Seasonal fluxes and age of particulate organic carbon exported from Arctic catchments impacted by localized permafrost slope disturbances

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Abstract

Projected warming is expected to alter the Arctic permafrost regime with potential impacts on hydrological fluxes of particulate organic carbon (POC) and sediment. Previous work has focused on large Arctic basins and revealed the important contribution of old carbon in river POC, but little is known about POC fluxes from smaller coastal watersheds, particularly where widespread postglacial raised marine sediments represent a potential source of old soil carbon that could be mobilized by permafrost disturbance. To evaluate these processes, the characteristics of POC, particulate nitrogen (PN) and suspended sediment transport from paired small coastal Arctic watersheds subject to recent permafrost disturbance were investigated at the Cape Bounty Arctic Watershed Observatory (CBAWO) in the Canadian High Arctic. Approximately 2% of the total suspended sediment load from both watersheds was composed of POC and the majority of the sediment and POC fluxes occurred during the spring snowmelt period. Radiocarbon analysis of POC indicates recent permafrost disturbances deliver substantially older POC to the aquatic system. Localized permafrost slope disturbances have a measurable influence on downstream POC age and dominate (estimated up to 78% of POC) sediment fluxes during summer baseflow. The elevation of disturbances and Holocene emergence data show limited age sensitivity of POC to the location of disturbance and suggest slope failures are likely to deliver carbon with a relatively similar age range to the aquatic system, regardless of landscape location.

Keywords: Arctic, particulate organic matter, radiocarbon, suspended sediment, permafrost

1. Introduction

Arctic soils have been shown to contain a large amount of carbon (Ping et al. 2008, Tarnocai et al. 2009) and projected climate change (ACIA 2005) along with degrading permafrost (Schuur et al. 2008) are expected to change river carbon export through altered surface and subsurface flow pathways and surface disturbance (Lafrenière and Lamoureux 2013). Both dissolved organic carbon (DOC) and particulate organic carbon (POC) exhibit a wide range of sources and are crucial components in aquatic and coastal ecosystems (Kuzyka et al. 2008, Vonk et al. 2010, Gustafsson et al. 2011, Woods et al. 2011, Lantuit et al. 2013). Characterization of the flux and composition of POC in Arctic watersheds have received limited research attention, despite the potential for POC from a variety of sources, including bedrock and surficial sediments, as well as evidence that permafrost disturbance and related erosion is accelerating in many areas (Jorgenson et al. 2006, 2008).
Lantz and Kokelj 2008, Lamoureux and Lafrenière 2009, Lantuit et al 2013). This lack of knowledge regarding POC fluxes and sources in Arctic catchments is important given the increased attention being directed towards understanding the effect of permafrost disturbance on downstream aquatic systems (Bowden et al 2008, Thompson et al 2008, Vonk et al 2010, Thienpont et al 2012).

A key approach to recognizing potential changes in the source of organic carbon in watersheds is through radiocarbon analysis of POC transported by surface waters. Results from radiocarbon analyses demonstrate that old carbon represents 28–79% of the total exported POC in several large Arctic rivers (Guo et al 2007), but the old fraction varies substantially by fluvial setting (Frey and McClelland 2009, Gustafsson et al 2011). Considerable research effort has focused on large rivers with diverse POC sources, including basins that contain upstream boreal ecosystems (Guo et al 2007, 2012). Hence, the flux and age of POC from basins located fully in the Arctic landscapes remains poorly understood particularly from the smaller coastal watersheds that are common in the Canadian Arctic Archipelago. Recent permafrost disturbance has substantially affected a number of Arctic catchments in this region (Lamoureux and Lafrenière 2009, Lewis et al 2012, Woods et al 2011) and represents a potentially important perturbation to POC fluxes into downstream ecosystems that are already showing evidence of impacts caused by recent climate change (Smol et al 2005).

To address this gap in knowledge, we examined the impact of 2007–8 permafrost slope disturbance on the seasonal fluxes of fluvial POC and suspended sediment from several small High Arctic watersheds. Additionally, we undertook an exploratory analysis of the radiocarbon composition of the POC to test the hypothesis that permafrost disturbance of soils underlain by postglacial marine sediments would mobilize old carbon to downstream aquatic systems and sought to investigate these dynamics with paired watersheds with varying degrees of recent disturbance at the Cape Bounty Arctic Watershed Observatory (CBAWO) (74°55′N, 109°30′W), Melville Island, in the Canadian High Arctic. CBAWO consists of paired watersheds (West and East, names unofficial), with a number of instrumented subcatchments in the West watershed (figure 1).

Exceptionally warm temperatures (mean July air temperature 10.8 °C compared to 1949–97 mean of 4.0 °C, Mould Bay, NT station) and major rainfall events in 2007 resulted in substantial permafrost disturbance, primarily in the West watershed where the active layer reached depths in excess of 1.0 m compared to 0.5–0.7 cm in prior years (detailed in Lamoureux and Lafrenière 2009). Subsurface melt of massive ground ice, together with soil water from the rainfall resulted in a large number of slope disturbances, or active layer detachments (ALD). The ALD are shallow slope failures that move up to 300 m down slope and contain fragmented soil and vegetation mixed with underlying marine clay (figure 2). We mapped the extent of these disturbances at the end of July 2007 and 2008, and established hydrometric stations to monitor the outflow from four subcatchments that ranged from undisturbed (Goose) to highly disturbed (Ptarmigan, Big Slide, ALD05) (figures 1, 2). The overall goal of this research was to determine the extent to which permafrost disturbance altered the age of POC transported by streams and rivers in small High Arctic watersheds, as a precursor to improving watershed hydrological and biogeochemical models.

2. Methods

During the 2008 melt season we recorded stage at outlet stations on the West and East Rivers and four subcatchment streams (figure 1) at 10 min intervals with barometrically compensated Onset U20 pressure loggers (precision ±5 mm). Discharge for each channel was manually rated daily to establish stage–discharge rating curves. Suspended sediment samples were collected with ISCO 3700C pump samplers at the West and East River stations at 3-hour intervals and manually from the subcatchments 2–3 times daily for determination of suspended sediment concentration (SSC). Samples were filtered volumetrically through tared 1 μm glass fiber filters, freeze-dried and weighed for sediment mass to calculate SSC. Daily 1.0 l water samples were collected at 1000 and 1800 h from the West and East Rivers for analysis of POC concentrations. Additionally, 3.0 l water samples for carbon isotope analyses were collected from each river at six representative times during the runoff season: the onset of melt (June 15–16), near peak flow (June 20), twice during the recession

Figure 1. The West and East watersheds at the Cape Bounty Arctic Watershed Observatory (CBAWO). Subcatchment watersheds are named, and watershed areas are shown as light gray polygons with dashed black outline. Contour interval is 10 m and is based on NTS sheet 78F/15. Active layer detachments that formed in 2007 and 2008 are indicated as filled dark gray polygons and represent mapped extents as of August 1, 2008. Locations for stream gauging and particulate organic carbon (POC) sampling are indicated by filled black circles (▲), and the MainMet automatic weather station is shown by a dark gray triangle (▲).
of nival peak (June 28, July 3) and during baseflow conditions (July 21). Samples for carbon isotopes were also collected from the undisturbed Goose and disturbed Ptarmigan subcatchments on the same days prior to flow cessation on July 3.

Water samples were immediately pressure filtered through tared and ashed 0.7 µm glass fiber filters that were subsequently wrapped in pre-ashed aluminum foil and stored frozen. Between samples the stainless steel filtration apparatus was cleaned with 30% hydrogen peroxide and deionized water. In the laboratory, the samples for POC and PN determinations were acid fumed with 50 ml of 6% trace metal grade H$_2$SO$_3$ for 20 h following standard methods (Kennedy et al. 2005, Komada et al. 2008). After fumigation the samples were dried overnight at 50°C and individually weighed and pelletized in tin disks. The sample pellets were analyzed using a ThermoQuest EA1112 CHNS elemental analyzer (Coastal Groundwater Geochemistry Laboratory, Woods Hole Oceanographic Institution (WHOI)).

Processing of the radiocarbon POC samples was conducted in an identical manner, although samples were fumed with concentrated trace metal grade HCl. Radiocarbon analyses were obtained from the WHOI National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) and reported as uncalibrated $^{14}$C ages and $\Delta^{13}$C activity. The stable isotope composition is reported as permil (‰) $\delta^{13}$C, relative to the Pee Dee Belemnite (PDB) reference standard.

3. Results

3.1. Sediment and particulate organic carbon transport

Seasonal trends in discharge ($Q$), SSC and POC in the two main rivers are generally quite similar although the West River is characterized by higher discharge and runoff due to enhanced accumulation of snow in topographic depressions (Lewis et al. 2012). SSC and POC co-vary strongly with discharge in both rivers, although the relationships during peak snowmelt are different from that of the rest of the season (figure 3). The correlation between SSC and $Q$ following the snowmelt period is weaker for West River ($r = 0.78$) than for the East ($r = 0.90$) as a result of high sediment yields associated with storm flow during late July (figure 4(a)). The relationships between POC and discharge ($Q$) are generally not as robust as SSC (figure 4(b)) although POC and SSC are strongly correlated in both the West ($r^2 = 0.86$) and East Rivers ($r^2 = 0.69$), such that POC averages 2% of the SSC in both rivers (figure 4(c), table 1). The ratio of POC to SSC is generally between 1 and 2% most of the time, however, at discharges below about 0.1 m$^3$ s$^{-1}$ the ratio of POC to SSC varies between about 1–8% (figure 5). The sediment and POC concentrations for a given discharge are 32% higher in East River than in the West River, however, due to higher mean discharge and runoff in
the West River, the mean concentrations of POC and SSC and total (kg) and specific (kg km\(^{-2}\) m\(^{-3}\)) POC and PON fluxes are larger from the disturbed West River (table 1).

Streams from the smaller disturbed subcatchments are characterized by high SSC compared to the rivers (figure 6). Although the three disturbed subcatchments represent only 8.3% of the West watershed area, they contributed an estimated 2–32% of the SSC load during the snowmelt period in June (figure 7). During baseflow in mid-July when only Big Slide Creek was flowing, it contributed greater than 50% of the West River daily suspended sediment load on many days (figure 7). The exceptional load of 112% estimated to be derived from the Big Slide subcatchment on July 13 likely represents downstream channel sediment storage in the West River.

Seasonal patterns in POC and PN concentrations for the East and West Rivers are also similar and largely follow SSC. Concentrations of POC and PN peak June 21–25 immediately following peak discharges, then decline during baseflow and increased during the July rainfall runoff (figure 3). Overall, POC was approximately 2% of the particulate load (table 1) and POC:PN ratios were generally between 6 and 10 (catchment averages of 8.1–8.5, table 1) in the two catchments (figure 2). There were no relationships between either the C:N ratio or the carbon fraction of the SSC and discharge. The highest C:N ratios (15–19) occur in the West River during the early runoff.

### 3.2. POC radiocarbon ages

Stream POC radiocarbon analyses reveal substantial contributions of old carbon in both river systems (table 2). The West River, with 2.8% of the watershed area disturbed, was characterized by POC ranging from 2620 to 5830 yr BP, compared to POC from the less disturbed East River watershed (1.0%) that varied from 680 to 4130 yr BP. Notably, the POC age was similar for both rivers in late June during maximum snowmelt discharge, but the West River exhibited substantially older POC during baseflow in July, and particularly during initial flow June 15–16, when the age difference was 3510 yr BP (table 2).
Figure 4. West and East River discharge \((Q \text{ m}^3 \text{ s}^{-1})\), suspended sediment concentration (SSC) and particulate organic carbon (POC) concentration \((\text{mg l}^{-1})\) in 2008. (a) Discharge–SSC with measurements during peak snowmelt (nival) and the remainder of the season. (b) Discharge–POC with measurements during peak snowmelt (nival) and the remainder of the season. (c) SSC–POC for the entire season with a best fit linear relationship indicated for each river.

Figure 5. The proportion of particulate organic carbon to suspended sediment concentration (POC/SSC) in per cent (%) relative to discharge for the West and East Rivers. Note the wide range of %POC/SSC at low discharge values in both rivers.

A single sample from the undisturbed Goose subcatchment yielded a modern \(^{14}\text{C}\) age, consistent with the low suspended sediment levels in this stream (mean 5.5 mg l\(^{-1}\), \(n = 62\)). By contrast, the highly disturbed Ptarmigan subcatchment (10.8%) with high SSC (mean 1140 mg l\(^{-1}\), \(n = 51\)) yielded two POC samples during snowmelt discharge of 6600 and 6740 yr BP, the oldest POC ages of all samples (table 2). Additional samples from the subcatchments were not possible due to cessation of flow shortly after snowmelt and also due to loss of the June 28th Goose sample during analysis.

Overall the \(^{13}\text{C}\) values of the POC are within the range of that expected for POC derived from C3 terrestrial vegetation (Buckeridge et al 2010), although \(^{13}\text{C}\) values of freshwater and marine POC (phytoplankton and zooplankton) also fall within this range (Raymond and Bauer 2001; Guo et al 2007). There were no discernible relationships between \(^{13}\text{C}\), C:N and \(^{14}\text{C}\) of the POC in the West and East River samples. Modern POC from Goose yielded one of the most depleted \(^{13}\text{C}\) values (\(-29.1\%\)) and the oldest POC age from Ptarmigan had the most enriched \(^{13}\text{C}\) values (\(-25.7, -25.9\%\)) (table 2), suggesting that the undisturbed Goose watershed is a source of younger more depleted \(^{13}\text{C}\) organic matter, while the disturbed and incised Ptarmigan stream is a source of older and relatively enriched \(^{13}\text{C}\) organic carbon. The range of POC \(^{13}\text{C}\) in West and East Rivers suggests a complicated mix of sources ranging from generally older and more depleted POC in the West watershed, to younger and more enriched \(^{13}\text{C}\) in the East watershed although we note that \(t\)-tests (two sided)
Figure 6. Stream discharge ($Q$ m$^3$ s$^{-1}$) and suspended sediment concentration (SSC) (mg l$^{-1}$) for four gauged subcatchments of the West River in 2008. Note that most creeks ceased to flow in early July after the depletion of snow cover, while Big Slide continued to flow due to the presence of a large perennial snow bank in the subcatchment. The time of the radiocarbon dates from stream particulate organic carbon (POC) samples from Goose and Ptarmigan creeks are indicated along with the uncorrected $^{14}$C age (yr before present (BP)).

Figure 7. The proportion of 2008 daily suspended sediment flux in the West River contributed from the three primary disturbed subcatchments. Daily fluxes from each subcatchment and the West River were used to determine the daily proportion, and channel storage or in-channel sources of sediment were not considered. The areal proportion of the total West River catchment for each subcatchment is: Big Slide (1.8%), Ptarmigan (2.7%) and ALD05 (3.8%) (figure 1). Note that discharge in Ptarmigan and ALD05 largely ceased in early July while a perennial snow bank in Big Slide maintained flow throughout the period.
larger Ob and Yenisei Rivers (Gebhardt and West Rivers are generally similar to those from the much
more extensive SSC dataset. The strong correlation of POC and SSC indicates that the more extensive SSC dataset
ratios were broadly similar as well. The strong correlation of POC with SSC suggests that the more extensive SSC dataset
is indicative of POC transport in this setting (table 1). It is notable that the mean concentrations of POC and PN in the East
and West Rivers are generally similar to those from the much larger Ob and Yenisei Rivers (Gebhardt et al 2004), although the relative POC content of suspended matter is substantially lower at Cape Bounty (~2% here versus 10% in Gebhardt et al
2004) due to high suspended sediment loads (table 1).

Despite these overall similarities, the POC radiocarbon ages in the main rivers and the subcatchments reveal the substantial difference in the age of organic carbon supplied. Analyses to constrain the age of sediment and soil sources are unavailable. However, the glacioisostatic history of the area suggests that considerably older marine sediment and organic carbon could be contributing to the observed POC ages. Deglaciation of southern Melville Island occurred at c. 11 000–11 500 yr BP and the marine transgression reached 90–110 m asl (Hodgson et al 1984). The disturbances in Ptarmigan (figure 1) range from 63 to 85 m asl, suggesting that disturbance could mobilize marine sediment dating to 10 000 to 12 000 yr BP (figure 8) (Hodgson et al 1984). While subject to uncertainties, particularly the relative proportion of younger terrestrial carbon and the spatial pattern of soil erosion within disturbances, the contribution of old marine carbon to the POC from Ptarmigan can be estimated. Assuming modern carbon contributions as evidenced by POC in Goose, and old carbon of uniform age of two half-lives as an estimated mean value based on age-elevation extent of the disturbance (11 136 yr BP) (figure 8), the POC transported in Ptarmigan would be composed of 78% old carbon. This estimate likely represents a maximum, as the age of surface sediment material will reasonably vary by elevation and the complex incorporation of terrestrial organic material during the Holocene. However, the rapid early emergence in the region indicates that the observed disturbances are constrained by a relatively narrow range of marine ages (figure 8). Hence, while the age of POC from Ptarmigan likely represents an older end member the range of potential POC ages from disturbed land is limited to approximately 9000–12 000 yr BP, with considerable uncertainty associated with the emergence data (figure 8).

### Table 2. Radiocarbon analyses from particulate organic carbon (POC) at Cape Bounty, 2008 runoff season.

| Catchment date | Laboratory reference | δ^{13}C_{PDB} (‰) | F modern | ^{14}C Age | Age error | ^{14}C
|----------------|----------------------|-------------------|---------|-----------|-----------|-------|
| **West River** |                      |                   |         |           |           |       |
| 06/15/2008     | OS-73096             | −27.1             | 0.5936  | 4190      | 45        | −411  |
| 06/20/2008     | OS-73067             | −26.8             | 0.7214  | 2620      | 35        | −284  |
| 06/28/2008     | OS-73062             | −28.2             | 0.6234  | 3790      | 40        | −381  |
| 07/03/2008     | OS-73059             | −28.3             | 0.5149  | 5330      | 50        | −489  |
| 07/12/2008     | OS-73058             | −29.2             | 0.4836  | 5830      | 50        | −520  |
| 07/21/2008     | OS-73890             | −25.8             | 0.5174  | 5290      | 50        | −486  |
| **East River** |                      |                   |         |           |           |       |
| 06/16/2008     | OS-73094             | −26.3             | 0.9186  | 680       | 30        | −88   |
| 06/20/2008     | OS-73879             | −26.2             | 0.7238  | 2600      | 45        | −281  |
| 06/28/2008     | OS-73894             | −26.8             | 0.5977  | 4130      | 60        | −407  |
| 07/03/2008     | OS-73060             | −27.1             | 0.6338  | 3660      | 95        | −371  |
| 07/12/2008     | OS-73897             | −26.2             | 0.6339  | 3660      | 50        | −371  |
| **Goose (Undisturbed)** | OS-73068 | −29.1 | 1.0605 | >Mod       |           | 53    |
| 07/03/2008     | OS-73068             | −29.1             | 1.0605  | >Mod       |           | 53    |
| **Ptarmigan (Disturbed)** | OS-73880 | −25.8 | 0.4323 | 6740      | 45        | −571  |
| 06/20/2008     | OS-73880             | −25.8             | 0.4323  | 6740      | 45        | −571  |
| 06/28/2008     | OS-73881             | −25.6             | 0.4395  | 6600      | 50        | −564  |

4. Discussion and conclusions

In general, neither the seasonal trends nor the C:N composition of the particulate suspended matter varied substantially between the more disturbed West and the relatively undisturbed East watershed. The East River exhibited higher SSC at lower discharge compared to the West river (t = 0.017 two sided, n = 530), which may reflect the availability of sediment in the catchment (figure 3(a)). Detailed sediment budget work on the West River suggests that a large proportion of the suspended sediment is stored during the season, particularly as discharge wanes in the summer (Veillette 2011), which may reflect perturbation of the fluvial system by direct disturbance and sediment loading from slope disturbances. Substantial storage in the West River channel likely buffers downstream transport of eroded particulate matter from disturbances, resulting in minimal perturbation of the loads (Lewis et al 2012). Similar sediment budget analyses are not available for the East River, which limits assessing the differences in SSC loading. Regardless, the two rivers exhibited peak sediment and POC concentrations during the snowmelt runoff, and the particulate carbon composition (%C of SSC) and C:N ratios were broadly similar as well. The strong correlation of POC with SSC indicates that the more extensive SSC dataset is indicative of POC transport in this setting (table 1). It is notable that the mean concentrations of POC and PN in the East and West Rivers are generally similar to those from the much larger Ob and Yenisei Rivers (Gebhardt et al 2004), although the relative POC content of suspended matter is substantially lower at Cape Bounty (~2% here versus 10% in Gebhardt et al 2004) due to high suspended sediment loads (table 1).
Using a similar set of estimated boundary conditions, the old POC content of the West and East Rivers would be 42–72% and 18–57%, respectively. The higher estimated proportion of old carbon in West River likely reflects the greater extent of permafrost disturbances in the watershed. The estimated old carbon content of the West River POC during July (c. 60–70%) is consistent with the independent estimates of suspended sediment contributions from the disturbed subcatchments (figure 7). Hence, these results point to the dominance of sediment transport from highly localized disturbances during summer baseflow, and radiocarbon analyses during that period suggest that a substantial quantity of POC is sourced from these disturbances. By contrast, the sediment and POC transport during maximum snowmelt reveals limited impact of the disturbances in terms of both suspended sediment and old POC transport (figure 3). The snowmelt period is characterized by the highest flux of POC in this setting and others (Bowden et al. 2008; Gustafsson et al. 2011; Lewis et al. 2012). The exception to this is during the initial runoff on June 15, when the two rivers exhibited the largest POC age difference. This divergence may represent early season transport of old POC delivered directly to the West River channel from an active layer detachment (ALD) in late 2007 (Lamoureux and Lafrenière 2009). Substantial sediment storage in the channel during waning flow has been noted in the West River (Veillette 2011), hence the relatively old first POC in 2008 may reflect initial release of old POC stored in the channel during a previous season. Hence, while the role of individual ALD in terms of POC delivery remains uncertain given the limits of the current data set, particularly given the potential for downstream storage in river channels. By contrast, all disturbances in the East watershed were located up slope from the channel and particulate delivery from disturbances was visibly minimal.

These results provide important insights into the carbon dynamics in permafrost environments subject to recent and projected disturbance (Schuur et al. 2008). While permafrost carbon pools are generally characterized as large and subject to perturbation, the mineral soils at our study site in the High Arctic have lower carbon content than those reported in the lower Arctic (Ping et al. 2008). Hence, while considerable attention has been given to the cycling of old DOC that can occur over large areas in response to active layer expansion (Neff et al. 2006, Frey and McClelland 2009), our results also identify POC changes caused by highly localized physical disturbance. The seasonal variations in POC age at Cape Bounty suggest that localized disturbance is capable of affecting the character of POC in a larger watershed in complex ways, particularly during summer baseflow. During July 2008, flow from one disturbed tributary delivered a suspended sediment load comparable to the overall West River watershed and at a time characterized by the oldest West River POC. While POC samples and radiocarbon ages are not available from this particular tributary, the substantially older POC in West River at that time compared to the less disturbed East River (and the oldest ages from the significantly disturbed PT site), suggests that a subcatchment (Big Slide) with 1.8% of the watershed area can appreciably alter the downstream fluvial carbon flux. By contrast, during peak snowmelt discharge, sediment and POC transport generally originated from similar sources in both watersheds. As the flux of both suspended sediment and POC during the snowmelt period dominates the seasonal flux in these small High Arctic fluvial systems, these results point to highly seasonal downstream effects of permafrost disturbance on POC source.

Similarly, complementary studies at CBAWO suggest that recently disturbed soils are characterized by highly labile and reactive organic matter. Recently disturbed soil organic matter (SOM) contained high concentrations of bacterial phospholipid fatty acid (PLFA) biomarkers and large contributions from bacterial protein/peptides (Pautler et al. 2010). Similar analyses from soils from an older (>60 years) permafrost disturbance indicate depletion of bacterial biomarkers and bacterial mineralization of SOM (Pautler et al. 2010). Low C:N of POC in this system (~8) suggests that the particulate organic content is relatively labile, unless the organic matter is associated with or coated by mineral particles that could reduce the bioavailability of the organic matter (Jastrow et al. 2007).

While similar detailed investigations are necessary in the High Arctic aquatic system, the available data in this study suggest that the mobilization of POC has potential to impact downstream biogeochemical cycling and aquatic ecosystems (Frey and McClelland 2009). The permafrost disturbance and POC transport at Cape Bounty is in addition to anticipated increased channel bank erosion in Arctic rivers and which is also expected to erode old organic matter (Guo et al. 2012).
Increased delivery of POC and suspended sediment can particularly impact lake water optics, increase potential decomposition and bottom water oxygen consumption in downstream lakes (Thompson et al. 2008, Dugan et al. 2012). In lake systems with limited nutrients and persistent ice cover (9–11 months per year), these effects may be particularly important. Similarly, the increased flux of labile POC downstream to Arctic coastal marine ecosystems is of particular importance given the high productivity in these zones.

More broadly, these results provide key constraints over POC fluxes from low-order coastal watersheds of the Canadian Arctic Archipelago and provide insights into the impact of localized permafrost disturbance to improve our understanding of Arctic terrestrial–marine linkages in a changing climate. Results also suggest that scaling to larger catchments requires consideration of catchment particulate organic matter sources and pathways. Notably, the significant association between suspended sediment and particulate organic carbon and nitrogen observed in these catchments indicates that targeted sampling of catchment areas with high sediment fluxes will help to constrain the major sources and constrain the flux and age of carbon in Arctic river systems, particularly where localized catchment disturbance may be present in subcatchments. Hence, while the particulate carbon budget for larger or more complex Arctic river systems will reflect catchment-specific factors, characterizing the response of these rivers to permafrost change and landscape disturbance at larger scales can be likely be improved through targeted measurements where sediment fluxes are evident.

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