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Key Points:
- The prevalence of bioavailable DOM reflects ecosystem productivity in Arctic margins
- Hot spots of labile DOM are widely distributed during summer in the Chukchi Sea
- Shelf regions are important sources of bioavailable DOM for microbial food webs in the central basins

Supporting Information:
- Supporting Information S1

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Pan-Arctic Distribution of Bioavailable Dissolved Organic Matter and Linkages With Productivity in Ocean Margins

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Abstract Rapid environmental changes in the Arctic Ocean affect plankton productivity and the bioavailability of dissolved organic matter (DOM) that supports microbial food webs. We report concentrations of dissolved organic carbon (DOC) and yields of amino acids (indicators of labile DOM) in surface waters across major Arctic margins. Concentrations of DOC and bioavailability of DOM showed large pan-Arctic variability that corresponded to varying hydrological conditions and ecosystem productivity, respectively. Widespread hot spots of labile DOM were observed over productive inflow shelves (Chukchi and Barents Seas), in contrast to oligotrophic interior margins (Kara, Laptev, East Siberian, and Beaufort Seas). Amino acid yields in outflow gateways (Canadian Archipelago and Baffin Bay) indicated the prevalence of semilabile DOM in sea ice covered regions and sporadic production of labile DOM in ice-free waters. Comparing these observations with surface circulation patterns indicated varying shelf subsidies of bioavailable DOM to Arctic deep basins.

1. Introduction

The Arctic Ocean is an enclosed sea with over half of its 9.5×10^6 km^2 surface area occupied by shallow continental shelves (Jakobsson et al., 2004). The extensive shelves receive and modify inflows from the Pacific and Atlantic Oceans and runoff from Arctic rivers and are important regions of dense water formation and biological production (Carmack & Wassmann, 2006; Jones & Anderson, 1986; Sakshaug, 2004). Strong spatial and temporal variations in solar radiation, sea ice extent, and nutrient supply result in considerable heterogeneity in primary production over the Arctic shelves (Sakshaug, 2004; Tremblay & Gagnon, 2009). The varying productivity affects the production and release of bioavailable dissolved organic matter (DOM), a source of carbon and energy that sustains the structure and functioning of microbial food webs.

Bioavailable DOM occurs in labile and semilabile forms that reflect biological processes on varying timescales (Carlson & Hansell, 2015). A variety of processes, including extracellular release by phytoplankton, zooplankton grazing, and viral lysis, collectively referred to as plankton production in this study, release labile DOM that is subject to rapid (hours-weeks) microbial utilization and transformation (Carlson & Hansell, 2015). The occurrence of short-lived labile DOM can result in patchy and brief bursts of microbial growth and respiration, thereby triggering the formation of hot spots and hot moments (Azam & Malfatti, 2007; McClain et al., 2003). Microbial alterations reduce the bioavailability of DOM, and the biodegraded components of a semilabile nature can be utilized over longer timescales (months to years) (Carlson & Hansell, 2015). Despite the well-known mechanisms for the production and consumption of bioavailable DOM, monitoring plankton production and food web dynamics in the Arctic Ocean still remains challenging, and little is known about the distributions of bioavailable DOM in this remote region.

Measurements of specific biochemicals provide useful insights about the abundance of bioavailable components of DOM (Amon & Benner, 2003; Benner, 2003; Goldberg et al., 2010; Mannino & Harvey, 2000; Shen, Fichot, et al., 2016). Previous bioassay incubations with DOM produced during an Arctic diatom bloom have established the use of carbon-normalized yields of amino acids as biochemical indicators of labile DOM (Davis & Benner, 2007). Amino acids are bioreactive and preferentially utilized over bulk DOM during microbial degradation, resulting in varying yields of amino acids that can be used to estimate the abundance of labile DOM. An early field survey of amino acid yields over the Chukchi Sea revealed active plankton production of labile DOM in shelf waters during the summer (Davis & Benner, 2007). A comparison of amino acid yields in shelf waters of the Chukchi Sea with those in the adjacent Beaufort Sea indicated more bioavailable DOM was present in the Chukchi Sea, and the comparison reflected the contrasting primary productivity between the two systems at the time of sampling (Shen et al., 2012). These studies demonstrated regional variability in DOM bioavailability that reflects ecosystem productivity and dynamics, and they indicated the export of bioavailable DOM from shelf waters to the Canada Basin. In the present study, the amino acid yield indicator is extended across major Arctic margins to evaluate pan-Arctic variability in the abundance and bioavailability of DOM. The labile component of bioavailable DOM is quantified and compared among three major types of shelves (inflow, interior, and outflow shelves), and possible factors and processes that shape the observed patterns are discussed.

2. Sampling and Methods

Water samples were collected during seven expeditions to the Arctic Ocean as part of different research projects between June and October of 2002–2013 (Table 1). These cruises surveyed more than 150 stations between 60°N and 82°N around the Arctic Ocean with extensive occupation of continental shelves and adjacent marginal seas (Figure 1). Seawater samples were collected using Niskin bottles mounted on a conductivity-temperature-depth/rosette. In this study, surface waters (upper 20 m) with salinities ≥27 were used to exclude low salinity waters dominated by riverine inputs and to better reflect marine primary productivity.

Water samples were filtered through precleaned glass fiber filters (0.7 μm pore size) or Supor membranes (0.2 μm pore size) for paired analyses of dissolved organic carbon (DOC) and total (free and combined) dissolved amino acids. Concentrations of DOC were measured using high-temperature combustion and a Shimadzu total organic carbon analyzer (Benner & Strom, 1993). The instrumental blanks (Milli-Q) were negligible, and the DOC concentrations for deep-sea reference standards (Florida Strait deep water provided by University of Miami) were within 5% of reported values. The final concentrations of DOC were calculated using an external calibration curve generated with five concentrations of standards (glucosamine). Concentrations of total dissolved amino acids were determined as the sum of 18 amino acids that were hydrolyzed using a microwave-assisted vapor phase method and then separated as *o*-phthaldialdehyde derivatives using high-performance liquid chromatography. Further details of amino acid hydrolysis and chromatographic separation are described by Kaiser and Benner (2005) and Shen et al. (2012). The carbon-normalized yield of amino acids (%DOC) was calculated as in equation (1):

$$\text{Amino acid yield } (\%\text{DOC}) = [\text{C in amino acids}]/[\text{DOC}] \times 100 \quad (1)$$

where [DOC] and [C in amino acids] are the concentration of bulk DOC and the concentration of carbon in all measured amino acids except the nonprotein amino acids (β-alanine and γ-aminobutyric acid).

An amino acid yield >0.7% (i.e., average value of deep-sea refractory DOM) indicated the presence of bioavailable DOM, and an amino acid yield >1.1% indicated the occurrence of labile DOM, the most bioavailable form of organic matter fueling microbial food webs. The cutoff yield values used here follow Davis and Benner (2007) and were based on changes in amino acid yields during bioassay experiments with phytoplankton-derived DOM and depth profiles of amino acid yields in the Canada Basin. In the present study, the concentrations of labile DOC were derived from amino acid yields following the approach of Davis and Benner (2007). In brief, the average deep-sea concentrations of DOC and amino acids were subtracted from surface water values to estimate concentrations of bioavailable DOC (BDOC) and calculate the corresponding amino acid yields ($BDOC_{yield}$). BDOC was separated into labile (L) and semilabile (S) fractions, which were estimated by solving a set of two-component mixing models:

$$BDOC_{yield} = \left(L_{yield} \times L_{fraction}\right) + \left(S_{yield} \times S_{fraction}\right) \quad (2)$$

$$L_{fraction} + S_{fraction} = 100\% \quad (3)$$

where L_{yield} and S_{yield} are end-member values for amino acid yields of labile and semilabile DOC (see Davis & Benner, 2007)

3. Results and Discussion

Surface water samples were collected from inflow, outflow, and interior shelves that vary markedly in topology, hydrology, and primary productivity (Carmack & Wassmann, 2006) (Figure 1). The shallow Chukchi Sea

Table 1
Concentrations of Dissolved Organic Carbon (DOC), Total Dissolved Amino Acids (TDAA), and DOC-Normalized Yields of TDAA in Surface Waters (≤20 m) of Arctic Margins

Sampling location	Research project[a]	Longitude	Latitude	Sampling date	Salinity	DOC (μmol/L)	TDAA (nmol/L)	TDAA (%DOC)	n
Chukchi Sea	SBI	152–168°W	65–74°N	Jul–Aug 2002	27.8–32.2 (30.1 ± 1.4)	67–121 (83 ± 15)	264–983 (470 ± 201)	1.0–3.2 (1.6 ± 0.7)	10
	SBI	152–169°W	65–74°N	Jul–Aug 2004	29.0–32.7 (30.6 ± 1.1)	64–114 (79 ± 14)	156–949 (460 ± 190)	0.8–4.2 (1.9 ± 0.8)	20
	RUSALCA	167–178°W	68–73°N	Sep 2012	27.3–32.3 (29.8 ± 1.7)	56–143 (80 ± 20)	212–757 (355 ± 126)	1.0–3.4 (1.6 ± 0.7)	27
Beaufort Sea	Malina	127–155°W	69–72°N	Aug 2009	27.2–31.8 (29.1 ± 1.3)	66–146 (84 ± 19)	160–769 (265 ± 137)	0.7–3.3 (1.1 ± 0.5)	21
Amundsen Gulf	CFL	114–134°W	69–72°N	Jul–Aug 2009	27.6–30.7 (29.2 ± 1.1)	66–114 (78 ± 12)	206–318 (236 ± 27)	0.9–1.1 (1.0 ± 0.1)	13
Archipelago	TARA	78–104°W	68–74°N	Sep–Oct 2013	29.5–30.0 (29.8 ± 0.2)	56–86 (73 ± 9)	166–257 (203 ± 30)	0.8–1.1 (1.0 ± 0.1)	8
Baffin Bay	TARA	53–76°W	71–73°N	Oct 2013	30.0–33.0 (31.2 ± 1.4)	66–97 (77 ± 10)	207–288 (241 ± 35)	0.9–1.4 (1.1 ± 0.2)	6
Davis Strait	TARA	51–56°W	60–70°N	Oct 2013	30.0–34.2 (32.5 ± 1.7)	56–77 (70 ± 7)	157–343 (232 ± 69)	0.8–1.7 (1.2 ± 0.3)	8
Nordic Seas	TARA	0–15°E	67–76°N	Jun 2013	34.6–35.2 (35.0 ± 0.2)	59–90 (70 ± 10)	130–279 (180 ± 51)	0.6–1.2 (0.9 ± 0.2)	9
Barents Sea	TARA	38–66°E	71–79°N	Jul 2013	34.3–34.9 (34.7 ± 0.3)	66–91 (77 ± 12)	244–317 (280 ± 28)	1.1–1.6 (1.3 ± 0.2)	6
Svalbard	NABOS	31–32°E	81–82°N	Oct 2008	33.3–34.2 (33.9 ± 0.5)	57–63 (60 ± 3)	127–152 (142 ± 13)	0.6–0.8 (0.7 ± 0.1)	3
Kara Sea	TARA	68–87°E	76–79°N	Jul–Aug 2013	27.4–34.3 (33.0 ± 2.3)	59–102 (74 ± 22)	77–298 (158 ± 68)	0.4–1.1 (0.8 ± 0.2)	8
Laptev Sea	NABOS	101–126°E	77–81°N	Oct 2008	28.6–33.0 (32.0 ± 1.3)	73–138 (92 ± 18)	149–208 (188 ± 17)	0.5–0.9 (0.7 ± 0.1)	11
E. Siberian Margin	NABOS	136–162°E	79–81°N	Oct 2008	27.2–32.2 (30.2 ± 2.0)	98–143 (116 ± 19)	185–295 (241 ± 38)	0.6–0.8 (0.6 ± 0.1)	11
E. Siberian Sea	NABOS	166.3°E	70.7°N	Oct 2008	30.8	100	298	1.1	1

[a]SBI, Shelf-Basin Interactions; RUSALCA, Russian-American Long-term Census of the Arctic; CFL, Circumpolar Flaw Lead; TARA, Tara Oceans Polar Circle; NABOS, Nansen and Amundsen Basin Observational System. Data are reported as range (average ± standard deviation).

and relatively deep Barents Sea are inflow shelves receiving nutrients from the North Pacific and Atlantic Oceans, respectively, and they are among the most productive regions in the Arctic Ocean (30–720 g C m^{-1} yr^{-1}) (Hill et al., 2013; Sakshaug, 2004). The Kara, Laptev, East Siberian, and Beaufort Seas are interior shelves characterized by strong riverine influences and low primary production (20–70 g C m^{-2} yr^{-1}) (Sakshaug, 2004; Sorokin & Sorokin, 1996; Williams & Carmack, 2015). The Canadian Arctic Archipelago is a shallow outflow shelf with complex topography and relatively low productivity (20–65 g C m^{-2} yr^{-1}) (Michel et al., 2006; Sakshaug, 2004).

Concentrations of DOC in surface waters of the Arctic Ocean margins varied approximately threefold from 56 to 146 μmol L^{-1} (Table 1) and showed a pan-Arctic variability closely linked to hydrological conditions (Figure 1). Elevated concentrations of DOC (>100 μmol L^{-1}) in the Kara Sea, Laptev Sea, East Siberian Sea, and Beaufort Sea are consistent with previous observations in these regions indicating the influence of continental runoff on the interior shelves (Alling et al., 2010; Fichot et al., 2013; Kattner et al., 1999). The remarkably high concentrations of DOC (130–140 μmol L^{-1}) over the Siberian margin (~160°E) resulted from enhanced cross-shelf export of terrigenous DOC-rich shelf water, which was promoted by local atmospheric circulation patterns (Bauch et al., 2011; Kaiser et al., 2017). During summer-fall 2008 southeasterly winds in the East Siberian Sea deflected shelf waters offshore where they mixed with basin and Pacific-derived waters (Kaiser et al., 2017). Compared to interior shelves, the inflow and outflow shelves (Chukchi Sea, Barents Sea, and Canadian Arctic Archipelago) received lower riverine inputs and had lower concentrations of DOC in surface waters (70–90 μmol L^{-1}; Figure 1). However, these DOC values remain high relative to the range of average values (55–70 μmol C L^{-1}) in the inflowing surface waters from the Pacific and Atlantic Oceans (Anderson & Amon, 2015, and reference therein).

Compared to the concentrations of DOC, amino acid yields exhibited much greater variability in the surface waters, ranging tenfold from 0.4% to 4.2% of the DOC (Table 1 and Figure 2). The broad range of amino acid yields depicted a wide spectrum of DOM bioavailability, ranging from labile to refractory in surface waters of Arctic margins. In comparison, less variation in amino acid yields (approximately threefold) was observed in depth profiles (mostly 0.5–1.5%) of the Pacific and Atlantic Oceans (Kaiser & Benner, 2009), Japan Sea (Kim et al., 2017), and Southern Ocean (Shen et al., 2017; Tremblay et al., 2015), and in surface waters of the Louisiana margin (mostly 0.7–2.0%) (Shen, Fichot, et al., 2016). These cross-system comparisons highlight the dramatic variability in composition and bioavailability of DOM in the Arctic Ocean.

The dynamic nature of bioavailable DOM indicated by amino acid yields has been associated with the extent of ecosystem productivity (Shen et al., 2012). Labile DOM enriched in amino acids (>1.1%) is subject to rapid microbial utilization (hours to weeks) (Davis & Benner, 2007), and the abundance of amino acid-rich DOM is indicative of regions with active plankton production (Shen et al., 2012). This observation is supported by a significant correlation between amino acid yields (mostly >1.1%) and chlorophyll

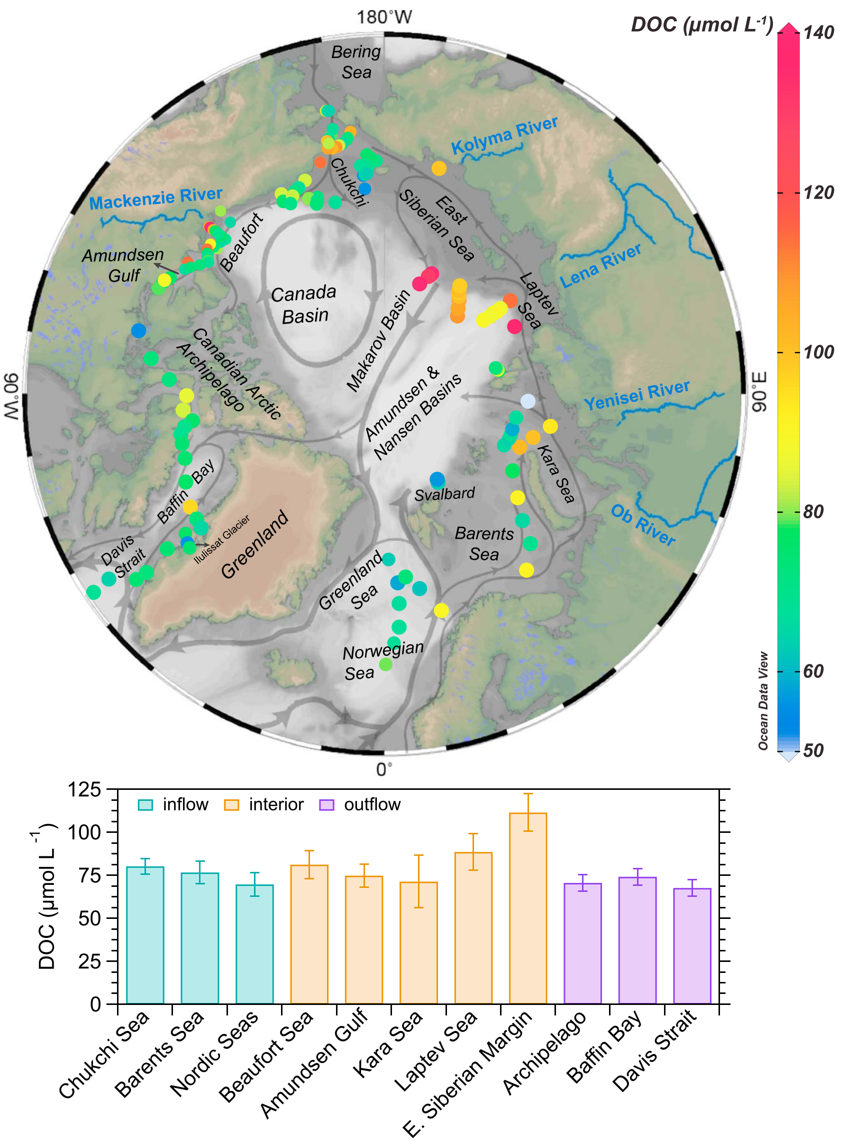

Figure 1. Pan-Arctic distributions of concentrations of dissolved organic carbon (DOC) in surface water (≤20 m). Schematic surface circulation was modified from Talley et al. (2011). The lower panel shows the average concentration of DOC in different shelf regions. The error bar represents two times standard error.

fluorescence in surface waters of the Chukchi Sea during summer (<40 m: r = 0.65, p < 0.001, n = 62) (Davis & Benner, 2005, 2007). Phytoplankton directly release some fixed carbon as DOM during growth and senescence, but zooplankton grazing is considered a more important source of phytoplankton-derived DOM (Nagata, 2000). Grazing reduces phytoplankton biomass and chlorophyll but enhances nutrient cycling and ecosystem productivity (Banse, 1995), so the observed relationship between chlorophyll and dissolved amino acid yields demonstrates a linkage between bioavailable DOM and phytoplankton productivity. In addition, amino acid yields are positively correlated with DOC $\Delta^{14}C$ values (r = 0.94, p < 0.0001, n = 8) in the water column of the Canada Basin (Druffel et al., 2017), indicating the decreasing bioavailability of DOM during aging in the water column. These observations further demonstrate the utility of amino acid yields in relating DOM bioavailability to different productivity regimes in Arctic marine ecosystems.

The pan-Arctic distributions of amino acid yields displayed regional patterns that differed from those of DOC concentrations and, in general, reflected varying productivity among different types of Arctic shelves (Figure 2). The two inflow shelves have the highest rates of primary production in the Arctic Ocean (Sakshaug, 2004), and the prevalence of bioavailable DOM was evident in these regions during the

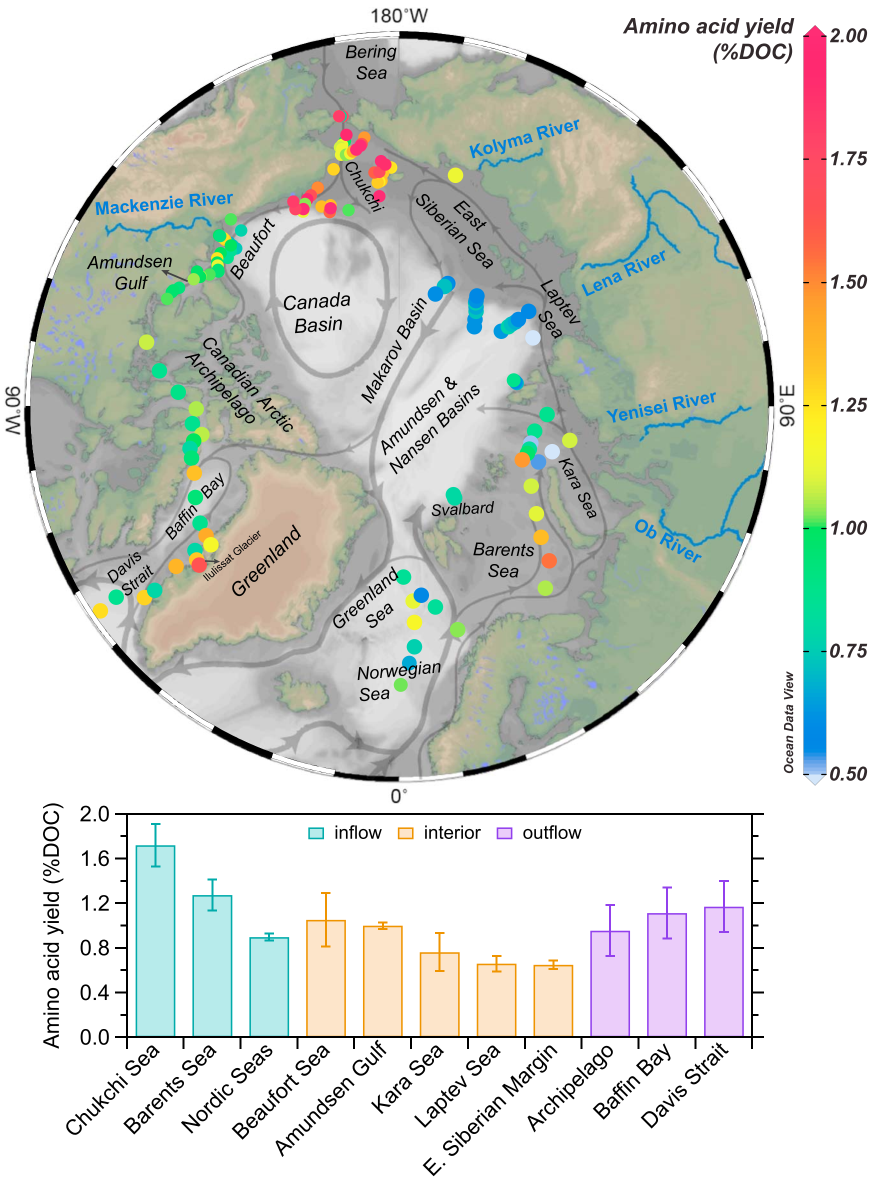

Figure 2. Pan-Arctic distributions of carbon-normalized yields (%DOC) of amino acids in surface water (≲20 m). Schematic surface circulation was modified from Talley et al. (2011). The lower panel shows the average amino acid yield in different shelf regions. The error bar represents two times standard error.

productive season (Figure 2). High amino acid yields (2–4%) were widespread and occurred repeatedly over the Chukchi Sea during the summers of 2002, 2004, and 2012 (Table 1). These elevated yields were equivalent to high concentrations of labile DOC (5–12 μmol L^{-1}; Figure 3) and were consistent with high primary productivity (avg.: 0.4–1.6 g C m^{-2} d^{-1}) during the sampling periods (Kirchman et al., 2009; Yun et al., 2016). The active production of labile DOM sustained high rates of bacterial production in the shelf waters (avg.: 25–50 mg C m^{-2} d^{-1}) (Kirchman et al., 2009), resulting in formation of hot spots with enhanced microbial metabolism and nutrient regeneration. In comparison, yields of amino acids (1.1–1.6%) and concentrations of labile DOC (1–3 μmol L^{-1}) in the Barents Sea during summer 2013 were lower than most values observed in the Chukchi Sea (Figures 2 and 3). These observations highlight spatial and temporal heterogeneity in the distributions of hot spots and hot moments in these relatively productive inflow shelf environments.

In contrast, amino acid yields determined in surface waters of interior shelves were among the lowest observed (mostly 0.5–1.1%; Table 1 and Figure 2). The low amino acid yields were in sharp contrast to the

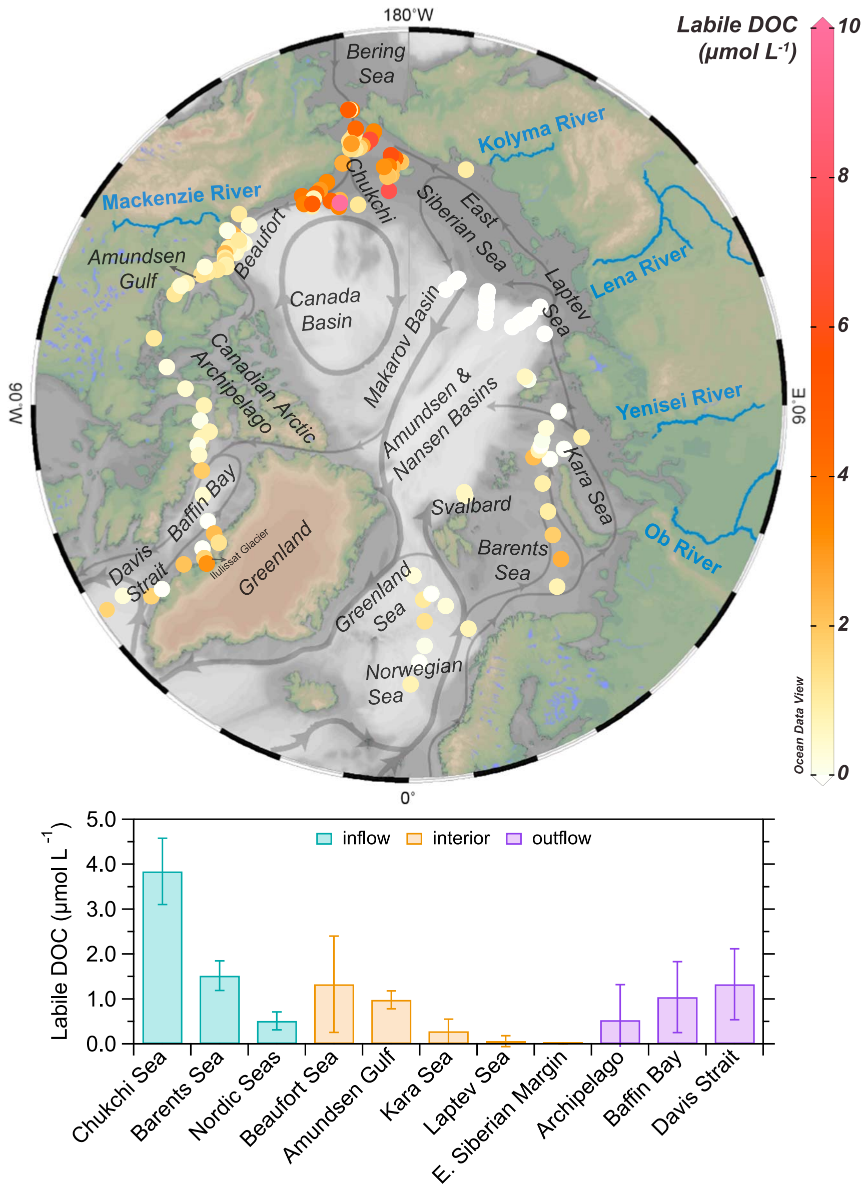

Figure 3. Pan-Arctic distributions of concentrations of labile dissolved organic carbon (DOC) in surface water (≤20 m). Schematic surface circulation was modified from Talley et al. (2011). The lower panel shows the average concentration of labile DOC in different shelf regions. The error bar represents two times standard error.

elevated DOC concentrations in the region, indicating an abundance of DOM with limited bioavailability. The generally low bioavailability of DOM in interior shelves is due in part to the generally low primary production associated with high water turbidity and low nutrient concentrations (Carmack et al., 2004; Williams & Carmack, 2015). Concentrations of labile DOC (~1.0 μmol L^{-1}) in the Beaufort Sea and Amundsen Gulf were greater than those in the Kara Sea (<0.5 μmol L^{-1}) during the summer (Figure 3). Very low concentrations of labile DOC (<0.1 μmol L^{-1}) were observed in the Laptev Sea and East Siberian margin during the fall (Figure 3). Some of the observed regional variability in bioavailable DOM was seasonal, as, primary production declines from summer to fall. Another important factor influencing the abundance of bioavailable DOM is water residence time. Surface waters have considerably shorter residence times on the narrow Beaufort shelf (several months) than the wide Eurasian and Siberian shelves (a few years) (Hanzlick & Aagaard, 1980; Macdonald et al., 1989; Schlosser et al., 1994). Longer shelf residence times over the Eurasian and Siberian shelves facilitate the microbial utilization of bioavailable DOM (Kaiser et al., 2017). The relatively low bioavailability of DOM in the Beaufort Sea was found to limit bacterial growth and production even during the summer (Ortega-Retuerta et al., 2012), and this is likely the case on the other oligotrophic interior shelves.

Amino acid yields in the outflow gateways indicated the presence of bioavailable DOM in the Canadian Arctic Archipelago and the production of labile DOM in Baffin Bay (Figures 2 and 3). Water samples were collected during a low-light period (September–October), and the observed spatial variation in DOM bioavailability appeared to reveal light-driven changes in primary productivity across regions with varying sea ice extent. Sea ice was present in surface waters of the Canadian Archipelago during sampling, further reducing the light availability and plankton production. The relatively long water transit time through the Archipelago (several years) (Nguyen et al., 2011) allows extensive microbial degradation, which could also have contributed to the low bioavailability of DOM ($<$1.0 μmol L^{-1} of labile DOC; Figure 3). In comparison, elevated amino acid yields (1.1–1.4%) were observed along the west Greenland coast indicating plankton production of labile DOC (~2 μmol L^{-1}; Figure 3). These areas were influenced by the warm West Greenland Current and were ice-free during the sampling months. In addition, most stations were located near the outflow of glaciers (e.g., the Ilulissat Glacier; Figure 3) and could have received additional input of nutrients from glacial meltwater (Jensen et al., 1999). Previous seasonal surveys in the west Greenland coastal region have observed low-moderate levels of phytoplankton biomass and production during the fall (Juul-Pedersen et al., 2015). The negative correspondence between DOM bioavailability and sea ice extent has also been observed in surface waters of the Southern Ocean during austral winter (Shen et al., 2017).

The extensive continental shelves are a major source of bioavailable DOM, and comparison of cross-shelf distributions of bioavailable DOM with known water circulation patterns implies variable transport of shelf-derived substrates to central basins. Wind-driven water transport, eddies, and brine formation deliver water and DOM from the shelves to different regions of deep basins (Davis & Benner, 2007; Mathis et al., 2007; Shen, Benner, et al., 2016). The upper water column of the Canada Basin receives Pacific waters that are modified on the productive Chukchi shelf (Davis & Benner, 2007; Jones & Anderson, 1986; Shen, Benner, et al., 2016). The Makarov, Amundsen, and Nansen Basins receive Atlantic waters that flow through the Barents Sea and the Eurasian and Siberian shelves (Rudels, 2009). DOM in these eastern Arctic regions is typically of lower bioavailability than that in the Chukchi Sea (Figures 2 and 3). Thus, it seems that the Canada Basin receives more bioavailable DOM than the other Arctic basins. The decadal residence time in the surface Canada Basin further facilitates microbial and photochemical processing of DOM and associated release of inorganic nutrients into oligotrophic waters (Rutgers Van Der Loeff et al., 1995; Shen, Benner, et al., 2016; Walsh et al., 1989). Bioavailable DOM exported off the shelves may also provide priming agents for the co-metabolism of refractory DOM in the adjacent deep basins (Guenet et al., 2010).

Overall, this study illustrates a pan-Arctic correspondence between ecosystem production and DOM bioavailability in ocean margins. Heterogeneous distributions of bioavailable DOM were observed among the inflow, outflow, and interior shelves, reflecting spatial and temporal variabilities in environmental conditions and biological productivity throughout the Arctic margins. Climate change in the Arctic is rapidly altering physico-chemical conditions (e.g., sea ice extent, water stratification, and nutrient supply) and shaping plankton community structure and function in a very complex manner (Blais et al., 2017; Steiner et al., 2015). Increasing upwelling and diatom abundance along interior shelves will likely enhance productivity and DOM bioavailability, whereas increasing meltwater and stratification might reduce productivity in outflow shelves (Blais et al., 2017; Williams & Carmack, 2015). Fluctuations in marine productivity affect production of bioavailable DOM that fuels the diverse microbial food webs and the rapid regeneration of nutrients in margin surface waters. The application of amino acid-based molecular indicators would facilitate broad-scale mapping of bioavailable DOM and help decipher the dynamics of the changing Arctic ecosystems.

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References

Alling, V., Sanchez-Garcia, L., Porcelli, D., Pugach, S., Vonk, J. E., van Dongen, B., … Andersson, P. (2010). Nonconservative behavior of dissolved organic carbon across the Laptev and East Siberian seas. *Global Biogeochemical Cycles*, *24*, GB4033. https://doi.org/10.1029/2010GB003834

Amon, R. M. W., & Benner, R. (2003). Combined neutral sugars as indicators of the diagenetic state of dissolved organic matter in the Arctic Ocean. *Deep-Sea Research Part I*, *50*(1), 151–169. https://doi.org/10.1016/S0967-0637(02)00130-9

Anderson, L. G., & Amon, R. M. W. (2015). DOM in the Arctic Ocean. In D. A. Hansell & C. A. Carlson (Eds.), *Biogeochemistry of marine dissolved organic matter* (2nd ed., pp. 609–633). Boston, MA: Academic Press. https://doi.org/10.1016/B978-0-12-405940-5.00014-5

Azam, F., & Malfatti, F. (2007). Microbial structuring of marine ecosystems. *Nature Reviews Microbiology*, *5*(10), 782–791. https://doi.org/10.1038/nrmicro1747

Banse, K. (1995). Zooplankton: Pivotal role in the control of ocean production: I. Biomass and production. *ICES Journal of Marine Science*, *52*(3-4), 265–277. https://doi.org/10.1016/1054-3139(95)80043-3

Bauch, D., Gröger, M., Dmitrenko, I., Hölemann, J., Kirillov, S., Mackensen, A., … Andersen, N. (2011). Atmospheric controlled freshwater release at the Laptev Sea continental margin. *Polar Research*, *30*(1), 5858. https://doi.org/10.3402/polar.v30i0.5858

Benner, R. (2003). Molecular indicators of the bioavailability of dissolved organic matter. In S. Findlay & R. Sinsabaugh (Eds.), *Aquatic ecosystems: Interactivity of dissolved organic matter* (pp. 121–137). Amsterdam: Academic Press. https://doi.org/10.1016/B978-012256371-3/50006-8

Benner, R., & Strom, M. (1993). A critical evaluation of the analytical blank associated with DOC measurements by high-temperature catalytic oxidation. *Marine Chemistry*, *41*(1-3), 153–160. https://doi.org/10.1016/0304-4203(93)90113-3

Blais, M., Ardyna, M., Gosselin, M., Dumont, D., Bélanger, S., Tremblay, J.-É., … Poulin, M. (2017). Contrasting interannual changes in phytoplankton productivity and community structure in the coastal Canadian Arctic Ocean. *Limnology and Oceanography*.

Carlson, C. A., & Hansell, D. A. (2015). DOM sources, sinks, reactivity, and budgets. In D. A. Hansell & C. A. Carlson (Eds.), *Biogeochemistry of marine dissolved organic matter* (2nd ed., pp. 65–126). Boston, MA: Academic Press. https://doi.org/10.1016/B978-0-12-405940-5.00003-0

Carmack, E. C., Macdonald, R. W., & Jasper, S. (2004). Phytoplankton productivity on the Canadian Shelf of the Beaufort Sea. *Marine Ecology Progress Series*, *277*, 37–50. https://doi.org/10.3354/meps277037

Carmack, E. C., & Wassmann, P. (2006). Food webs and physical-biological coupling on pan-Arctic shelves: Unifying concepts and comprehensive perspectives. *Progress in Oceanography*, *71*(2-4), 446–477. https://doi.org/10.1016/j.pocean.2006.10.004

Davis, J., & Benner, R. (2005). Seasonal trends in the abundance, composition and bioavailability of particulate and dissolved organic matter in the Chukchi/Beaufort Seas and western Canada Basin. *Deep-sea research. Part II: Topical Studies in Oceanography*, *52*(24-26), 3396–3410. https://doi.org/10.1016/j.dsr2.2005.09.006

Davis, J., & Benner, R. (2007). Quantitative estimates of labile and semi-labile dissolved organic carbon in the western Arctic Ocean: A molecular approach. *Limnology and Oceanography*, *52*(6), 2434–2444. https://doi.org/10.4319/lo.2007.52.6.2434

Druffel, E., Griffin, S., Glynn, C., Benner, R., & Walker, B. (2017). Radiocarbon in dissolved organic and inorganic carbon of the Arctic Ocean. *Geophysical Research Letters*, *44*, 2369–2376. https://doi.org/10.1002/2016GL072138

Fichot, C. G., Kaiser, K., Hooker, S. B., Amon, R. M. W., Babin, M., Bélanger, S., … Benner, R. (2013). Pan-Arctic distributions of continental runoff in the Arctic Ocean. *Scientific Reports*, *3*(1). https://doi.org/10.1038/srep01053

Goldberg, S. J., Carlson, C. A., Bock, B., Nelson, N. B., & Siegel, D. A. (2010). Meridional variability in dissolved organic matter stocks and diagenetic state within the euphotic and mesopelagic zone of the North Atlantic subtropical gyre. *Marine Chemistry*, *119*(1-4), 9–21. https://doi.org/10.1016/j.marchem.2009.12.002

Guenet, B., Danger, M., Abbadie, L., & Lacroix, G. (2010). Priming effect: Bridging the gap between terrestrial and aquatic ecology. *Ecology*, *91*(10), 2850–2861. https://doi.org/10.1890/09-1968.1

Hanzlick, D., & Aagaard, K. (1980). Freshwater and Atlantic water in the Kara Sea. *Journal of Geophysical Research*, *85*(C9), 4937–4942. https://doi.org/10.1029/JC085iC09p04937

Hill, V. J., Matrai, P. A., Olson, E., Suttles, S., Steele, M., Codispoti, L., & Zimmerman, R. C. (2013). Synthesis of integrated primary production in the Arctic Ocean: II. In situ and remotely sensed estimates. *Progress in Oceanography*, *110*, 107–125. https://doi.org/10.1016/j.pocean.2012.11.005

Jakobsson, M., Grantz, A., Kristoffersen, Y., & Macnab, R. (2004). Physiography and bathymetry of the Arctic Ocean. In R. Stein & R. Macdonald (Eds.), *The organic carbon cycle in the Arctic Ocean* (pp. 1–6). Berlin: Springer-Verlag. https://doi.org/10.1007/978-3-642-18912-8_1

Jensen, H. M., Pedersen, L., Burmeister, A., & Winding Hansen, B. (1999). Pelagic primary production during summer along 65 to 72 N off West Greenland. *Polar Biology*, *21*(5), 269–278. https://doi.org/10.1007/s003000050362

Jones, E. P., & Anderson, L. G. (1986). On the origin of the chemical-properties of the Arctic-ocean halocline. *Journal of Geophysical Research*, *91*(C9), 759–767.

Juul-Pedersen, T., Arendt, K. E., Mortensen, J., Blicher, M. E., Søgaard, D. H., & Rysgaard, S. (2015). Seasonal and interannual phytoplankton production in a sub-Arctic tidewater outlet glacier fjord, SW Greenland. *Marine Ecology Progress Series*, *524*, 27–38. https://doi.org/10.3354/meps11174

Kaiser, K., & Benner, R. (2005). Hydrolysis-induced racemization of amino acids. *Limnology and Oceanography: Methods*, *3*(8), 318–325. https://doi.org/10.4319/lom.2005.3.318

Kaiser, K., & Benner, R. (2009). Biochemical composition and size distribution of organic matter at the Pacific and Atlantic time-series stations. *Marine Chemistry*, *113*(1-2), 63–77. https://doi.org/10.1016/j.marchem.2008.12.004

Kaiser, K., Benner, R., & Amon, R. M. W. (2017). The fate of terrigenous dissolved organic carbon on the Eurasian shelves and export to the North Atlantic. *Journal of Geophysical Research: Oceans*, *122*, 4–22. https://doi.org/10.1002/2016JC012380

Kattner, G., Lobbes, J. M., Fitznar, H. P., Engbrodt, R., Nöthig, E. M., & Lara, R. J. (1999). Tracing dissolved organic substances and nutrients from the Lena River through Laptev Sea (Arctic). *Marine Chemistry*, *65*(1-2), 25–39. https://doi.org/10.1016/S0304-4203(99)00008-0

Kim, T.-H., Kim, G., Shen, Y., & Benner, R. (2017). Strong linkages between surface and deep-water dissolved organic matter in the East/Japan Sea. *Biogeosciences*, *14*(9), 2561–2570. https://doi.org/10.5194/bg-14-2561-2017

Kirchman, D. L., Hill, V., Cottrell, M. T., Gradinger, R., Malmstrom, R. R., & Parker, A. (2009). Standing stocks, production, and respiration of phytoplankton and heterotrophic bacteria in the western Arctic Ocean. *Deep-Sea Research. Part II: Topical Studies in Oceanography*, *56*(17), 1237–1248. https://doi.org/10.1016/j.dsr2.2008.10.018

Macdonald, R., Carmack, E., McLaughlin, F., Iseki, K., Macdonald, D., & O'Brien, M. (1989). Composition and modification of water masses in the Mackenzie Shelf Estuary. *Journal of Geophysical Research*, *94*(C12), 18,057–18,070. https://doi.org/10.1029/JC094iC12p18057

Mannino, A., & Harvey, H. R. (2000). Biochemical composition of particles and dissolved organic matter along an estuarine gradient: Sources and implications for DOM reactivity. *Limnology and Oceanography*, *45*(4), 775–788. https://doi.org/10.4319/lo.2000.45.4.0775

Mathis, J. T., Pickart, R. S., Hansell, D. A., Kadko, D., & Bates, N. R. (2007). Eddy transport of organic carbon and nutrients from the Chukchi Shelf: Impact on the upper halocline of the western Arctic Ocean. *Journal of Geophysical Research*, *112*, C05011. https://doi.org/10.1029/2006JC003899

McClain, M. E., Boyer, E. W., Dent, C. L., Gergel, S. E., Grimm, N. B., Groffman, P. M., … Mayorga, E. (2003). Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. *Ecosystems*, *6*(4), 301–312. https://doi.org/10.1007/s10021-003-0161-9

Michel, C., Ingram, R., & Harris, L. (2006). Variability in oceanographic and ecological processes in the Canadian Arctic Archipelago. *Progress in Oceanography*, *71*(2-4), 379–401. https://doi.org/10.1016/j.pocean.2006.09.006

Nagata, T. (2000). Production mechanisms of dissolved organic matter. *Microbial Ecology of the Oceans*, 121–152.

Nguyen, A. T., Menemenlis, D., & Kwok, R. (2011). Arctic ice-ocean simulation with optimized model parameters: Approach and assessment. *Journal of Geophysical Research*, *116*, C04025. https://doi.org/10.1029/2010JC006573

Ortega-Retuerta, E., Jeffrey, W., Babin, M., Bélanger, S., Benner, R., Marie, D., … Joux, F. (2012). Carbon fluxes in the Canadian Arctic: Patterns and drivers of bacterial abundance, production and respiration on the Beaufort Sea margin. *Biogeosciences*, *9*(9), 3679–3692. https://doi.org/10.5194/bg-9-3679-2012

Rudels, B. (2009). Arctic Ocean Circulation. In J. H. Steele, S. A. Thorpe, & K. K. Turekian (Eds.), *Encyclopedia of ocean sciences* (2nd ed., pp. 211–225). Oxford: Academic Press. https://doi.org/10.1016/B978-012374473-9.00601-9

Rutgers Van Der Loeff, M. M., Key, R. M., Scholten, J., Bauch, D., & Michel, A. (1995). 228 Ra as a tracer for shelf water in the Arctic Ocean. *Deep-Sea Research. Part II: Topical Studies in Oceanography*, *42*(6), 1533–1553. https://doi.org/10.1016/0967-0645(95)00053-4

Sakshaug, E. (2004). Primary and secondary production in the Arctic seas. In R. Stein & R. Macdonald (Eds.), *The organic carbon cycle in the Arctic Ocean* (pp. 57–81). Berlin: Springer-Verlag. https://doi.org/10.1007/978-3-642-18912-8_3

Schlosser, P., Bauch, D., Fairbanks, R., & Bönisch, G. (1994). Arctic river-runoff: Mean residence time on the shelves and in the halocline. *Deep-Sea Research Part I*, *41*(7), 1053–1068. https://doi.org/10.1016/0967-0637(94)90018-3

Shen, Y., Benner, R., Murray, A. E., Gimpel, C., Mitchell, B. G., Weiss, E. L., & Reiss, C. (2017). Bioavailable dissolved organic matter and biological hot spots during austral winter in Antarctic waters. *Journal of Geophysical Research: Oceans*, *122*, 508–520. https://doi.org/10.1002/2016JC012301

Shen, Y., Benner, R., Robbins, L. L., & Wynn, J. G. (2016). Sources, distributions, and dynamics of dissolved organic matter in the Canada and Makarov Basins. *Frontiers in Marine Science*, *3*(198). https://doi.org/10.3389/fmars.2016.00198

Shen, Y., Fichot, C. G., & Benner, R. (2012). Dissolved organic matter composition and bioavailability reflect ecosystem productivity in the Western Arctic Ocean. *Biogeosciences*, *9*(12), 4993–5005. https://doi.org/10.5194/bg-9-4993-2012

Shen, Y., Fichot, C. G., Liang, S.-K., & Benner, R. (2016). Biological hot spots and the accumulation of marine dissolved organic matter in a highly productive ocean margin. *Limnology and Oceanography*, *61*(4), 1287–1300. https://doi.org/10.1002/lno.10290

Sorokin, Y. I., & Sorokin, P. Y. (1996). Plankton and primary production in the Lena River estuary and in the south-eastern Laptev Sea. *Estuarine, Coastal and Shelf Science*, *43*(4), 399–418. https://doi.org/10.1006/ecss.1996.0078

Steiner, N., Azetsu-Scott, K., Hamilton, J., Hedges, K., Hu, X., Janjua, M. Y., … Merzouk, A. (2015). Observed trends and climate projections affecting marine ecosystems in the Canadian Arctic. *Environmental Reviews*, *23*(2), 191–239. https://doi.org/10.1139/er-2014-0066

Talley, L. D., Pickard, G. L., Emery, W. J., & Swift, J. H. (2011). Arctic Ocean and Nordic Seas. In L. D. Talley, et al. (Eds.), *Descriptive Physical Oceanography (Sixth Edition)* (pp. 401–436). Boston, MA: Academic Press. https://doi.org/10.1016/B978-0-7506-4552-2.10012-5

Tremblay, J. E., & Gagnon, J. (2009). The effects of irradiance and nutrient supply on the productivity of Arctic waters: A perspective on climate change. In J. C. J. Nihoul & A. G. Kostianoy (Eds.), *Influence of climate change on the changing Arctic and sub-Arctic conditions* (pp. 73–93). Dordrecht, Netherlands: Springer. https://doi.org/10.1007/978-1-4020-9460-6_7

Tremblay, L., Caparros, J., Leblanc, K., & Obernosterer, I. (2015). Origin and fate of particulate and dissolved organic matter in a naturally iron-fertilized region of the Southern Ocean. *Biogeosciences*, *12*(2), 607–621. https://doi.org/10.5194/bg-12-607-2015

Walsh, J. J., McRoy, C. P., Coachman, L. K., Goering, J. J., Nihoul, J. J., Whitledge, T. E., … Dean, K. (1989). Carbon and nitrogen cycling within the Bering/Chukchi Seas: Source regions for organic-matter effecting AOU demands of the Arctic Ocean. *Progress in Oceanography*, *22*(4), 277–359. https://doi.org/10.1016/0079-6611(89)90006-2

Williams, W. J., & Carmack, E. C. (2015). The 'interior'shelves of the Arctic Ocean: Physical oceanographic setting, climatology and effects of sea-ice retreat on cross-shelf exchange. *Progress in Oceanography*, *139*, 24–41. https://doi.org/10.1016/j.pocean.2015.07.008

Yun, M., Whitledge, T., Stockwell, D., Son, S., Lee, J., Park, J., … Lee, S. (2016). Primary production in the Chukchi Sea with potential effects of freshwater content. *Biogeosciences*, *13*(3), 737–749. https://doi.org/10.5194/bg-13-737-2016

Geophysical Research Letter

Supporting Information for

Pan-Arctic distribution of bioavailable dissolved organic matter and linkages with productivity in ocean margins

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Supplementary Table 1. Sampling location and concentrations of dissolved organic carbon (DOC), labile DOC, total dissolved amino acids (TDAA), and DOC-normalized yields of TDAA in surface waters (≤20 m) of Arctic margin.

Sampling location	Project	Station	Date	LAT	LONG	Bott_Dep	Dep	Temp	Salinity	DOC	Labile DOC	TDAA	TDAA yield
				N	E	m	m	˚C		μmol L^{-1}	μmol L^{-1}	nmol L^{-1}	%DOC
E. Chukchi	RUSALCA	CEN1B	9/6/2012	70.62	-177.97	42	0	-0.1	28.5	67.9	1.9	248	1.24
E. Chukchi	RUSALCA	CEN2	9/6/2012	70.57	-177.64	45	0	-0.6	28.8	71.3	2.0	270	1.26
E. Chukchi	RUSALCA	CEN3	9/6/2012	70.28	-176.67	57	0	0.5	30.4	74.8	4.4	419	1.89
E. Chukchi	RUSALCA	HC3	9/8/2012	71.00	-175.93	48	0	1.2	31.7	71.1	2.2	278	1.32
E. Chukchi	RUSALCA	CEN4	9/6/2012	69.98	-175.69	63	0	4.1	31.6	75.3	5.9	456	2.29
E. Chukchi	RUSALCA	HC18	9/9/2012	71.62	-175.41	55	0	-0.8	28.6	63.9	2.1	250	1.33
E. Chukchi	RUSALCA	HC2	9/7/2012	70.90	-175.01	74	0	2.7	31.8	69.6	3.5	335	1.72
E. Chukchi	RUSALCA	HC22	9/8/2012	71.71	-174.89	71	0	-0.3	27.9	65.9	1.8	233	1.22
E. Chukchi	RUSALCA	HC22	9/8/2012	71.71	-174.89	71	20	-0.4	31.5	75.3	1.7	263	1.17
E. Chukchi	RUSALCA	HC70	9/11/2012	72.94	-174.42	100	0	-1.1	27.3	56.0	7.3	450	3.21
E. Chukchi	RUSALCA	HC70	9/11/2012	72.94	-174.42	100	20	-1.2	30.1	65.6	2.4	284	1.41
E. Chukchi	RUSALCA	HC26	9/8/2012	71.79	-174.39	55	0	-0.4	27.8	56.1	2.0	212	1.31
E. Chukchi	RUSALCA	HC1	9/7/2012	70.92	-173.90	40	0	3.8	32.0	67.8	3.1	310	1.59
E. Chukchi	RUSALCA	CL8	9/13/2012	67.87	-172.55	53	3	2.6	28.0	103.8	3.4	423	1.48
E. Chukchi	RUSALCA	CL8	9/13/2012	67.87	-172.55	53	15	2.5	32.0	143.1	8.6	757	2.11
E. Chukchi	RUSALCA	CL6A	9/3/2012	68.33	-171.74	58	0	2.8	30.8	73.4	3.4	318	1.63
E. Chukchi	RUSALCA	CL6	9/2/2012	68.52	-171.46	60	0	2.7	31.0	72.1	6.7	467	2.56
E. Chukchi	RUSALCA	CL6	9/2/2012	68.52	-171.46	60	12	2.4	31.4	75.1	10.2	638	3.42
E. Chukchi	RUSALCA	CL5	9/2/2012	68.75	-170.42	61	15	2.4	32.4	65.8	6.7	460	2.70
E. Chukchi	RUSALCA	CL4	9/2/2012	68.88	-169.61	58	0	4.9	30.9	83.4	2.7	335	1.40
E. Chukchi	RUSALCA	CL3R	9/12/2012	69.00	-168.90	57	0	4.6	27.5	97.8	2.4	362	1.30
E. Chukchi	RUSALCA	CL3	9/2/2012	69.00	-168.89	54	0	7.5	28.7	109.1	1.7	364	1.15
E. Chukchi	RUSALCA	CS12	9/1/2012	67.87	-168.31	58	0	2.9	27.7	78.7	1.0	233	1.01
W. Chukchi	RUSALCA	CL2	9/2/2012	69.03	-167.93	51	0	7.8	29.0	103.2	1.1	322	1.04
W. Chukchi	RUSALCA	CS16	9/1/2012	68.13	-167.64	51	0	5.4	31.3	67.4	1.5	233	1.14
W. Chukchi	RUSALCA	CS17	9/1/2012	68.30	-167.04	40	0	7.9	28.9	100.4	1.3	311	1.09
W. Chukchi	RUSALCA	CL1	9/2/2012	68.95	-166.92	47	0	8.5	27.8	106.7	1.5	345	1.13
W. Chukchi	SBI	1	7/16/2002	65.67	-168.21	42	17	9.6	30.2	121.0	2.1	494	1.17
W. Chukchi	SBI	7	7/18/2002	68.52	-167.39	45	11	7.7	31.4	82.0	2.9	399	1.38
W. Chukchi	SBI	43	8/18/2002	73.63	-165.40	123	16	-0.2	28.0	67.3	1.2	264	1.02
W. Chukchi	SBI	8	7/19/2002	69.96	-164.40	33	11	1.2	30.3	86.6	2.8	428	1.40
W. Chukchi	SBI	39	8/17/2002	72.80	-161.09	51	11	-0.3	27.8	73.4	2.4	344	1.35
W. Chukchi	SBI	39	8/17/2002	72.80	-161.09	51	19	-1.5	32.2	92.3	11.7	983	3.23
W. Chukchi	SBI	38	8/16/2002	72.99	-160.65	95	16	-1.0	30.3	74.4	2.1	339	1.22
W. Chukchi	SBI	10	7/20/2002	71.06	-159.48	76	16	-1.6	31.5	73.9	6.7	581	2.42
W. Chukchi	SBI	26	8/5/2002	72.62	-158.68	117	11	-1.2	29.9	80.4	4.5	479	1.35
W. Chukchi	SBI	19	7/29/2002	71.94	-152.06	2118	17	-1.4	29.4	76.7	2.7	393	1.41
W. Chukchi	SBI	5	7/18/2004	65.72	-168.90	47	11	4.4	32.7	64.1	3.7	353	1.77
W. Chukchi	SBI	6	7/19/2004	67.36	-168.90	49	11	8.6	32.3	67.4	4.3	420	1.93
W. Chukchi	SBI	3	7/18/2004	65.68	-168.56	52	11	2.9	32.2	66.6	0.8	156	0.81
W. Chukchi	SBI	1	7/18/2004	65.66	-168.21	40	9	9.9	30.1	83.9	4.8	515	1.82
W. Chukchi	SBI	7	7/19/2004	68.50	-167.40	44	11	9.8	30.8	109.1	1.7	384	1.13
W. Chukchi	SBI	8	7/20/2004	69.95	-164.40	32	13	7.0	30.5	114.1	2.6	479	1.30
W. Chukchi	SBI	59	8/22/2004	73.06	-160.83	152	15	-0.2	29.0	70.4	13.0	949	4.23
W. Chukchi	SBI	55	8/19/2004	73.31	-160.13	1233	15	1.6	29.0	73.5	3.4	400	1.58
W. Chukchi	SBI	14	7/21/2004	71.06	-159.44	75	11	-0.7	29.9	83.6	3.3	406	1.51
W. Chukchi	SBI	14	7/21/2004	71.06	-159.44	75	19	-0.7	32.0	97.6	7.1	693	2.26
W. Chukchi	SBI	15	7/21/2004	71.44	-157.27	126	8	-0.7	29.1	67.6	3.0	355	1.66
W. Chukchi	SBI	15	7/22/2004	71.44	-157.27	126	18	-1.0	31.0	72.4	6.1	564	2.55
W. Chukchi	SBI	21	7/23/2004	71.62	-155.89	202	12	-0.9	29.7	72.5	4.2	413	1.95
W. Chukchi	SBI	22	7/25/2004	71.93	-154.83	435	10	-0.2	29.8	75.4	1.7	297	1.24
W. Chukchi	SBI	23	7/26/2004	71.96	-154.72	775	18	-0.1	31.5	78.0	11.3	818	3.76
W. Chukchi	SBI	35	8/5/2004	72.22	-153.99	2039	10	4.8	30.4	80.8	4.8	525	2.13

Sampling location	Project	Station	Date	LAT	LONG	Bott_Dep	Dep	Temp	Salinity	DOC	Labile DOC	TDAA	TDAA yield
				N	E	m	m	˚C		μmol L^{-1}	μmol L^{-1}	nmol L^{-1}	%DOC
W. Chukchi	SBI	36	8/7/2004	72.39	-153.57	2890	16	3.2	29.6	71.0	1.0	247	1.12
W. Chukchi	SBI	25	7/26/2004	71.29	-152.54	50	20	5.4	30.8	80.6	2.9	387	1.61
W. Chukchi	SBI	25	7/26/2004	71.30	-152.53	54	16	6.3	30.6	83.5	3.8	451	1.83
W. Chukchi	SBI	32	8/2/2004	71.93	-152.07	2187	14	0.1	31.0	75.4	3.5	396	1.78
Beaufort	CFL	9	2008	69.76	-133.36	6.8	0		29.9	106.2	0.9	318	1.00
Beaufort	CFL	1601-10A	2008	71.57	-130.71	330	5	4.8	27.3	81.1	0.5	198	0.88
Beaufort	MALINA	690	8/1/2009	69.48	-137.93	51	12	1.6	29.0	80.8	1.1	263	1.02
Beaufort	MALINA	540	8/17/2009	70.76	-137.87	1522	3			65.8	0.4	160	0.78
Beaufort	MALINA	320	8/9/2009	71.56	-133.95	1115	20	-0.7	28.0	70.4	0.2	169	0.74
Beaufort	MALINA	340	8/9/2009	71.17	-133.83	590	20	0.0	28.6	72.5	0.1	172	0.73
Beaufort	MALINA	360	8/8/2009	70.80	-133.73	74	20	-0.6	29.7	70.5	0.0	163	0.70
Beaufort	MALINA	380	8/8/2009	70.39	-133.60	62	6	3.7	27.7	77.0	2.3	297	1.33
Beaufort	MALINA	390	7/31/2009	70.18	-133.56	58	4	5.2	27.2	103.7	2.3	364	1.26
Beaufort	MALINA	390	7/31/2009	70.18	-133.56	58	10	2.2	29.8	85.3	0.9	240	0.98
Beaufort	MALINA	394	8/3/2009	69.85	-133.49	14	4	5.4	27.5	146.0	0.1	387	0.91
Beaufort	MALINA	394	8/3/2009	69.85	-133.49	14	11	0.1	31.0	92.4	11.6	769	3.29
Beaufort	MALINA	345	8/14/2009	71.41	-132.64	580	4	2.0		65.7	0.6	174	0.84
Beaufort	MALINA	260	8/4/2009	71.27	-130.60	59	12	4.3	29.4	73.5	0.4	187	0.83
Beaufort	MALINA	280	8/4/2009	70.87	-130.51	38	4	4.7	27.6	91.6	1.0	265	1.00
Beaufort	MALINA	280	8/4/2009	70.87	-130.51	38	18	1.2	30.8	80.2	0.3	202	0.82
Beaufort	MALINA	170	8/7/2009	70.92	-128.92	35	5	3.3	29.3	113.7	2.3	397	1.26
Beaufort	MALINA	170	8/7/2009	70.92	-128.92	35	20	-1.2	31.8	70.1	0.4	181	0.79
Beaufort	MALINA	150	8/7/2009	71.16	-128.16	66	10	3.5	29.4	76.9	1.0	227	0.99
Beaufort	MALINA	135	8/20/2009	71.31	-127.50	225	4	2.1	27.9	68.2	0.7	184	0.89
Beaufort	TARA	196	9/14/2013	71.89	-154.91		3.1	2.5	28.8	82.8	0.7	247	1.04
Amundsen Gulf	CFL	CA04-07	2008	71.07	-133.58	296	5	6.1	27.6	76.4	1.1	222	1.00
Amundsen Gulf	CFL	CA05-08	2008	71.32	-127.74	179	4	5.2	28.2	69.0	1.5	218	1.12
Amundsen Gulf	CFL	412-10A	2008	71.56	-126.92	416	5	7.0	28.8	78.7	0.8	230	0.94
Amundsen Gulf	CFL	437-10A	2008	71.70	-126.62	440	5	7.2	28.2	68.3	0.9	206	0.95
Amundsen Gulf	CFL	1901-10A	2008	71.22	-124.70	274	5	7.3	29.2	73.1	1.2	234	1.02
Amundsen Gulf	CFL	CA18-08	2008	70.69	-123.05	541	4	8.1	30.2	70.1	1.3	225	1.07
Amundsen Gulf	CFL	405-10A	2008	70.69	-122.90	584	5	7.4	30.7	73.5	1.1	230	1.00
Amundsen Gulf	CFL	404-10A	2008	70.35	-121.60	479	5	7.6	30.5	66.4	1.3	224	1.05
Amundsen Gulf	CFL	402-10A	2008	69.60	-118.13	433	5	8.0	29.1	77.1	0.8	226	0.93
Amundsen Gulf	CFL	401-10A	2008	69.24	-116.60	176	5	2.5	30.7	76.5	0.9	234	0.96
Amundsen Gulf	CFL	400-10A	2008	69.11	-114.79	138	5	3.2	27.7	78.8	1.2	253	1.02
Amundsen Gulf	TARA	underway	9/22/2013	70.23	-123.56		1.5	0.8	29.1	114.2	0.3	318	0.98
Amundsen Gulf	TARA	underway	9/23/2013	69.27	-117.04		1.5			89.4	0.4	244	0.96
Archipelago	TARA	underway	9/25/2013	68.70	-104.18		1.5			55.7	1.1	168	1.08
Archipelago	TARA	underway	9/26/2013	70.24	-98.28		1.5			73.4	0.2	193	0.87
Archipelago	TARA	200	9/27/2013	71.99	-93.52		3.9	-1.4	29.5	72.9	0.4	198	0.89
Archipelago	TARA	underway	9/28/2013	73.52	-89.19		1.5			85.9	0.8	257	1.06
Archipelago	TARA	202	10/3/2013	73.17	-85.05		3.2	-1.1	29.5	83.4	0.1	206	0.87
Archipelago	TARA	underway	10/4/2013	73.86	-81.68		1.5			76.4	0.8	232	1.07
Archipelago	TARA	203	10/5/2013	73.09	-80.37		2.8	-0.9	30.0	70.4	0.8	205	1.00
Archipelago	TARA	204	10/6/2013	72.67	-78.47		2.9	-0.7	29.8	69.2	0.1	166	0.80
Baffin Bay	TARA	underway	10/7/2013	72.63	-75.91		1.5			75.1	0.5	210	0.94
Baffin Bay	TARA	205	10/8/2013	72.47	-71.89		3.6	-0.4	32.0	75.3	1.9	279	1.34
Baffin Bay	TARA	underway	10/9/2013	71.82	-65.89		1.5			76.6	0.4	207	0.94
Baffin Bay	TARA	underway	10/10/2013	71.19	-59.45		1.5			96.7	0.0	245	0.86
Baffin Bay	TARA	underway	10/11/2013	71.06	-56.07		1.5	2.6	33.0	73.4	2.2	288	1.42
Baffin Bay	TARA	206	10/12/2013	70.96	-53.60		2.8	1.5	32.1	65.7	1.3	220	1.17
Davis Strait	TARA	210	10/27/2013	61.54	-55.99		3.0	5.3	34.2	64.4	0.3	157	0.86
Davis Strait	TARA	underway	10/28/2013	59.66	-55.53		3.0	5.4	34.2	68.5	1.7	246	1.27
Davis Strait	TARA	underway	10/14/2013	69.55	-54.79		1.5	3.2	33.1	76.9	0.0	171	0.79
Davis Strait	TARA	underway	10/21/2013	67.49	-54.28		1.5			74.9	2.1	299	1.38

Sampling location	Project	Station	Date	LAT	LONG	Bott_Dep	Dep	Temp	Salinity	DOC	Labile DOC	TDAA	TDAA yield
				N	E	m	m	˚C		μmol L^{-1}	μmol L^{-1}	nmol L^{-1}	%DOC
Davis Strait	TARA	underway	10/25/2013	63.56	-53.08		1.5			74.8	1.7	274	1.30
Davis Strait	TARA	209	10/23/2013	64.71	-53.01		4.1	2.4	32.7	73.0	0.0	170	0.79
Davis Strait	TARA	207	10/15/2013	69.21	-52.80		3.9	2.2	32.7	56.2	1.7	198	1.32
Davis Strait	TARA	208	10/20/2013	69.11	-51.51		3.0	3.2	33.0	75.1	3.1	343	1.65
Nordic Seas	TARA	158	6/3/2013	67.14	0.25		2.9	8.1	35.1	79.4	0.8	224	1.03
Nordic Seas	TARA	163	6/9/2013	76.18	1.31		3.1	1.8	34.8	63.2	0.3	152	0.84
Nordic Seas	TARA	159	6/5/2013	68.98	2.14		3.6	7.6	35.2	67.7	0.0	130	0.67
Nordic Seas	TARA	160	6/6/2013	70.36	3.60		3.2	7.3	35.2	67.3	0.1	151	0.77
Nordic Seas	TARA	162	6/8/2013	74.17	3.91		2.8	2.3	34.9	58.7	1.1	182	1.12
Nordic Seas	TARA	161	6/7/2013	72.37	3.92		3.8	5.4	35.1	66.7	1.3	223	1.18
Nordic Seas	TARA	164	6/11/2013	74.61	6.53		3.1	4.7	35.1	73.2	0.0	130	0.59
Nordic Seas	TARA	165	6/12/2013	73.45	10.19		3.1	5.7	35.1	61.8	0.3	149	0.83
Nordic Seas	TARA	166	6/13/2013	71.21	14.63		3.1	9.7	34.6	89.9	0.7	279	1.04
Barents Sea	TARA	167	6/30/2013	71.01	38.71		4.1	8.8	34.7	90.9	0.8	288	1.06
Barents Sea	TARA	168	7/1/2013	72.51	44.07		2.8	7.2	34.9	69.5	2.5	317	1.55
Barents Sea	TARA	169	7/3/2013	74.38	47.23		3.0	4.8	34.9	65.7	1.8	253	1.35
Barents Sea	TARA	170	7/4/2013	75.94	51.85		3.1	3.5	34.9	90.7	1.0	302	1.11
Barents Sea	TARA	171	7/5/2013	77.59	58.64		3.1	1.8	34.7	78.0	0.9	244	1.09
Barents Sea	TARA	175	7/10/2013	79.22	66.34		2.7	1.3	34.3	65.8	2.2	274	1.47
Svalbard	NABOS	49	10/27/2008	81.41	30.97	209	6	1.0	34.1	63.3	0.5	152	0.80
Svalbard	NABOS	49	10/27/2008	81.41	30.97	209	10	1.5	34.2	60.0	0.1	127	0.65
Svalbard	NABOS	46	10/26/2008	81.67	31.29	2000	12	-1.5	33.3	57.0	0.6	147	0.80
Kara Sea	TARA	172	7/6/2013	77.94	68.06		3.9	-0.4	33.8	102.2	0.0	165	0.54
Kara Sea	TARA	184	8/6/2013	79.04	69.65		3.1	2.9	34.1	63.8	0.8	175	0.97
Kara Sea	TARA	174	7/9/2013	79.02	71.64		3.1	0.7	34.0	68.2	0.2	163	0.82
Kara Sea	TARA	178	7/15/2013	77.16	73.21		2.8	1.6	34.3	100.8	0.0	124	0.44
Kara Sea	TARA	186	8/12/2013	79.05	74.14		2.9	3.1	33.8	59.2	0.0	77	0.50
Kara Sea	TARA	182	8/4/2013	75.97	78.65		3.1	2.5	27.4	93.8	0.9	298	1.09
Kara Sea	TARA	173	7/8/2013	78.95	79.38		3.0	-0.4	33.5	66.7	0.3	172	0.87
Kara Sea	TARA	187	8/14/2013	78.12	86.56		3.0	2.3	33.5	39.0	0.0	89	0.87
Severnaya Zemlya	NABOS	42	10/23/2008	80.38	100.96	181	11	-1.8	32.4	77.8	0.0	185	0.71
Severnaya Zemlya	NABOS	41	10/22/2008	80.46	101.39	229	11	-1.8	32.1	89.2	0.0	193	0.64
Severnaya Zemlya	NABOS	40	10/22/2008	80.53	102.03	275	10	-1.8	32.2	79.9	0.0	149	0.55
Severnaya Zemlya	NABOS	39	10/22/2008	80.61	102.52	333	12	-1.8	32.7	73.4	0.6	203	0.88
Laptev Sea	NABOS	1	10/7/2008	78.51	125.76	2000	10	-1.8	32.6	88.8	0.0	197	0.69
Laptev Sea	NABOS	4	10/8/2008	79.18	125.94	2000	10	-1.8	32.6	87.1	0.0	188	0.78
Laptev Sea	NABOS	2	10/7/2008	78.83	125.99	2000	10	-1.8	32.4	90.9	0.0	208	0.72
Laptev Sea	NABOS	28	10/18/2008	78.17	126.01	2000	13	-1.7	33.0	86.6	0.0	177	0.60
Laptev Sea	NABOS	32	10/19/2008	77.07	126.17	229	11	-1.7	30.7	113.7	0.0	207	0.56
Laptev Sea	NABOS	6	10/9/2008	79.87	126.25	2000	10	-1.7	32.7	89.4	0.0	180	0.64
Laptev Sea	TARA	189	8/27/2013	77.92	116.95		3.1	0.2	28.6	138.0	0.0	185	0.48
Lomonosov Ridge	NABOS	7	10/10/2008	81.27	136.50	2000	9	-1.8	32.3	109.5	0.0	222	0.63
Lomonosov Ridge	NABOS	10	10/11/2008	80.79	138.81	2000	7	-1.7	31.9	106.6	0.0	202	0.63
Lomonosov Ridge	NABOS	12	10/11/2008	80.23	141.21	2000	7	-1.7	31.8	106.3	0.0	250	0.73
Lomonosov Ridge	NABOS	13	10/11/2008	79.94	142.33	2000	7	-1.7	31.4	100.1	0.0	223	0.67
Lomonosov Ridge	NABOS	15	10/12/2008	79.69	143.58	485	13	-1.7	31.4	97.6	0.0	242	0.76
Lomonosov Ridge	NABOS	16	10/12/2008	79.55	144.00	277	12	-1.7	31.5	101.5	0.0	204	0.63
Lomonosov Ridge	NABOS	17	10/12/2008	79.20	144.84	95	11	-1.7	31.1	97.6	0.0	185	0.59
E. Siberian Margin	NABOS	18	10/13/2008	79.45	158.36	305	10	-1.5	27.5	140.8	0.0	260	0.58
E. Siberian Margin	NABOS	19	10/13/2008	79.59	158.78	707	11	-1.5	27.2	141.3	0.0	275	0.61
E. Siberian Margin	NABOS	20	10/13/2008	79.76	159.34	2000	11	-1.5	28.0	131.2	0.0	295	0.72
E. Siberian Margin	NABOS	24	10/14/2008	80.56	162.20	2000	12	-1.6	28.5	143.3	0.0	294	0.61
E. Siberian Sea	TARA	192	9/3/2013	70.70	166.33		3.9	-0.4	30.8	99.9	1.0	298	1.13