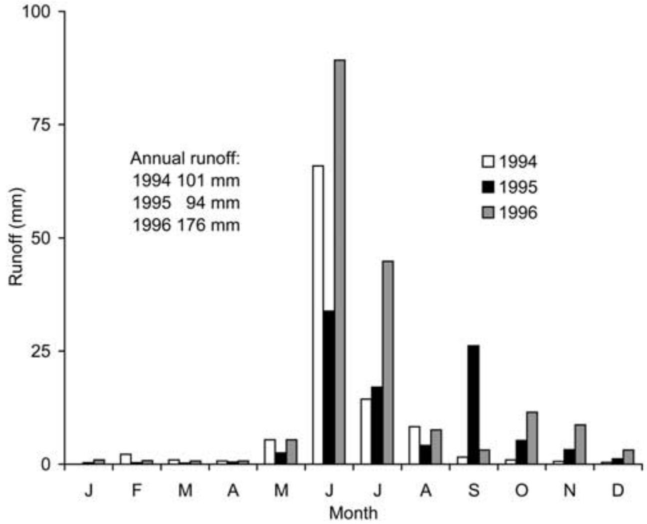

Figure 6. Modeled monthly runoff 1994 to 1996 in the Sapochi River (T. Whidden, personal communication).

in those 3 years (Figure 6). Thus export of DOC from the Sapochi River and the East and West Basin catchments ranges from 1.7 to 3.2 g m^{-2} yr^{-1}, assuming an average DOC concentration of 18 mg L^{-1}.

4. Discussion

[19] The pathways of DOC in this northern boreal landscape are summarized in Figure 7. DOC concentrations in precipitation normally range from 1 to 3 mg L^{-1} in boreal environments [*Willey et al.*, 2000; *Lindroos et al.*, 2001], substantially less than recorded in precipitation in BOREAS in 1994 and 1996. In boreal Finland, annual DOC deposition in precipitation in forests ranged from 1 to 2.5 g m^{-2} yr^{-1} [*Lindroos et al.*, 2001], compared to the 1.6 to 2.8 g m^{-2} observed from May to September 1994 at Thompson. *Willey et al.* [2000] noted that determination of DOC by high temperature combustion may involve some errors through solvent and instruments. These errors, however, are likely to be small and cannot account for the large and consistent DOC concentrations recorded in precipitation in this study.

[20] *Li et al.* [1997] reported that about 2 million ha of forest burnt during the 1994 summer, primarily in the area to the north and northwest of the NSA and that smoke was blown over the NSA. They showed that aerosol loading increased from day of year 160 through 230 (early June to mid-July), the period during which the highest DOC concentration in precipitation was recorded. *Gao et al.* [2003] observed a large concentration of water-soluble organic compounds in aerosols derived from fires in Southern Africa. Carbonaceous material typically formed half of the aerosol mass, while specific carbohydrates and organic acids constituted an average of 6% of the water-soluble fraction. The high concentrations of DOC in precipitation in the BOREAS area may result, then, from the leaching of DOC from aerosols produced by forest fires. In addition, the sample represented bulk precipitation, thus combining wet deposition, dry deposition, and the leaching of particulate matter deposited during and between precipitation events.

[21] The concentration and flux of DOC in throughfall and stemflow measured at the BOREAS sites is within the ranges and similar to the means collated in the review of temperate forests by *Michalzik et al.* [2001]: throughfall 3 to 35 (mean ~15) mg L^{-1} and 4 to 16 (mean ~10) g m^{-2}; forest floor leachate 20 to 90 (mean ~30) mg L^{-1} and 10 to 40 (mean ~22) g m^{-2}; B soil horizon 2 to 35 (mean ~15) mg L^{-1} and 1 to 20 (mean ~5) g m^{-2}; C soil horizon 1 to 16 (mean ~8) mg L^{-1} and 1 to 7 (mean ~4) g m^{-2}. In a series of boreal forest sites in Finland, *Lindroos et al.* [2001] observed DOC throughfall deposition rates of 2.5 to 7.5 g m^{-2} yr^{-1}.

[22] The DOC sorption experiment showed that in the profiles the sorption strength increased with depth in the soil profile, reducing the DOC_{np} concentrations and strength of sorption was generally greater in the sandy soils than those of a clayey texture, probably related to Fe and Al hydroxides and oxides in the sandy Brunisol soils. The sorption capacity of the soils, however, was also related to the source of the DOC, with the aspen leachate being more strongly

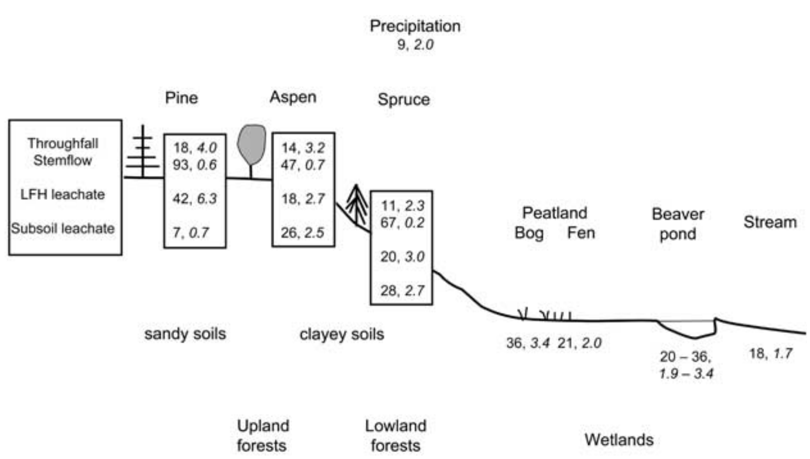

Figure 7. Summary of the concentration (mg L^{-1}) and flux (g m^{-2}) of DOC in hydrologic pathways in the northern boreal landscape, mid-May to mid-September 1994.

adsorbed by the sandy soils than the leachate from the lichen-pine site. *Moore and Matos* [1999] have shown that solutions can vary greatly in their DOC sorption characteristics and of seven samples tested the aspen leachate had the lowest DOC_{np} concentrations and the lichen-pine leachate had the highest. This is probably related to differences in the DOC chemistry, such as the hydrophobic and hydrophilic fractions [*Moore and Matos*, 1999; *Kaiser et al.*, 1996].

[23] The results of this sorption experiment cannot readily be translated into field conditions, because of the effects of temperature, soil-to-solution ratio, soil storage, and DOC concentration and chemistry. The results show, however, that concentrations of DOC will decrease as the soil solution passes through the soil profile, especially in the sandy upland soils. This explains the pronounced decrease in DOC concentration between the forest floor and subsoil seepage in the sandy jack pine soils (from 40 to 7 mg L^{-1}). There was little change between forest floor concentration and that of the seepage at the aspen and spruce sites, because of the more limited DOC sorption capacity of the clayey soils and their low permeability, so that much of the runoff will pass across the surface of the mineral soil.

[24] DOC concentrations in the peatlands were similar to those observed in other northern peatlands, with a general increase from fen to bog sites [*Fraser et al.*, 2001; *Moore et al.*, 2003]. As runoff from peatlands does not generally pass through mineral soils, these high DOC concentrations are supplied to beaver ponds and streams and increase the DOC export from the landscape.

[25] Although their coverage is generally small, beaver ponds play a disproportionately large role in C cycling and biogeochemistry in boreal landscapes [e.g., *Naiman et al.*, 1986, 1994; *Roulet et al.*, 1997; *Dove et al.*, 1999]. Concentrations of DOC are large in Thompson beaver pond water (average 24 mg L^{-1}), but there is little apparent increase in DOC concentration as the water passes through a beaver pond, or a chain of beaver ponds, despite the large amount of organic sediment and debris on base of beaver ponds. This pattern was also observed by *Naiman et al.* [1986] in beaver ponds near Sept-Iles, eastern Quebec. Although the organic sediments on the beaver pond floor may release DOC to the water column, photolysis and microbial utilization may reduce DOC concentrations. *Bourbonniere et al.* [1997] showed that CO production in a beaver pond near Thompson was restricted primarily to the top 5 to 10 cm, from water containing 26 to 29 mg DOC L^{-1}. *Granéli et al.* [1988] estimated that an average of 2.4% of DOC in surface water from Swedish lakes, containing up to 20 mg DOC L^{-1}, could be converted to dissolved inorganic carbon (DIC) over 6 hours under full-light around solar noon in a similar latitude to Thompson. Thus, with average [DOC] of 25 mg L^{-1} and 5 cm depth of light penetration, about 30 mg m^{-2} d^{-1} of DOC could be converted to DIC daily and degassed from the beaver pond surface. There is also evidence that UV light increases the bio-availability of DOC in surface waters, leading to a further decrease in DOC concentration as water passes through the beaver pond [*Lindell et al.*, 1996].

[26] The seasonal fluxes of DOC in this northern boreal landscape are small compared to the fluxes of C in net primary productivity of forests, 200 to 380 g C m^{-2} [*Gower et al.*, 1997], and wetlands, 160 to 430 g C m^{-2} [*Trumbore et al.*, 1999], and the accumulation of organic C in upland soils, −22 to 68 g C m^{-2} yr^{-1} [*Rapalee et al.*, 1998], and wetland soils, 10 to 55 g C m^{-2} yr^{-1} [*Trumbore et al.*, 1999]. The fluxes of DOC, between 2 and 8 g m^{-2}, are also small compared to other landscapes [*Aitkenhead and McDowell*, 2000; *Michalzik et al.*, 2001]. Soil C:N ratios in the surface horizons of the NSA ranges from 25:1 to 90:1 in deciduous and coniferous forests respectively [*Savage et al.*, 1997], and 20:1 to 100:1 in rich fens and bogs respectively [*Trumbore et al.*, 1999]. The global relationship between soil C:N ratio and DOC export reported by *Aitkenhead and McDowell* [2000] suggests that DOC export from this landscape should be between 3.6 (C:N ratio 20:1) and 18.2 (C:N ratio 50:1) g C m^{-2} yr^{-1}, much larger than observed. Although there is no major terrestrial sink of DOC, apart from the sandy subsoils beneath jack pine covering 6% of the area, there is limited biological productivity and water movement resulting in small DOC fluxes. This contrasts with landscapes such as the Amazon, for example, where DOC production and transport is large and upland soils have the capacity to sorb DOC [*McClain et al.*, 1997].

[27] **Acknowledgments.** The author gratefully acknowledges the field support of Michele Culhane, Lianne Bellisario, Jill Bubier, and Kathleen Savage and the laboratory assistance of Mike Dalva and Laud Matos. Ted Whidden graciously provided information and estimates of the water budget for the Northern Study Area, arising from work of the BOREAS hydrology group of Rick Soulis and Nick Kouwen (University of Waterloo). Nigel Roulet kindly commented upon on an early draft of the manuscript. The project was funded by the Natural Sciences and Engineering Research Council of Canada, and the BOREAS program.

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T. R. Moore, Department of Geography and Centre for Climate and Global Change Research, McGill University, 805 Sherbrooke Street West, Montreal, Québec, Canada H3A 2K6. (tim.moore@mcgill.ca)