Estimating the Impact of Seawater on the Production of Soil Water-Extractable Organic Carbon during Coastal Erosion

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The production of water-extractable organic carbon (WEOC) during arctic coastal erosion and permafrost degradation may contribute significantly to C fluxes under warming conditions, but it remains difficult to quantify. A tundra soil collected near Barrow, AK, was selected to evaluate the effects of soil pretreatments (oven drying vs. freeze drying) as well as extraction solutions (pure water vs. seawater) on WEOC yields. Both oven drying and freeze drying significantly increased WEOC release compared with the original moist soil samples; dried samples released, on average, 18% more WEOC than did original moist samples. Similar results were observed for the production of low-molecular-weight dissolved organic C. However, extractable OC released from different soil horizons exhibited differences in specific UV absorption, suggesting differences in WEOC quality. Furthermore, extractable OC yields were significantly less in samples extracted with seawater compared with those extracted with pure water, likely due to the effects of major ions on extractable OC flocculation. Compared with samples from the active horizons, upper permafrost samples released more WEOC, suggesting that continuously frozen samples were more sensitive than samples that had experienced more drying–wetting cycles in nature. Specific UV absorption of seawater-extracted OC was significantly lower than that of OC extracted using pure water, suggesting more aromatic or humic substances were flocculated during seawater extraction. Our results suggest that overestimation of total terrestrial WEOC input to the Arctic Ocean during coastal erosion could occur if estimations were based on WEOC extracted from dried soil samples using pure water.

Dissolved organic carbon (DOC) plays an important role in the biogeochemical cycles of carbon and bioactive elements in aquatic environments (Anderson, 2002; Hedges, 2002). The production of DOC from tundra soils, degrading permafrost, and peatlands may represent an important flux under conditions of ongoing arctic warming (Frey and Smith, 2005; Guo and Macdonald, 2006). However, detailed production pathways of soil DOC in a changing climate are poorly understood. Studies on DOC in different ecosystems have mainly utilized temperate-region forest soils (Chantigny, 2003); few studies have been published on Arctic soils (Michaelson and Ping, 1996). Compared with other ocean basins, the Arctic Ocean receives high terrestrial inputs of freshwater and organic C on a volume basis (Dittmar and Kattner, 2003). Basic pathways of terrestrial input consist of river and direct coastal erosion (Anderson, 2002; Stein and Macdonald, 2004). Tundra soils along the arctic coastline store vast amounts of organic C and ice-wedge polygons (Jorgenson and Brown, 2005). Although Arctic coastal erosion is limited to the short summer season, mass wasting rates of 2 to 6 m yr^{-1} have commonly been found along steep slopes at the coastal edge (Brown et al., 2003). If the mean annual temperature continues to increase or the summer season continues to lengthen, as has been hypothesized (Osterkamp, 2003; Chapin et al., 2005; Jorgenson et al., 2006), the magnitude of permafrost degradation and coastal and riverbank erosion may increase, increasing the total export of terrestrial DOC to the Arctic Ocean (Guo et al., 2007).

Thus accurate measurement of the amount of soil DOC is important to study the role that terrestrial DOC plays in global C balance models. Methods used for soil DOC extraction may affect measurements of DOC quantity and attributes (Haynes, 2005). Dissolved organic C is generally measured in extracted soil solutions or saturation paste extracts (Burford and Bremner, 1975). Compared with moist samples, dried samples are easier to store, transport, and handle in the laboratory. Due to spatial variation of soil components in tundra soils caused by cryoturbation or freeze–thaw activity, the advantages of using dried soil samples may be even greater, especially for upper

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Abbreviations: DOC, dissolved organic carbon; EC, electrical conductivity; HMW-DOC, high-molecular-weight dissolved organic carbon; LMW-DOC, low-molecular-weight dissolved organic carbon; SOC, soil organic carbon; SUVA, specific UV absorption; WEOC, water-extractable organic carbon.

permafrost than for soils in temperate regions. However, many studies have shown that air drying soils before DOC extraction results in a substantial increase of water-extractable organic carbon (WEOC) concentration (Lundquist et al., 1999; Haynes, 2000; Chow et al., 2006). One mechanism proposed for the increased WEOC is the lysis of microbial biomass by desiccation (West et al., 1992). In addition, Haynes and Swift (1991) suggested that a cycle of drying and wetting results in disruption of soil organo-mineral associations, with the subsequent release of some of the low-molecular-weight (LMW) humic components. Bolan et al. (1999) reported that freeze drying had no effect on WEOC production compared with both air drying and oven drying, both of which increased WEOC release. Although tundra soils experience natural freeze–thaw cycles, it is still unclear whether freeze drying is more appropriate for tundra soils than air- or oven-drying.

In addition, factors that affect the behavior of DOC in solution also impact DOC measurement. In general, DOC is measured when the solution has reached equilibrium between absorption and desorption. Therefore, factors that promote DOC coagulation such as increasing ionic strength and more polyvalent ions may decrease DOC concentration at equilibrium. Using a flocculation technique in the study of the molecular-size distribution of DOC, Römkens and Dolfing (1998) reported that the amount of extracted DOC decreased with increased extraction solution concentrations of Ca^{2+} (0–10 mM) and the maximum decrease in DOC concentration could reach 50% of the initial DOC (60–90 mg C L^{-1}). The coastal Arctic Ocean seawater contains high concentrations of major ions, such as Ca^{2+}, Mg^{2+}, Na^+, Cl^-, and SO_4^{2-}, although salinity (31 g kg^{-1}) is slightly lower than that of offshore seawater (Guéguen et al., 2005). Therefore, pure water or the commonly used 0.5 M K_2SO_4 extraction of WEOC may overestimate the "real" DOC and, consequently, overestimate potential DOC input to the ocean from coastal erosion. Moreover, the molecular-weight composition of terrestrial DOC may be altered by major ions present in seawater. However, little information is available on the direct impact of seawater on the production of soil WEOC during coastal erosion. Quantitative estimation of soil WEOC yields during coastal erosion is critical for a better understanding of the flux, C budget, and ecological function of this WEOC. The objectives of this study were to evaluate: (i) impacts of soil pretreatments (oven drying vs. freeze drying) on WEOC quantity and quality; and (ii) effects of different extraction solutions (pure water and seawater with different salinities) on measurement of quantity and properties of WEOC from a tundra soil collected in northern Alaska.

Materials and Methods

Soil Sampling Sites

Barrow, AK, has a cold, maritime climate. Winters are long, dry, and cold, and summers are short, moist, and cool. The mean air temperature is –12°C; on average, July is the warmest month at 4.7°C, and February is the coldest at –26.6°C (The Alaska Climate Research Center, 2006). Mean annual precipitation is

124 mm, 40% of which falls as rain during July and August. The winter snow pack averages 20 to 40 cm, but snow accumulation on the landscape is highly variable because of variation in terrain roughness and drifting due to strong easterly winds. The vegetation communities belong to Bioclimate Subzone C with vegetation dominated by wetland species including sedges (*Carex aquatilis, Eriophorum triste, E. Scheuchzeri),* grasses (*Arctophila fulva, Alopecurus alpinus, Dupontia fisheri*), and mosses (Anonymous, 2000). The landform is dotted by thaw lakes and dominated by frost polygons that occupy nearly 80% of the land surface. In the upper 2 m, ice may occupy up to 20% of the total volume of the soil.

Soil samples were collected from a bluff (71°19′ S, –156°34′ E) along the coastline of Elson Lagoon in the Beaufort Sea portion of the Arctic Ocean, near Barrow, AK, in August 2005. The soil was classified as coarse-loamy, mixed, nonacid, pergelic Ruptic Histoturbel. The bluff was elevated about 3 m above sea level, and thawed soil was removed from the exposure before sampling. The active horizon depth was about 50 cm, judged from cryogenic structure (Hoefle et al., 1998). Soil horizon sequence was recorded as Oe (0–5 cm), Bw (5–20 cm), Oajj (20–50 cm), and Oejj/Bgf (50–75 cm). The active horizon and frozen samples were collected using a knife and cordless power drill, respectively. For each horizon, duplicate soil samples were collected 50 to 100 cm apart. Once collected, soil samples from the thawed active horizon were stored at 4°C in a refrigerator, while samples from the permafrost were kept frozen. Temperatures for oven-dried and freeze-dried soil samples were 50 and –50°C, respectively. After drying, the samples were manually ground to pass a 2-mm screen.

Measurements of Soil Properties

Soil texture was analyzed using the hydrometer method (Gee and Bauder, 1986). Soil pH was measured in water suspension (1:10). Soil water content was measured using weight differential at 105°C. Total organic C of soil samples was measured according to the method of Guo et al. (2004). Briefly, freeze-dried samples were finely ground in a commercial grinder to pass through a 50-μm sieve. Soil samples (about 0.5–40 mg, depending on the C concentration) were weighed into Sn foil capsules. Carbon content was determined using an elemental analyzer (Carlo Erba EA-1108, Lakewood, NJ, USA). The electrical conductivity (EC) was measured by electroconductivity cell and meter (YSI Model 35) performed on a saturated soil paste extract according to Rhodes (1982).

Soil Sample Pretreatments and Ionic Strength on Water-Extractable and Low-Molecular-Weight Organic Carbon

Soil WEOC was extracted with pure water with a background DOC concentration of ?2 μM using a soil/water ratio of 5:50 (mass/volume) for ground oven-dried, freeze-dried, and original moist soil samples. Soil suspensions were shaken at 2.5 reciprocal excursions per second for 2 h. Then, suspensions were centrifuged at relative centrifugal force of 5590 × *g* for two 10-min bouts. The supernatant was then filtered through a 0.7-μm glass fiber filter (Whatman, Springfield

Mill, UK). Filter paper was pre-combusted at 450°C for 5 h and rinsed with 20 mL pure water before use. The WEOC solutions were acidified immediately for DOC measurement.

Water-extractable organic C was further size-fractionated into LMW and high-molecular-weight (HMW) DOC fractions using ultrafiltration as described in Guo and Santschi (1996). In brief, WEOC was filtered using a stirred-cell ultrafiltration unit (Amicon 8050) and a 3 kDa membrane. Therefore, the HMW-DOC is operationally defined here as the 3 kDa to 0.7-µm fraction, while the LMW-DOC is the <3 kDa fraction.

To examine the effects of ionic strength on WEOC yield, WEOC was extracted from freeze-dried soil with seawater solutions of different salinities, following the procedures described above. Natural seawater (pH 8.2) collected from offshore Barrow, AK, was treated by UV irradiation (450W, ACE UV lamp Model 7480) overnight to remove background DOC before soil DOC extraction (Chen et al., 2004). Extraction solutions consisted of original seawater and 50 and 25% seawater solutions created by dilution with pure water. These solutions had specific conductivities of 5.89, 3.93, and 1.96 S m^{-1}, respectively. In addition, three soil/solution ratios, 1:5, 1:10, and 1:20 (mass/volume), were used to test the effect of different soil/solution ratios on organic C extraction.

Total WEOC and LMW-DOC concentrations were determined by the high-temperature combustion method with a Shimadzu TOC-V analyzer (Guo et al., 1994). To reduce the effects of concentration differences, all WEOC samples were diluted to ~1.0 mg/L before UV measurement. Specific absorption at 280 nm was measured with a UV spectrophotometer (Agilent 4835) to estimate the aromaticity of the water-extractable organic matter (WEOM) (Chin et al., 1994).

Statistical Analysis

Because this study focused on methodology evaluation, soil samples from different horizons rather than whole soil profiles were used. Treatments included soil pretreatments (oven-drying, freeze-drying, and field-moist soil samples), extract solutions (four levels), and soil/solution ratio (three levels). The replication for all treatments was two. Differences in DOC, LMW-DOC, and UV among drying methods were tested using a one-way or two-way ANOVA. Separation of means among treatments was made by LSD. A $p < 0.05$ was considered significant. Equal variance was tested by Levene's test. Data were analyzed using SPSS (SPSS, 2001).

Table 1. Properties of soil samples by horizon. EC, SOC, and WEOC refer to electric conductivity, soil organic C, and water-extractable organic C, respectively.

Soil horizon	Particle-size distribution			pH	EC	SOC	Water content
	Sand	Silt	Clay				
	——g kg^{-1}——				S m^{-1}	——g kg^{-1}——	
Oa	NA†	NA	NA	5.2	3.3	340.2	2090
Bw	500	308	192	4.9	4.8	21.3	1670
Oajj	NA	NA	NA	5.4	8.3	166.5	1910
Oejj/Bgf	632	292	76	5.6	40.8	69.8	5020

† Not available.

Results

Soil Properties

The soil horizons sampled for this study include the three from the active horizon (Oe, Bw, and Oajj) and the upper permafrost (Oejj/Bgf). The texture of the Bw and Oejj/Bgf horizons was sandy loam (Table 1). The Oe and Oajj horizons had texture of peaty muck and muck, respectively. Soil pH values ranged from moderately to slightly acid (pH 4.9–5.6). Soil water content ranged from 170 to 5020 g kg^{-1}. Saturated paste extracts of all soil horizons had low EC except those of the lowermost horizons. There was a large variation in SOC concentration among different soil horizons (Table 1). The Oe horizon had the greatest SOC (340 g C kg^{-1} soil), followed by the Oajj and Oejj/Bgf horizons with the lowest in the Bw horizon (2.0 g C kg^{-1} soil).

Drying Effects on Water-Extractable Organic Carbon and Its Size Fractions

Soil pretreatments significantly affected the amount of WEOC ($p = 0.002$) (Fig. 1). The DOC yields were higher for both freeze-dried and oven-dried samples than for original moist samples for all soil horizons, indicating that dried samples produced higher WEOC during soil extraction. Compared with the original moist soil samples, WEOC of all dried soil samples averaged 18% higher across all horizons. Although oven-dried samples released more WEOC than did freeze-dried samples, the difference was not statistically significant.

Similar to bulk WEOC, the production of LMW-DOC was greater in dried samples than in original moist samples for all four horizons. Compared with the original moist samples, the LMW-DOC yield was 14 and 32% greater for freeze-dried and oven-dried samples, respectively. In addition, oven-dried samples also produced more LMW-DOC than did freeze-dried samples, but again the difference was not statistically significant. Within the bulk soil WEOC pool, LMW-DOC comprised 25 to 37% of WEOC, with the higher fractions of LMW-DOC generally found at greater depths (Fig. 1).

Specific UV absorption (SUVA) by WEOC was also significantly affected by sample pretreatments ($p < 0.001$) (Fig. 1). Drying the samples significantly decreased the SUVA of WEOC from all samples; however, different soil horizons responded differently. The greatest decrease was observed for samples from the mineral horizon (Bw); the smallest decrease was observed for samples from the upper permafrost (Oejj/Bgf). Samples from the two organic horizons in the active layer had similar SUVA. In addition, drying methods also affected SUVA of WEOC. In general, WEOC from oven-dried samples exhibited lower SUVA than did freeze-dried samples.

Effects of Ionic Strength on Water-Extractable Organic Carbon Production

Extraction solutions significantly affected WEOC release from both mineral and organic horizon samples ($p = 0.003$) (Fig. 2). Compared with pure water, seawater significantly decreased

WEOC yields for all samples. Samples extracted with seawater produced 33 to 98% less WEOC than soils extracted by pure water. The largest difference occurred in mineral samples, where a three- to fourfold decrease in WEOC was observed, and the least variation was observed for samples from the upper permafrost (Oejj/Bgf) (Fig. 2). Soil samples from the active layer and the upper permafrost had similar responses to seawater extracts. There was no significant difference in WEOC yield among treatments with 100% seawater and seawater diluted to 50 or 25%.

In addition to salinity, the soil/solution ratio also affected soil WEOC yields (Fig. 2). The concentration of WEOC significantly increased with increasing soil/solution ratios ($p = 0.02$), except for soil samples from the Oejj/Bgf horizon. Since the effects of seawater on LMW-DOC were similar among samples from different soil horizons, only results for the Oajj and Oejj/Bgf cm are presented here (Fig. 3). Compared with bulk WEOC, the LMW-OC yield was less affected by the composition of the extracting solutions. However, the effect of soil/solution ratio on LMW-OC yield was similar to the effect on bulk WEOC yield.

Specific UV absorption of WEOC also was significantly affected by extract solutions ($p < 0.001$) (Fig. 4). Greater SUVA values were observed for WEOC extracted by pure water than by original seawater or diluted seawater. The difference in SUVA between WEOC extracted by pure water and original seawater was 240, 132, 58, and 131% for Oe, Bw, Oajj, and Oejj/Bgf horizons, respectively. The greatest relative difference was observed for soils from the surface horizon. Similar to WEOC, SUVA increased with increasing ratio of soil to extract solution.

Discussion

Soil Properties

The SOC content in different horizons of this soil ranged from 340.2 to 21.3 g C kg^{-1} soil. These values are consistent with those reported previously by Michaelson and Ping (1996), Hoefle et al. (1998), and Jorgenson and Brown (2005). These authors found that SOC ranged from 3.0 to 430 g C kg^{-1} soil in the Alaskan arctic tundra. The presence of deeper organic layers may be attributed to cryoturbation (Ping et al., 1998). Similar soil profiles have been reported by Brown (1965) and Michaelson and Ping (1996). Thus, our results indicate that the selected soil profile was a typical tundra soil and had a wide range of SOC concentrations in mineral as well as organic horizons from the active layer to the upper permafrost horizon. Therefore, this study is well suited for examining the effects of different soil pretreatments and extraction solutions on WEOC yields from tundra soils, which may potentially be eroded and exported to the Beaufort Sea under persistent arctic warming. However, caution should be taken when applying our results to soils in other regions.

Drying Effects on Water-Extractable Organic Carbon and Its Molecular Weight Fractions

When subjected to oven drying or freeze drying, all soil samples examined released more WEOC than did the original moist
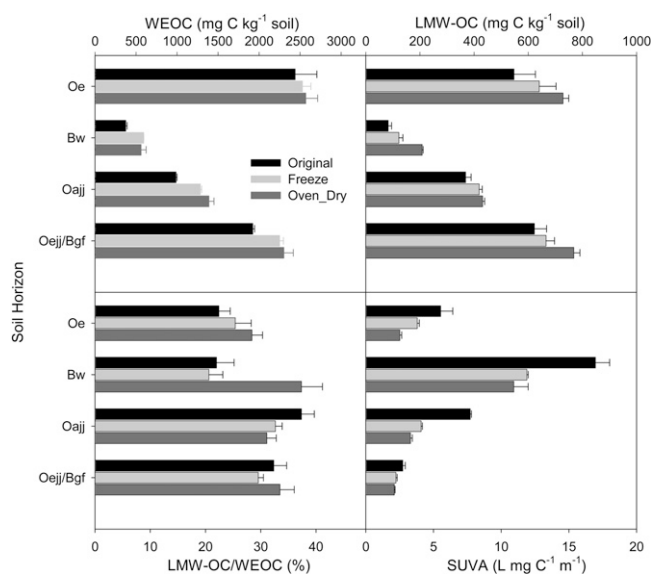

Fig. 1. Effects of drying methods on WEOC, low-molecular-weight DOC (LMW-DOC), the proportion of WEOC as LMW-DOC, and specific UV adsorption (SUVA) in horizons of a tundra soil from Barrow, AK. Error bars represent positive standard deviation of subsamples.

soil samples, consistent with many previous studies (Davidson et al., 1987; Borken et al., 1999; Haynes, 2005). There are two explanations for the increased production of WEOC after a drying–wetting cycle. The first argues that the lysis or metabolism of soil microbes during the drying–wetting cycle is responsible for the enlarged WEOC pool. Using pure-culture techniques, Halverson et al. (2000) found that soil bacteria released intracellular solutes in response to dilution stress. A similar response of soil fungi to water potential increase was reported by Brown (1990) and Carlile and Watkinson (1994). A second explanation is that SOC may be the main source of increased WEOC after rewetting. Using a ^{14}C labeling technique, Fierer and Schimel (2003) proposed that this increased extractable C must be derived from
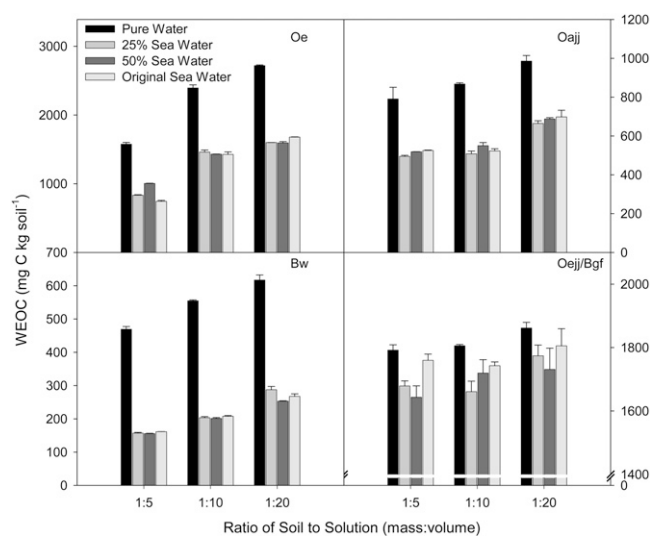

Fig. 2. Effects of extraction solution and seawater dilution on WEOC in horizons of a tundra soil from Barrow, AK. Error bars represent positive standard deviation of subsamples.
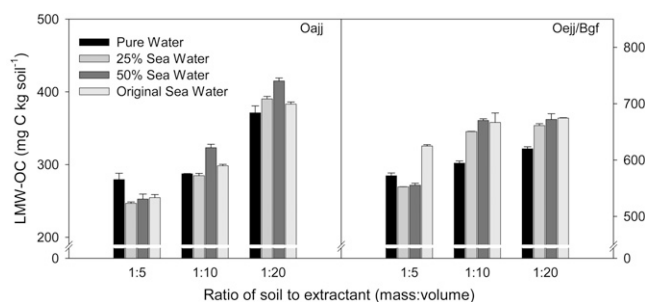
Fig. 3. Extraction solution and seawater dilution ratio on low-molecular-weight dissolved organic carbon (LMW-DOC) at depths of 20 to 50 cm and 50 to 75 cm for a tundra soil from Barrow, AK. Error bars represent positive standard deviation of subsamples.

SOC. Since we did not compare the changes in soil microbial biomass between treatments, we cannot reject the first assumption. A more realistic view may be a combination of the above two explanations.

Compared with samples from the active horizons, release of WEOC from samples of the upper permafrost horizon was more affected by the drying pretreatment. The difference in response may be related to previous drying–wetting cycles. In general, active layers experience more drying–wetting cycles in nature than do continuously frozen layers. Fierer and Schimel (2003) reported that exposure to frequent drying–rewetting events decreased the amounts of CO_2 released on rewetting in two Haploxerolls in California. They hypothesized that organic C made soluble on rewetting consisted primarily of osmoregulatory compounds that were released from microbial cells, not by lysis but to equilibrate with the new osmotic potential. The concentration of these releasable compounds might be greater in soil materials that do not undergo many wet–dry cycles than in those that do. Similar explanations may be applied to our study. In contrast to Bolan et al. (1999), our results showed that freeze-dried samples and oven-dried samples released similar amounts of WEOC.
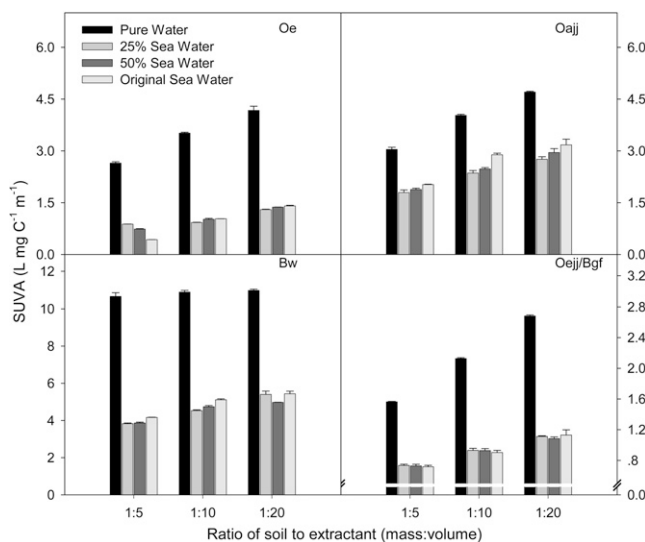

Fig. 4. Extraction solution and seawater dilution ratio on specific UV absorption (SUVA) of organic C extracted from horizons of a tundra soil from Barrow, AK. Error bars represent positive standard deviation of subsamples.

Although size-fractionation techniques have been widely applied to particulate organic C in the past 30 yr, few studies have used this technique to study soil WEOC (van Hees et al., 2004). DOC is generally young in ^{14}C age (Guo et al., 2007) and considered to be more labile than particulate organic matter (Kalbitz et al., 2003). Thus, WEOC may play a more active role in the biogeochemical cycling of SOC during coastal erosion and its mobilization across the arctic land–ocean interface (Guo and Macdonald, 2006). Figure 2 shows that the process of drying soils, especially oven drying, significantly increased the production of LMW-DOC, indicating that drying processes may make more LMW compounds susceptible to extraction by water. This result was further supported by the lower SUVA of WEOC extracted from oven-dried samples. The fraction of SOC that contributes to respiration may have consisted at least partially of LMW compounds, which have been reported to have a rapid turnover time (mean residence time 1–10 h) (van Hees et al., 2004). The proportion of WEOC as LMW-DOC did not show a consistent trend in response to drying pretreatments, but the overall ratio was higher for the upper permafrost than for the active horizons, indicating that the WEOC in frozen horizon may be more labile.

Ionic Strength Effects on Water-Extractable Organic Carbon and Its Molecular Weight Fractions

The data indicate that seawater extraction significantly reduced soil WEOC yields (Fig. 3), agreeing well with other laboratory observations. For example, Römkens and Dolfing (1998) reported that the significant reduction in WEOC caused by salt–solution extraction could be attributed mainly to flocculation. The presence of polyvalent cations such as Ca^{2+} and Mg^{2+} in seawater can contribute to this decrease (Lawrence et al., 1986; Aiken and Malcolm, 1987). Moreover, flocculation of soil colloids in seawater extracts may favor reabsorption of solubilized C onto the colloids. Similar results using K_2SO_4 extracts were reported by Haney et al. (1999). Dilution of seawater did not significantly affect WEOC production, although original seawater generally produced the lowest WEOC yield. This result is in contrast with that reported by Jones and Willett (2006). These authors reported that significantly more OC was recovered when it was extracted with 2 M KCl than with distilled water. One possible reason may be the presence of polyvalent cations (Ca^{2+} and Mg^{2+}) as well as the high concentration of other major ions in seawater, which will cause coagulation of soil particles and HMW-WEOC (e.g., Chin et al., 1998) and therefore reduction in WEOC yields.

In addition to the variation in WEOC yields with different extraction solutions, soil samples also varied in WEOC production. Compared with samples from active horizons, samples from the upper permafrost responded less to changes in extraction solutions between seawater and pure water. Our results indicate that most of the decrease in WEOC was associated with HMW-DOC (>3 kDa). This is consistent with the study of Römkens

and Dolfing (1998), who investigated properties of solutions of organic C extracted from samples of two Spodosols by NaNO₃. They found that when the solutions were amended with Ca^{2+} in concentrations ranging from 2.5 to 6 mM, HMW-DOC was coagulated and LMW-DOC remained in solution. These authors attributed this phenomenon to the difference in chemical characteristics of DOC. They argued that the higher charge and the higher ratio of carboxyl groups to phenol groups of HMW-DOC result in its preferential coagulation with increasing Ca^{2+} content. Similarly, coagulation of HMW-WEOC by seawater could cause a relative increase in the LMW-DOC fraction, and thus the lability of soil WEOC released during arctic coastal erosion. The increased lability of terrestrial-origin WEOC may decrease its residence time in the ocean. This is also consistent with the reported results that little terrestrial-derived, colored DOC is found in arctic seawater (Guéguen et al., 2005).

As with ionic strength, the soil/solution ratio of the extraction regulated both WEOC production and SUVA. In general, as the ratio of dry soil mass to volume of extractant decreased, WEOC and SUVA increased. Because method evaluation studies using tundra soil or organic soils are limited, our results will be compared with studies of mineral soils. Our result is consistent with those reported by others (e.g., Jones and Willett, 2006). Needelman et al. (2001) found that WEOC production increased as dry-soil/extractant ratio decreased in the range of 1:3 to 1:15. However, Needelman et al. (2001) also reported that the soil material with the largest organic C concentration in their study required the lowest dry-soil/extractant ratio for maximum extraction of C. This contrasts with our results, where the sample with the largest OC concentration (Oa horizon) had a greater positive response to diminishing dry-soil/extractant ratio than did the active-layer mineral-horizon sample (Bw horizon) (Fig. 2). Compared with WEOC in active layers, WEOC in upper permafrost (Oejj/Bgf horizon) responded inconsistently to the dry-soil/extractant ratio. The different responses from active horizons and the upper permafrost seem to correlate with different soil moisture regimes. Compared with active layers, the upper permafrost is frozen and super-saturated (Table 1). Moreover, increased SUVA with decreasing dry-soil/extractant ratio (1:5, 1:10, and 1:20) suggests that more aromatic substances were released from more diluted samples (Fig. 4). This effect is more evident for WEOC extracted by pure water than for WEOC extracted by seawater solutions.

Our results in this study of a single soil have implications for the estimation of organic C fluxes and C budget constraints and for quantifying WEOC yields from soil eroding into the Arctic Ocean (Stein and Macdonald, 2004). Current techniques of using pure water to extract DOC could substantially overestimate DOC flux through coastal erosion, perhaps by as much as a factor of two. On the other hand, the dry-soil/extractant ratio used may also play an important role in WEOC determination, especially for the active horizons. Thus, a more realistic estimate of WEOC input during coastal erosion may be the amount of WEOC extracted by original seawater at a lower soil/solution ratio than that used by this study.

Conclusions

For the soil examined, these following conclusions were reached:

1. Both oven drying and freeze drying significantly increased WEOC release compared with WEOC released from the original moist soil samples.

2. Most soil samples extracted with seawater exhibited significantly lower WEOC yields than those extracted with pure water.

3. Specific UV absorption of WEOC extracted using seawater was significantly lower than that of WEOC extracted using pure water, suggesting that some aromatic WEOC was coagulated during sea water extraction.

4. The soil/extractant ratio also affected WEOC production.

5. Overestimation of total terrestrial WEOC input to the Arctic Ocean during coastal erosion could occur if estimations are based on WEOC extracted from dried soil samples using pure water.

6. Based on the conclusions above we recommend that WEOC inputs resulting from coastal erosion be determined on site with fresh soils using sea water as an extractant using an extraction ratio of 1:10 (mass/volume).

Acknowledgments

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