New Zealand Journal of Marine and Freshwater Research, 2007, Vol. 41: 137–141

0028–8330/07/4101–0137

Short communication

Dissolved organic carbon in New Zealand peatlands

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Abstract We determined the concentration of dissolved organic carbon (DOC) and the specific ultraviolet absorbance (SUVA) of 193 samples of water collected from groundwater, porewater, drainage ditches, and streams at peatlands in New Zealand. There was a wide range in DOC concentration (from 7 to 184 mg litre^{-1}), with the smallest concentrations in peatlands where there appeared to be large amounts of iron. Concentrations were large (generally >50 mg litre^{-1}) in ombrotrophic (rain-fed) peatlands and reached the highest values (averaging 81 to 129 mg litre^{-1}) in water collected from the Torehape peatland (Waikato region), which is undergoing drainage and harvesting for peat and post-harvest restoration. These high DOC concentrations suggest that New Zealand peatlands export 10 to 50 g DOC m^{-2} yr^{-1}, a significant part of the overall carbon budget of peatlands. Most SUVA measurements ranged from 1.5 to 3.5 litre/mg DOC^{-1}/m^{-1}) and suggest that the DOC contains 12 to 25% aromatics.

Keywords DOC; peatlands; bog; fen; peat harvesting; SUVA

M06052; Online publication date 15 March 2007
Received 19 August 2006; accepted 22 December 2006

INTRODUCTION

Dissolved organic carbon (DOC) plays an important role in wetlands: concentrations are high compared to terrestrial soils and DOC influences porewater pH and nutrient and metal availability/toxicity (Thurman 1985). There can be a significant loss of C through run-off from the ecosystem DOC; DOC affects downstream ecosystems and chlorination of DOC-rich water can result in the production of carcinogens (Thurman 1985).

There is an absence of knowledge on DOC concentrations and chemistry in wetlands, particularly peatlands, of New Zealand, though work has been done on upland systems draining into streams (e.g., Findlay et al. 2001; Huryn et al. 2001; Riley et al. 2003). Collier et al. (1989) and Moore & Jackson (1989) examined DOC concentrations and fluxes in Westland (South Island) catchments containing Pakihi poorly drained soils, noting high DOC concentrations and export (30 to 38 mg litre^{-1} and 31 to 44 g m^{-2} yr^{-1}, respectively) and an increase in export with catchment drainage for forestry, in contrast to export of 8 to 21 g m^{-2} yr^{-1} in nearby upland forested and harvested sites (Moore 1989). In the Northern Hemisphere, several studies have recorded high DOC concentrations within peat porewaters and the concentration in streams is often closely related to the proportion of peatland within the catchment (e.g., Eckhardt & Moore 1990; Koprivnjak & Moore 1992; Mattson et al. 2005).

In New Zealand, peatlands cover c. 4000 km^2 (Rydin & Jeglum 2005), though widespread drainage and use has resulted in only 670 km^2 retaining native vegetation (P. Gerbeaux, Department of Conservation, and A. Ausseil, Landcare Research pers. comm.). The objective of this research was to produce an initial assessment of DOC in New Zealand peatlands and their drainage waters, by sampling of porewater, streams and drainage ditches to determine the DOC concentration and to examine the variation in DOC chemistry, through the specific ultraviolet absorbance (SUVA).

MATERIALS AND METHODS

Water samples were collected in February and March 2006, from peatlands at: Torehape (reserve and adjoining peat mine), Kopuatai, Whangamarino, and Opuatia (Waikato); Tongariro National Park (central North Island); and Awarua, Borland, Dunearn, and Pukerau (Southland) (Table 1). All the peatlands were classified as bogs (raised or blanket) according to Johnson & Gerbeaux (2004) and had undisturbed vegetation and hydrology except Dunearn, which had been partially drained, and Torehape, which had drained, harvested, bare and revegetated sections. Groundwater was collected from the water-table surface or from piezometers placed beneath the water table. Samples from the upper 25 cm layers of the peat were collected by digging shallow holes, or by gently squeezing the peat and collecting the expelled water. Samples were also collected from open water bodies, such as upland streams and pools, and from drainage ditches and streams within and leaving the peatland. After collection, the samples were stored at 4°C and filtered through Macherey-Nagel 85/90 glass-fibre filter papers, with a retention of 0.5 μm.

DOC concentration was determined on a Shimadzu TOC-5000 analyser after acidification of the sample. SUVA was derived from absorbance at a wavelength of 254 nm measured on a Shimadzu UV-160A spectrophotometer with a 1 cm quartz cell. SUVA is the absorbance per unit of DOC (mg litre^{-1}).

RESULTS AND DISCUSSION

Concentrations of DOC in all samples ranged from 7 to 184 mg litre^{-1} (Table 1), with an average of 60 mg litre^{-1} (± 42 SD). SUVA in peatland porewater and streams/ditches ranged from 0.7 to 6.3 litre/mg DOC^{-1}/m^{-1}, with an average of 2.7 litre/mg DOC^{-1}/m^{-1} (± 0.9 SD).

Some of the smallest DOC concentrations were recorded in samples from the water table collected at three small peatlands in Tongariro National Park (Table 2). There, the overall average was 15 mg litre^{-1} with concentrations decreasing slightly from the outer, drier edges of the peatlands to the central, waterlogged and sedge-dominated sections (Table 2). DOC concentrations in streams draining the peatlands were also low, as were those draining nearby upland soils (Table 1). These low concentrations may be related to the occurrence of high concentrations of iron in these peatlands, washed in by groundwater from the surrounding upland soils, or from weathering of the iron-rich, easily weathered rocks beneath the peatland. The oxidation of iron at the water table was shown by reddish brown flocs, particularly in the central, waterlogged section of the peatlands (T. R. Moore pers. obs.). The influence of iron oxidation on DOC, through sorption on the oxide surface, has been noted elsewhere (e.g., Moore 1987, 1988; McKnight et al. 1992; Moore et al. 1992) and results in low DOC concentrations and export from iron-rich catchments (e.g., Koprivnjak & Moore 1992). Groundwater in New Zealand contains varying but generally high

Table 1 Dissolved organic carbon (DOC) concentration (mg litre^{-1}) and specific ultraviolet absorbance (SUVA, litre/mg DOC^{-1}/m^{-1}) (mean ± SD) in peat porewater and streams/ditches by location, and of upland streams.

Site	Location	Latitude/ longitude	*n*	DOC	SUVA
Waikato	Kopuatai	37°24′S 175°33′E	12	53.0 ± 37.7	2.98 ± 0.87
	Torehape peat mine	37°19′S 175°27′E	49	109.4 ± 198	2.05 ± 0.45
	Torehape reserve	37°20′S 175°28′E	4	70.3 ± 9.2	2.76 ± 0.36
	Opuatia	37°26′S 175°04′E	41	32.1 ± 25.4	2.79 ± 0.83
	Whangamarino	37°18′S 175°08′E	14	91.4 ± 35.5	2.01 ± 0.46
Central North Island	Tongariro National Park	39°10′S 175°23′E	28	15.0 ± 5.8	3.23 ± 1.38
	Te Ponanga	39°00′S 175°44′E			
	Ketetahi	39°04′S 175°34′E			
	National Park	39°11′S 175°24′E			
Southland	Awarua	46°35′S 168°30′E	39	49.8 ± 18.6	3.10 ± 0.75
	Borland	46°45′S 167°30′E			
	Dunearn	46°00′S 168°10′E			
	Pukerau	46°09′S 169°15′E			
Upland streams at Tongariro National Park and Southland	Tongariro – 3 streams Borland – 3 streams	39°11′S 175° 24′E 45°45′S 167° 30′E	6	10.8 ± 6.8	1.68 ± 1.12

concentrations of iron, with median values ranging from 0.1 to 1.1 g m^{-3} (Daughney 2003).

Within the Waikato region, DOC concentrations were high in Whangamarino, Torehape reserve and Kopuatai peatlands, with average values of 91.4, 70.3, and 53.0 mg $litre^{-1}$, respectively (Table 1). The highest DOC concentrations were observed at the Torehape peat mine, averaging 109.4 mg $litre^{-1}$ (Tables 1 and 3). Ditches in the harvested and restored northern section of the mine had higher DOC concentrations than those in the southern, recently harvested section (126.6 and 81.1 mg $litre^{-1}$, respectively), though the water table in non-harvested areas also contained high DOC concentrations (116.5 mg $litre^{-1}$). As the restored section ditches generally contained more vegetation than those in the southern, recently harvested ditches, these DOC differences may have arisen from the vegetation within the ditch. However, a comparison of vegetated and non-vegetated ditches in the restored area showed that this is unlikely with average DOC concentrations of 128.6 and 126.9 mg l^{-1}, respectively. Samples collected from the Opuatia peatland contained smaller concentrations of DOC, with an average of 32.1 mg $litre^{-1}$, probably because of the relatively strong influence of DOC-poor groundwater in this system (C. Fritz pers. comm.). Concentrations of DOC from peatlands in Southland averaged 49.8 mg $litre^{-1}$, within a range of 21 to 97 mg $litre^{-1}$.

Caution should be exercised in comparing results, as there was usually only one-time sampling (in February or March at the end of summer and during a dry period, apart from Southland), the samples represent a variety of water types and sampling methods (streams, ditches, mixed water table, piezometers, and squeezed by hand) and degrees of disturbance (established piezometers, piezometers installed just before sampling, water seeping into holes dug into the peat). We likely sampled when DOC concentrations reached their peak. For example, stream DOC concentrations in Westland catchments during the winter were two-thirds to three-quarters of those observed during the summer (Moore 1989; Moore & Jackson 1989).

Differences in origin of plant material and decomposition pathways to produce DOC may result in differences in DOC chemistry (Thurman 1985). SUVA has recently been used as an index of the aromatic nature of DOC, with increasing SUVA correlating with increasing proportion of aromatics (Weishaar et al. 2003). It has been tested on a narrow range of natural waters and may be confounded by high concentrations of nitrate and iron, which absorb at 254 nm (Weishaar et al. 2003). The SUVA of most of the New Zealand peat water samples fell in the range of 1.5 to 3.5 litre/mg DOC^{-1}/m^{-1} (Table 1), which corresponds to between 12 and 25% aromatics in the sample (Weishaar et al. 2003). In general, there were few consistent differences in SUVA among the samples (Tables 1 to 3). SUVA values were lowest at the Torehape site, which may be related to the very high DOC concentrations and the possibility of non-linear absorbance at high DOC concentrations. The highest SUVA values were found in samples from Tongariro National Park, which may be associated with high iron concentrations (Weishaar et al. 2003).

Table 2 Dissolved organic carbon (DOC) concentration (mg $litre^{-1}$) and specific ultraviolet absorbance (SUVA, litre/mg DOC^{-1}/m^{-1}) (mean ± SD) in peat porewater at dry edge and wet central position and outlet streams in peatlands at Tongariro National Park, New Zealand.

Position	*n*	DOC	SUVA
Dry edge	13	18.8 ± 6.4	3.51 ± 1.55
Wet centre	10	11.5 ± 2.3	2.97 ± 1.40
Streams	3	13.0 ± 3.9	3.28 ± 0.70
Upland streams	3	5.62 ± 1.3	1.88 ± 1.47

Table 3 Dissolved organic carbon (DOC) concentration (mg $litre^{-1}$) and specific ultraviolet absorbance (SUVA, litre/mg DOC^{-1}/m^{-1}) (mean ± SD) in non-harvested water table, harvested and restored ditches, and restored non-vegetated and vegetated ditches at Torehape mine site, Waikato region, New Zealand.

Position	*n*	DOC	SUVA
Non-harvested peat field: water table	7	116.5 ± 15.3	1.84 ± 0.21
Harvested section: ditch	17	81.1 ± 10.2	2.48 ± 0.24
Restored section: ditch	25	126.6 ± 27.6	1.83 ± 0.40
Non-vegetated	11	126.9 ± 29.7	1.82 ± 0.41
Vegetated	11	128.6 ± 23.2	1.78 ± 0.36

As in temperate regions of the Northern Hemisphere, New Zealand peatlands contain large DOC concentrations (generally 10 to 100 mg $litre^{-1}$, mainly at the lower end), in porewater and in the streams and ditches draining them. Run-off rates range from 400 to 1000 mm yr^{-1}, based on annual precipitation and evaporation rates of 400 to 700 mm yr^{-1} (D. I. Campbell pers. comm.), in most of the New Zealand peatland regions. Thus, export of DOC would be between and 10 and 50 g m^{-2} yr^{-1}, allowing for dilution in run-off events and during the winter. This DOC export is a substantial portion of the overall C budget of peatlands and in some instances may be similar to carbon accumulation rates of 34–200 g m^{-2} yr^{-1} (Schipper & McLeod 2002; Nieveen & Schipper 2005). Given the current coverage of peatlands (c. 4000 km^2), they contribute c. 50 000 tons of DOC yr^{-1} to New Zealand aquatic systems, such as lakes and streams.

Ombrotrophic (rain-fed) peatlands appear to have some of the highest DOC concentrations (50 to 100 mg $litre^{-1}$), possibly because of an absence of DOC immobilisation by iron or base cations associated with groundwater flow. Although restricted to only one site at Torehape, it appears that disturbance of the peatland for harvesting and restoration activities can elevate DOC concentrations, possibly associated with faster rates of peat decomposition and thus DOC production under these drained conditions.

ACKNOWLEDGMENTS

We thank Maja Vojvodic-Vukovic and Landcare Research Massey laboratory for technical expertise and analysis. Neil Fitzgerald, Nick Singers, Brian Rance, and Gay Munro assisted in the field, and Christian Fritz supplied some of the Southland samples. This research was funded by the New Zealand Foundation for Research, Science and Technology (Landcare Research Maintaining and Restoring Wetlands project C09X0508; The University of Waikato Freshwater Restoration OBI UOW X0505), and a Royal Society of New Zealand International Science and Technology Linkages grant (ISAT contract B05-20).

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