Stratmann, T., Lund-Hansen, L.C., Sorrell, B.K. & Markager, S. (2017). Concentrations of organic and inorganic bound nutrients and chlorophyll a in the Eurasian Basin, Arctic Ocean, early autumn 2012. *Regional Studies in Marine Science*, 9, 69-75.

Published version: dx.doi.org/10.1016/j.rsma.2016.11.008

Link NIOZ Repository: www.vliz.be/nl/imis?module=ref&refid=282857

Highlights regarding the Short Communication entitled ”Concentrations of organic and inorganic bound nutrients and chlorophyll a in the Eurasian Basin, Arctic Ocean, early autumn 2012”

- A detailed nutrient data-set that covers 42 stations from below ice to the bottom of the Arctic Ocean
- A detailed nutrient data-set that is now available for the oceanographic community.
- 15 water masses were identified based on a N/P ratio.
- 13 of the water masses originated from the Atlantic Ocean.

Short communication

Concentrations of organic and inorganic bound nutrients and chlorophyll a in the Eurasian Basin, Arctic Ocean, early autumn 2012

Tanja Stratmann[a,b], Lars Chresten Lund-Hansen[a,c], Brian K. Sorrell[a,c], Stiig Markager[d]

[a]Aquatic Biology, Bioscience, Aarhus University, Ole Worms Allé 1, Build. 1134, 8000 Aarhus C, Denmark

[b]NIOZ Royal Netherlands Institute for Sea Research, Department of Estuarine and Delta Systems, and Utrecht University, P.O. Box 140, 4400 AC Yerseke, the Netherlands

[c]Arctic Research Center, Aarhus University, Ny Munkegade 112 Build. 1540, 8000 Aarhus C, Denmark

[d]Marine Ecology, Bioscience, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

Keywords:

Nutrients, DON, DOP, chlorophyll a, Arctic Ocean, September 2012

*Corresponding author. (L.C. Lund-Hansen)

Abstract

The study is based on CTD and water sampling in the Eurasian Basin of the Arctic Ocean in August-September 2012. The research icebreaker *Oden* and a helicopter were platforms for the sampling. We here report data for inorganic and organic bound nutrient (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}, $Si(OH)_4$, DON, DOP) concentrations and chlorophyll a between 10 m and 200 m at 29 stations and down to about 4500 m at 13 stations. The data set also includes below sea ice samples (1-2 m) sampling at 31 stations. A total number of 15 different water masses were identified, and their N:P relationship showed that 13 of these clearly originated from the Atlantic Ocean.

1. Introduction

The Arctic Ocean is the smallest of the world's five oceans, and despite its area as only 4 percent of the global sea surface it receives about 11 percent of global continental runoff of freshwater (Fichot et al., 2013). The runoff is highly variable due to changes in river runoff (Peterson et al., 2002), increased melting of sea ice, and meteorological oscillations over various time-scales (Rabe et al., 2014). The Arctic Ocean is of interest due to a significant decrease in summer ice extent (Stroeve et al., 2007) which reached a minimum in September 2012 (http://nsidc.org/arcticseaicenews/2012/09/arctic-sea-ice-extent-settles-at-record-seasonal-minimum), though with unchanged winter sea ice extent (Stroeve et al., 2007). There is an increasing number of studies on the water (Aagaard et al., 1985; Schlichtholz and Houssais, 1998; Yamamoto et al., 2008), heat (Zhang et al., 1998), and nutrient exchanges between the Arctic Ocean and the connected Pacific and Atlantic Oceans (Dittmar and Kattner, 2003; Holmes et al., 2012; Torres-Valdes et al., 2013). There are, however, few studies on nutrient concentrations, DON, DOP, and chlorophyll a in the Arctic Ocean that comprise the entire water column from the ice surface to the bottom of the deep basins. Here we report findings of concentrations of these nutrients including chlorophyll a in the surface and deep waters of the Eurasian part of the Arctic Ocean based on sampling in August-September 2012. These data are vital for future studies of Arctic Ocean nutrient cycling, exchanges and primary production.

2. Methods

Water samples were collected at 73 stations in the central Arctic Ocean (Fig. 1, Tab. 2) during the Danish-Swedish joint LOMROG III cruise aboard the Swedish icebreaker *Oden* between July 31 2012 and September 14 2012. Aboard *Oden*, CTD measurements and water sampling was performed with a SeaBird 911+ equipped with a rosette of 24 8L Niskin bottles (13 stations). CTD profiles were acquired on the ice with a SBE19*plus*V2 and under-ice water samples were taken with a single 2.7L Niskin bottle (29 stations). The 31 water samples from below the ice at 1-2 m depth at ice stations were collected by a bilge pump (Lund-Hansen et al., 2015). At all sampling locations water was sampled for the analysis of the inorganic nutrients (NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}, $Si(OH)_4$), DON, DOP and chlorophyll a at 10 m, 20 m, 40 m, 60 m, 100 m, 150 m and 200 m water depth. Additionally, at all sampling stations aboard *Oden*, nutrient samples were taken at 300 m, 500 m, 1000 m, 1500 m, 2000 m, 2500 m, 3000 m, 3500 m, 4000 m and close to the sea floor depending on the water depth at each specific location. Nutrient samples were kept frozen (-21°C) and chlorophyll samples preserved as 0.7 m GFF filters in ethanol until analysis at Aarhus University, Roskilde, Denmark. Nutrient analysis followed standard procedures (Hansen and Koroleff, 1999) (detection limits: NO_3^- = 0.1   mol L^{-1}, NO_2^- = 0.04   mol L^{-1}, NH_4^+ = 0.3   mol L^{-1}, PO_4^{3-} = 0.06   mol L^{-1}, $Si(OH)_4$ = 0.2   mol L^{-1}). Dissolved organic nitrogen (DON) and phosphorous (DOP) concentrations were calculated by subtracting the sum of inorganic nitrogen and phosphorus compounds, respectively, from the TN and TP concentration. The absorbance of chlorophyll a dissolved in ethanol was measured on a calibrated Turner Design fluorometer (TD-700) and then converted into concentrations based on a standard reference following Lund-Hansen et al. (2015).

3. Results and Discussion

Based on the classification schemes by Schlichtholz and Houssais (1999) and Matsuoka et al. (2012) we identified 15 different water masses in the Eurasian Basin of the central Arctic Ocean (Tab. 1). The source of these water masses was identified by plotting PO_4^{3-} versus NO_2^- + NO_3^- data, including Atlantic and Pacific reference lines (Fig. 2). Results show that nutrient data from stations and sampling depths (for details see below) followed the Atlantic water reference line (Azetsu-Scott et al., 2012). This demonstrates that the waters in the Eurasian Basin and along the Lomonosov Ridge, except the Pacific Winter Water, originate from the Atlantic Ocean. The NO/PO nutrient ratio has in earlier studies proven to be a very robust ratio of identifying shelf water in the Arctic Ocean (Wilson and Wallace, 1990).

The surface waters with a potential temperature θ of -1.65 ± 0.04 ºC and a salinity of 28.95 ± 2.94 consisted of the 'Upper Polar Mixed Layer', the 'Lower Polar Mixed Layer' and the 'Pacific Summer Water' (Tab. 1). Their phosphate concentration was 0.2 ± 0.1 mol L^{-1} (mean ± S.D.) (range: 0.1 – 0.3 mol L^{-1} and thus lower than in the Canada Basin (0.7 ± 0.1 mol L^{-1}) or the East Siberian Sea (0.8 ± 0.1 mol L^{-1}) (Amano-Sato et al., 2013) (Fig. 3). In contrast, the nitrate concentration (0.4 ± 0.6 mol L^{-1}; range: <0.1 mol L^{-1} = detection limit – 2.4) was comparable to Canada Basin (0.6 ± 1.4 mol L^{-1}) and East Siberian Sea (0.5 ± 1.1 mol L^{-1}) values (Amano-Sato et al., 2013) and Chukchi Sea concentration ranges (<0.01 = detection limit – 1.7 mol L^{-1}; Arrigo et al., 2014). We calculated a molar N:P ratio of 3.8 ± 2.8 : 1 for the surface waters of the central Eurasian Basin that differed significantly from the Redfield ratio of 16 : 1 (1-Sample Signed Rank Test, $p < 0.001$) which indicates a strong nitrogen limitation. These values are in the range of the

Amundsen Basin N:P ratio of 4.4: 1 documented by Wheeler et al. (1997). However, Wheeler et al. (1997) determined their N:P-ratio as the NO_3^- : PO_4^{3-} -ratio, thus our NO_3^- : PO_4^{3-} -ratio was even lower and accounted for 1.4 ± 1.5 : 1, implying a strong nitrate deficiency. The silicate concentration (2.2 ± 0.9 mol L^{-1}) was in the range of the concentration that Wheeler et al. (1997) measured in the Nansen Basin (2.0 ± 0.6 mol L^{-1}), but about half of the silicate concentrations from the Amundsen Basin (5.8 ± 0.1 mol L^{-1}; Wheeler et al., 1997), the Canada Basin (5 ± 4 mol L^{-1}; Amano-Sato et al., 2013) or the East Siberian Sea (5 ± 3 mol L^{-1}; Amano-Sato et al., 2013). The concentration of chlorophyll a was 0.3 ± 0.6 g L^{-1} and comparable to the chlorophyll a concentration in the Chukchi Sea (0.38 g L^{-1}; Arrigo et al., 2014). The range of DOP concentrations (0.2 ± 0.1 mol L^{-1}; range: 0.0 – 0.4 mol L^{-1}) was similar to the DOP range measured in the Beaufort Sea (~0.0 – 2.5 mol L^{-1}; Simpson et al., 2008), whereas the DON concentration ranging from 2.5 to 9.4 mol L^{-1} (5.2 ± 1.5 mol L^{-1}) was far narrower than the DON range in the Beaufort Sea (~0.0 – 27.5 mol L^{-1}; Simpson et al., 2008).

The halocline water in the Arctic Ocean was formed by the 'Upper Halocline Water' and the 'Lower Halocline Water' and was characterized by a salinity of 33.58 ± 0.66 and a potential temperature θ of -1.41 ± 0.57 ºC (Tab. 1). The phosphate concentration was 0.5 ± 0.2 mol L^{-1} (Fig. 3) and thus lower than the phosphate concentration at the Northwind Ridge (1.4 ± 0.4 mol L^{-1}), in the Canada Basin (1.5 ± 0.3 mol L^{-1}), or in the East Siberian Sea (1.5 ± 0.2 mol L^{-1}) (Amano-Sato et al., 2013) (Fig. 3). Additionally, the concentrations of inorganic nitrogen compounds in the central Arctic Ocean (NO_3^- = 5.0 ± 3.3 mol L^{-1}, NO_2^- <0.1 mol L^{-1} = detection limit, NH_4^+ = 0.5 ± 0.6 mol L^{-1}) differed from the concentrations at the Northwind Ridge (NO_3^- = 12.2 ± 3.6 mol L^{-1}, NH_4^+ = 0.2 ± 0.3 mol L^{-1}; Amano-Sato et al. 2013) or in the East Siberian Sea (NO_3^- = 12.6 ± 2.7 mol L^{-1}, NH_4^+ = 0.06 ± 0.16 mol L^{-1}; Amano-Sato et al., 2013). Only the ammonium concentrations were similar to the central Eurasian Basin and the Canada Basin (our measurements in the Eurasian Basin = 0.5 ± 0.6 mol L^{-1}; Canada Basin = 0.5 ± 1.0 mol L^{-1}, Amano-Sato et al., 2013). The silicate concentration (3.4 ± 2.2 mol L^{-1}; range: 0.2 ± 11.6 mol L^{-1}) was in the range of the concentration in the Nansen Basin (3.9 ± 0.4 mol L^{-1}; Wheeler et al., 1997), but lower than in the Amundsen Basin (7.2 ± 0.7 mol L^{-1}; Wheeler et al., 1997). In contrast, the highly silicate enriched Pacific-derived waters of the Amerasian Basin (Wheeler et al., 1997) had silicate concentrations that were more than seven times higher (Canada Basin = 25 ± 8 mol L^{-1}, East Siberian Sea 25 ± 6 mol L^{-1}; Amano-Sato et al., 2013). The chlorophyll a concentration and DOP concentration were both 0.1 ± 0.1 g L^{-1} and mol L^{-1}, respectively, whereas the DON concentration accounted for 4.2 ± 2.4 mol L^{-1}.

The Atlantic waters ('Warm Atlantic Water', 'Fresh Atlantic Water', 'Cold Atlantic Water' and 'Modified Atlantic Water') resulted in the warmest water masses (potential temperature θ = 1.02 ± 0.79 ºC; salinity = 34.78 ± 0.13) of the Arctic Ocean (Tab. 1). The phosphate concentration we measured in the Eurasian Basin was 0.8 ± 0.1 mol L^{-1} and thus comparable to phosphate concentrations in the Canada Basin or in the East Siberian Sea (0.9 ± 0.1 mol L^{-1}; Amano-Sato et al., 2013)(Fig. 3). In contrast, nitrate concentration was 11.2 ± 1.9 mol L^{-1} (nitrite <0.04 mol L^{-1} = detection limit; ammonia = 0.3 ± 0.3 mol L^{-1} = detection limit) resulting in a molar N:P ratio of 14.4 ± 2.1. This value coincides directly with the N:P ratio values that Wheeler et al. (1997) measured in the Amundsen Basin (14.4 ± 0.02) and in the Nansen Basin (14.4 ± 0.03). However, the silicate concentrations that were measured in this study (4.7 ± 0.8 mol L^{-1}) were lower than the concentrations measured in the Amundsen Basin (8.1 ± 1.5 mol L^{-1}; Wheeler et al., 1997) or in the Nansen Basin (6.1 ± 0.02 mol L^{-1}; Wheeler et al., 1997). The chlorophyll a concentration in the

Eurasian Basin measured in this study was 0.03 ± 0.01 g L^{-1}, the DON concentration was 3.8 ± 3.1 mol L^{-1} and the DOP concentration was 0.1 ± 0.2 mol L^{-1}.

Deep and bottom waters were formed by the 'Warm Norwegian Sea Deep Water', 'Cold Norwegian Sea Deep Water', 'Canadian Basin Deep Water' and the 'Eurasian Basin Deep Water' and had a potential temperature θ of -0.80 ± 0.18 ºC and a salinity of 34.93 ± 0.01 (Tab. 1). The phosphate concentration was 1.0 ± 0.1 mol L^{-1} and the only detected nitrogen compound nitrate had a concentration of 14.2 ± 0.8 mol L^{-1} (NO_2^- <0.04 mol L^{-1} = detection limit, NH_4^+ <0.3 mol L^{-1} = detection limit) (Fig. 3). Hence, both values were in the range of nitrate and phosphate in the deep Canadian Basin (NO_3^- ranges: 14.5 – 15.0 mol L^{-1}, PO_4^{3-} ranges: 1.0 – 1.05 mol L^{-1}; both Newton et al., 2013) and led to a molar N:P ratio of 14.2 ± 0.5. The silicate concentration was 9.4 ± 1.2 mol L^{-1}, the DON concentration 3.5 ± 2.1 mol L^{-1} and the DOP concentration 0.1 ± 0.1 mol L^{-1}. The chlorophyll a concentration was not measured at these depths.

Acknowledgments

This research was supported by the 'Continental Shelf Project of the Kingdom of Denmark' and the Swedish Polar Research Secretariat through the participation and logistics on the 2012 LOMROG III expedition to the North Pole. Additional financial support was provided by the Brdr. Hartmann's Foundation and the Carlsberg Foundation. We thank Steffen Malskær Olsen for providing us with the CTD cruise data, Kajsa Tönnesson for suppling us with chlorophyll a samples, and not at least cruise leader Christian Marcussen, Geological Survey of Denmark, for the successful LOMROG III cruise and very good cooperation.

Table 1: Chemical and physical characteristics of the water masses in the Eurasian basin of the central Arctic Ocean. Data are expressed as mean values ± standard deviations calculated for each water mass. UPML = Upper Polar Mixed Layer, LPML = Lower Polar Mixed Layer, PSW = Pacific Summer Water, PWW/ UHW = Pacific Winter Water/ Upper Halocline Water, LHW = Lower Halocline Water, AW_W = Warm Atlantic Water, AW_F = Fresh Atlantic Water, AW_C = Cold Atlantic Water, MAW = Modified Atlantic Water, AIW = Arctic Intermediate Water, UPDW = Upper Polar Deep Water, $NSDW_W$ = Warm Norwegian Sea Deep Water, CBDW = Canadian Basin Deep Water, $NSDW_C$ = Cold Norwegian Sea Deep Water and EBDW = Eurasian Basin Deep Water. After classification of water masses by Schlichtholz and Houssais (1999) and Matsuoka et al. (2012).

Water mass	N[1]	θT (°C)	Salinity	NO_3^- (µmol L^{-1})	NO_2^- (µmol L^{-1})[2]	NH_4^+ (µmol L^{-1})[2]	PO_4^{3-} (µmol L^{-1})	$Si(OH)_4$ (µmol L^{-1})	DON (µmol L^{-1})	DOP (µmol L^{-1})	Chl-a (µg L^{-1})
UPML	29 (21)	-1.65 ± 0.04	25.88 ± 1.62	0.6 ± 1.1	< detect. limit	0.4 ± 0.2	0.3 ± 0.2	2.5 ± 1.8	n. a.	n. a.	0.4 ± 0.8
LPML	6 (6)	-1.59 ± 0.02	29.22 ± 0.91	0.7 ± 1.0	< detect. limit	< detect. limit	0.3 ± 0.1	2.1 ± 0.8	5.6 ± 2.1	0.1 ± 0.1	0.3 ± 0.2
PSW	35 (32)	-1.66 ± 0.04	31.54 ± 0.48	0.3 ± 0.5	< detect. limit	0.5 ± 0.5	0.2 ± 0.1	2.1 ± 1.0	5.2 ± 1.4	0.2 ± 0.1	0.3 ± 0.5
LHW	75 (71)	-0.95 ± 0.61	34.27 ± 0.16	8.1 ± 2.2	< detect. limit	0.5 ± 0.9	0.7 ± 0.1	3.9 ± 1.4	3.1 ± 2.3	0.1 ± 0.1	0.1 ± 0.1
PWW/ UHW	117 (114)	-1.73 ± 0.08	33.13 ± 0.43	3.0 ± 2.2	< detect. limit	0.4 ± 0.4	0.4 ± 0.2	3.2 ± 2.6	4.9 ± 2.3	0.2 ± 0.1	0.1 ± 0.2
AW_F	21 (10)	1.45 ± 0.47	34.82 ± 0.09	11.6 ± 1.7	< detect. limit	0.3 ± 0.3	0.8 ± 0.1	4.4 ± 0.6	3.5 ± 1.9	0.1 ± 0.1	0.04 ± 0.03
AW_W	7 (5)	3.06 ± 0.36	35.03 ± 0.02	11.7 ± 0.6	< detect. limit	< detect. limit	0.8 ± 0.04	4.5 ± 0.6	3.5 ± 0.6	0.04 ± 0.1	0.04 ± 0.01
MAW	57 (43)	0.60 ± 0.32	34.72 ± 0.11	10.8 ± 2.2	< detect. limit	0.4 ± 0.4	0.8 ± 0.1	4.7 ± 0.9	4.0 ± 3.6	0.1 ± 0.2	0.02 ± 0.01
AW_C	3	1.26 ± 0.18	34.97 ± 0.02	12.5 ± 0.6	< detect. limit	< detect. limit	0.9 ± 0.02	5.1 ± 1.1	2.7± 1.2	0.02 ± 0.1	n.a.
UPDW	7	-0.23 ± 0.05	34.89 ± 0.00	12.6 ± 0.4	< detect. limit	< detect. limit	0.9 ± 0.03	6.1 ± 0.4	3.0 ± 2.1	0.1 ± 0.1	n. a.
AIW	9	-0.59 ± 0.19	34.92 ± 0.01	13.9 ± 0.5	< detect. limit	< detect. limit	1.0 ± 0.1	8.9 ± 1.4	2.3 ± 2.0	0.1 ± 0.1	n. a.
$NSDW_W$	12	-0.57 ± 0.20	34.91 ± 0.01	13.4 ± 1.1	< detect. limit	< detect. limit	1.0 ± 0.1	8.0 ± 1.6	3.9 ± 1.6	0.01 ± 0.4	n. a.
CBDW	5	-0.68 ± 0.14	34.93 ± 0.01	14.3 ± 0.8	< detect. limit	< detect. limit	1.0 ± 0.1	9.5 ± 0.4	3.4 ± 2.5	0.1 ± 0.1	n. a.
$NSDW_C$	4	-0.86 ± 0.03	34.92 ± 0.00	14.9 ± 0.2	< detect. limit	< detect. limit	1.1 ± 0.03	10.1 ± 0.2	3.9 ± 2.1	0.1 ± 0.1	n. a.
EBDW	28	-0.92 ± 0.02	34.93 ± 0.01	14.5 ± 0.4	< detect. limit	< detect. limit	1.0 ± 0.04	9.9 ± 0.3	3.3 ± 2.4	0.1 ± 0.1	n. a.

[1]Number in paranthesis is the number of chlorophyll a samples.

[2]The detection limit for NO_2^- is 0.04 mol L^{-1} and for NH_4^+ 0.3 mol L^{-1}. n.a. is not available.

Table 2: Sampling stations in the Eurasian Basin of central Arctic Ocean.

Station	Date	Longitude	Latitude	Max. sampling depth (m)
1*	8/2/2012	14.9330	82.95800	2624
2	8/3/2012	13.3375	84.53567	150
3	8/4/2012	6.4580	85.55117	200
4*	8/5/2012	1.9552	86.74317	4000
5	8/6/2012	-3.4558	87.03967	200
6	8/7/2014	-13.4652	87.32500	200
7	8/8/2014	-26.9747	87.73783	200
8*	8/9/2012	-37.7575	87.77000	3500
9	8/10/2012	-47.7420	87.75233	200
10	8/11/2012	-58.8878	87.65783	200
11	8/12/2012	-68.9313	87.63917	200
12	8/13/2012	-43.1753	88.26550	200
13	8/14/2012	-29.9508	88.23483	200
14	8/15/2012	-58.0167	88.27200	200
15*	8/16/2012	-69.4115	88.34667	1200
16	8/17/2012	-57.5500	88.63500	200
17	8/18/2012	-79.3022	89.01333	200
18*	8/20/2012	-58.8472	89.26500	3743
19	8/20/2012	-68.0293	89.13600	200
20	8/21/2012	-90.8875	88.89633	200
21	8/22/2012	155.5253	89.99250	200
22	8/23/2012	133.2017	89.50733	200
23	8/24/2012	149.9917	88.41217	200
24	8/24/2012	145.2760	88.05967	200
25	8/25/2012	124.9247	87.93450	200
26	8/25/2012	114.6947	87.88133	200
27	8/26/2012	104.5048	87.98917	200
28*	8/27/2012	78.2427	88.14933	4353
29	8/29/2012	70.1810	88.29217	200
30	8/30/2012	56.0498	88.75183	200
31*	8/31/2012	53.1030	88.79050	4360
32	9/2/2012	25.2865	88.28117	200
33	9/3/2012	11.3518	88.15900	200
34	9/4/2012	27.2690	87.82850	200
35	9/5/2012	18.9753	87.47067	200
36*	9/7/2012	5.2772	85.42650	3000
37*	9/8/2012	3.7215	84.37017	3778
38*	9/9/2012	15.1728	83.82350	4000
39	9/9/2012	14.9885	83.47200	150
40*	9/10/2012	14.7445	82.76867	1457
41*	9/11/2012	8.7520	82.19583	500
42*	9/11/2012	8.5982	81.86350	500
219‘	8/6/2012	0.0872	86.8657	1-2 m below ice
220‘	8/7/2012	-5.4301	87.0787	1-2 m below ice
221‘	8/8/2012	-16.3833	87.4506	1-2 m below ice
222‘	8/9/2012	-34.8366	87.7533	1-2 m below ice
223‘	8/10/2012	-42.5660	87.7881	1-2 m below ice
224‘	8/11/2012	-52.0040	87.7216	1-2 m below ice
225‘	8/12/2012	-59.6130	87.8460	1-2 m below ice
226‘	8/13/2012	-53.5920	87.1949	1-2 m below ice
227‘	8/14/2012	-30.7661	88.3466	1-2 m below ice
228‘	8/15/2012	-49.5848	88.1971	1-2 m below ice
229‘	8/16/2012	-69.6070	88.3475	1-2 m below ice

231‘	8/18/2012	-56.2744	89.2560	1-2 m below ice
232‘	8/19/2012	70.8348	89.1898	1-2 m below ice
233‘	8/20/2012	-65.4526	89.2799	1-2 m below ice
234‘	8/21/2012	-73.6948	89.9352	1-2 m below ice
235‘	8/22/2012	-62.2740	89.6198	1-2 m below ice
236‘	8/23/2012	135.9232	89.8372	1-2 m below ice
237‘	8/24/2012	135.5760	88.5010	1-2 m below ice
238‘	8/25/2012	122.1511	87.9757	1-2 m below ice
239‘	8/26/2012	109.4211	88.2191	1-2 m below ice
241‘	8/28/2012	73.4898	87.9424	1-2 m below ice
242‘	8/29/2012	72.8627	88.2607	1-2 m below ice
243‘	8/30/2012	68.4496	89.4548	1-2 m below ice
244‘	8/31/2012	55.9391	88.7125	1-2 m below ice
246‘	9/2/2012	22.3029	88.4698	1-2 m below ice
247‘	9/3/2012	23.8471	88.4062	1-2 m below ice
248‘	9/4/2012	30.0919	87.7392	1-2 m below ice
251‘	9/7/2012	20.6261	87.5993	1-2 m below ice
252‘	9/8/2012	5.2659	85.4272	1-2 m below ice
253‘	9/9/2012	9.1837	84.1211	1-2 m below ice
254‘	9/10/2012	15.1336	83.8242	1-2 m below ice

(*) Ship stations aboard *Oden*, (xxx‘) sea ice stations.

Figure legends:

Figure 1. Map of the Eurasian sector of the Arctic Ocean showing all sampling stations. The black symbols represent stations where only one water sample was taken at 1-2 m water below the ice. The red symbols show sampling stations where the upper 200 m of the water column were sampled and the yellow symbols represent stations with full vertical sampling profiles. CTD measurements exist for the whole water column at the yellow and red stations. The insert shows the sea ice extent on 16 September 2012 with orange line as the 1979-2000 median minimum extent (Imagery from the NASA MODIS instrument, courtesy NASA NSIDC DAAC)

Figure 2. Relationship of the nutrients NO_2^- + NO_3^- versus PO_4^{3-}. The Atlantic line from the study by Azetsu-Scott et al. (2012) is shown and the Pacific lines from studies by Yamamoto-Kawai et al. (2008) and Jones et al. (1998) are included as grey dashed line and black solid line, respectively. Signatures and acronyms: ▼ UPML, ● LPML, △ PSW, ◆ LHW, □ PWW/UHW, △ AW_F, □ AW_C, ● AW_W, ◆ MAW, ◆ $NSDW_C$, □ $NSDW_W$, △ CBDW, ◇ EBDW, ○ UPDW, ● AIW

Figure 3. Depth profiles of NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}, $Si(OH)_4$, chlorophyll a, DON and DOP at all stations (black open circles). The red filled squares represent the mean concentrations of each parameter comprising all sampling locations of the central Arctic Ocean ≥ 85°N and the light grey bars in the panels of NO_2^- and NH_4^+ show the detection limit of the instruments.

References

Aargaard, K., Swift, J.H., Carmack, E.C. 1985. Thermohaline circulation in the Arctic Mediterranean Seas. J. Geophys. Res. 90, C2, 4833-4846.

Amano-Sato, C., Akiyama, S., Uchida, M., Shimada, K., Utsumi, M. 2013. Archael distribution and abundance in water masses of the Arctic Ocean, Pacific sector. Aqua. Microb. Ecol. 69, 101-112.

Arrigo, K. R., Perovic, D. K., Pickart, R. S., Brown, Z. W., Van Dijken, G. L. Lowry, K. E., Mills, M. M., Palmer, M. A., Balch, W. M., Bates, N. R., Benitezx-Nelson, C. R., Brownlee, E., Frey, K. E., Laney, S. R., Mithis, J., Matsuoka, A., Mitchel, B. G., Moore, G. W. K., Reynolds, R. A., Sosik, H. M., Swift, J. H. 2014. Phytoplankton blooms beneath the sea ice in the Chukchi sea. Deep-Sea Research II 105, 1-16.

Azetsu-Scott, K., Petrie, B., Yeats, P., Lee, C. 2012. Composition and fluxes of freshwater through Davis Strait using multiple chemical tracers. J. Geophys. Res. 117, C12011, doi:10.1029/2012JC008172.

Dittmar, T., Kattner, G. 2003. The biogeochemistry of the river and shelf ecosystem of the Arctic Ocean: A review. Mar. Chem. 83, 103-120.

Fichot, C.G., Kaiser, K., Hooker, S.B., Amon, R.M.W., Babin, M., Belanger, S., Walker, S.A., Benner, R. 2013. Pan-Arctic distributions of continental runoff on the Arctic Ocean. Scientific Reports: 3, 1053, doi:10.1038/srep01053.

Hansen, H. P., Koroleff, F. 1999. Determiantion of nutrients. In: Grasshoff, K., Ehrhardt, M. (eds.) Methods of seawater analysis. 3rd edn. Wiley-VCH, Germany, pp. 159-228.

Holmes, R.M., McClelland, J.W., Peterson, B.J., Tank, S.E., Bulygina, E., Eglinton, T.I., Gordeev, V.V., Gurtovaya, T.Y., Raymond, P.A., Repeta, D.J., Staples, R., Striegl, R.G., Zhulidov, A.V. Zimov, A.A. 2012. Seasonal and annual fluxes of nutrients and organic matter from large rivers to the Arctic Ocean and surrounding seas. Est. and Coast. 35, 369-382.

Jones, E. P., Anderson, L. G., Swift, J. H. 1998. Distribution of Atlantic and Pacific waters in the upper Arctic Ocean: Implications for circulation. Geophys. Res. Let. 25, 765-768.

Lund-Hansen, L. C., Markager, S., Hancke, K., Stratmann, T., Rysgaard, S., Ramløv, H. Sorrell, B. K. 2015. Effects of sea-ice light attenuation and CDOM absorption in the water below the Eurasian sector of central Arctic Ocean (>88°N). Pol. Res. 34, 23978, doi:10.3402/polar.v34.23978.

Matsuoka, A., Bricaud, A., Para, J., Sempere, R., Prieur, L., Belanger, S., Basin, M. 2012. Tracing the transport of colored dissolved organic matter in water masses of the Southern Beaufort Sea: Relationship with hydrographic characteristics. Biogeosciences 9, 925-940.

Newton, R., Schlosser, P. Mortlock, R., Macdonald, R. 2013. Canadian Basin freshwater sources and changes: Results from the 2005 Arctic Ocean Section. J. Geophys. Res. 118, 2133-2154, doi:10.1002/jgrc.20101.

Peterson, B.J., Holmes, R.M., McClelland, J.W., Vörösmarty, C.J., Lammers, R.B., Shiklamanov, A.I., Shiklamanov, I.A., Rahmstorf S., 2002. Increasing river discharge to the Arctic Ocean. Science 298, 2171-2173.

Rabe, B., Karcher, M., Kauker, F., Schauer, U., Toole, J.M., Krishfield, R.A., Pisarev, S., Kikuchi, T., Su, J. 2014. Arctic Ocean basin liquid freshwater storage trend 1992-2012. Geophys. Res. Let. doi: 10.1002/2013GL058121

Schlichtholz, P., Houssais, M.-N. 1999. An inverse modeling study in Fram Strait. Part II: water mass distribution and transports. Deep-Sea Research II, 46, 1137-1168.

Simpson, K. G., Tremblay, J.-É., Gratton, Y., Price, N. M. 2008. An annual study of inorganic and organic nitrogen and phosphorus and silic acid in the southeastern Beaufort Sea. J. Geophys. Res. 113, C07016, doi:10.1029/2007JC004462.

Torres-Valde´s, S., Tsubouchi, T., Bacon, S., Naveira-Garabato, A. C., Sanders, R., McLaughlin, F. A., Petrie, B., Kattner, G., Azetsu-Scott, K., Whitledge, T. E. 2013. Export of nutrients from the Arctic Ocean. J. Geophys. Res. 118, doi:10.1002/jgrc.20063.

Stroeve J., Holland, M.M, Meier, W., Scambos, T., Serreze, M. 2007. Arctic sea ice decline: Faster than forecast. Geophys. Res. Let. 34, L09501, doi: 10.1029/200GL029703.

Wheeler, P. A., Watkins, J. M., Hansing, R. L. 1997. Nutrients, organic carbon and organic nitrogen in the upper water column of the Arctic Ocean: implications for the sources of dissolved organic carbon. Deep-Sea Research II 44, 1571-1592.

Wilson, C., Wallace, D.W.R. 1990. Using the nutrient ratio NO/PO as a tracer of continental shelf waters in the central Arctic Ocean. J. Geophys. Res. 95, C12, 22.193-22.208.

Zhang J., Rothrock D.A., Steele M. 1998. Warming of the Arctic Ocean by a strengthened Atlantic inflow. Geophys. Res. Let. 25, 1745-1748.

Yamamoto-Kawai, M., Mclaughlin, F. A., Carmack, E. C., Nishino, S., Shimada, K. 2008. Freshwater budget of the Canada Basin, Arctic Ocean, from salinity, delta O-18, and nutrients. J. Geophys. Res. 113, C01007, doi:10.1029/2006JC003858.

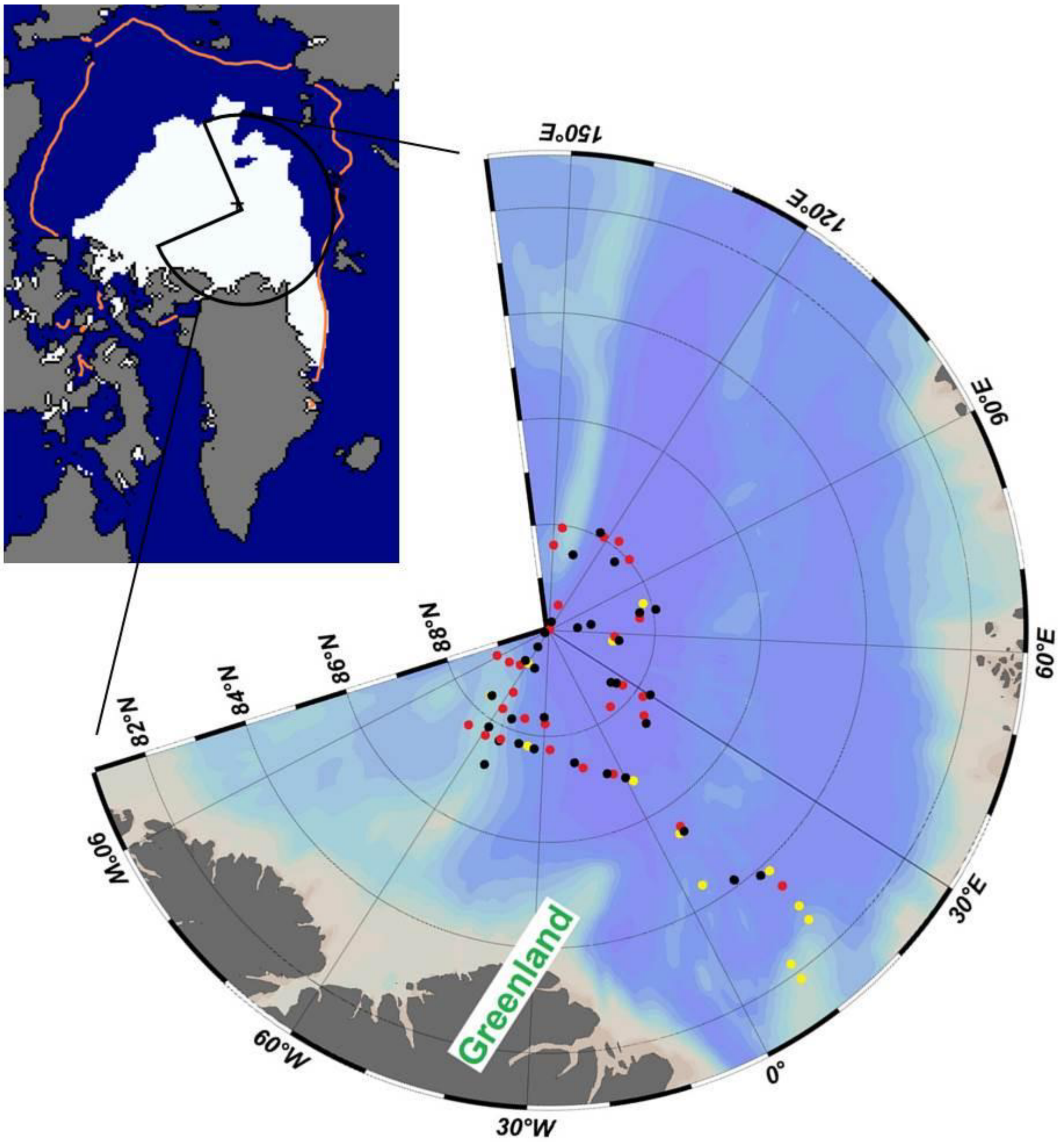

Fig. 1.

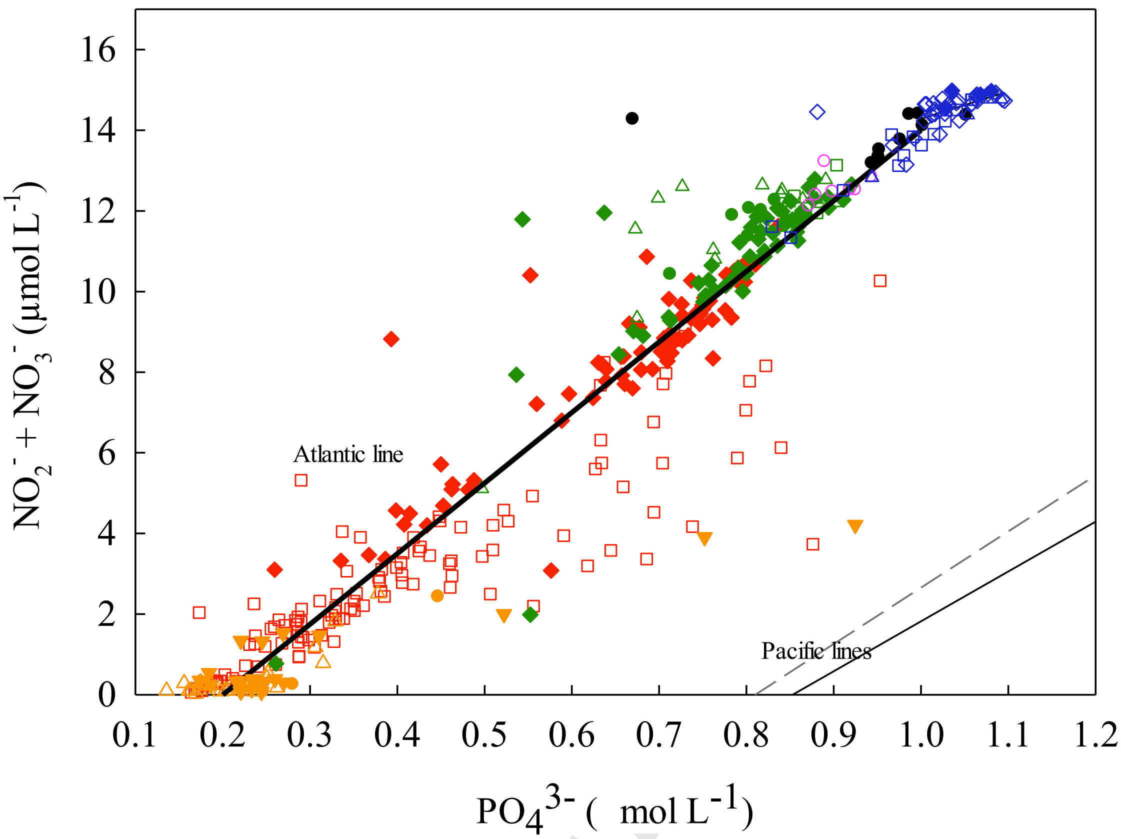
16
14
12
10
8
6
4
2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Atlantic line
Pacific lines
$NO_2^- + NO_3^-$ (µmol L^{-1})
PO_4^{3-} (mol L^{-1})

Fig. 2.

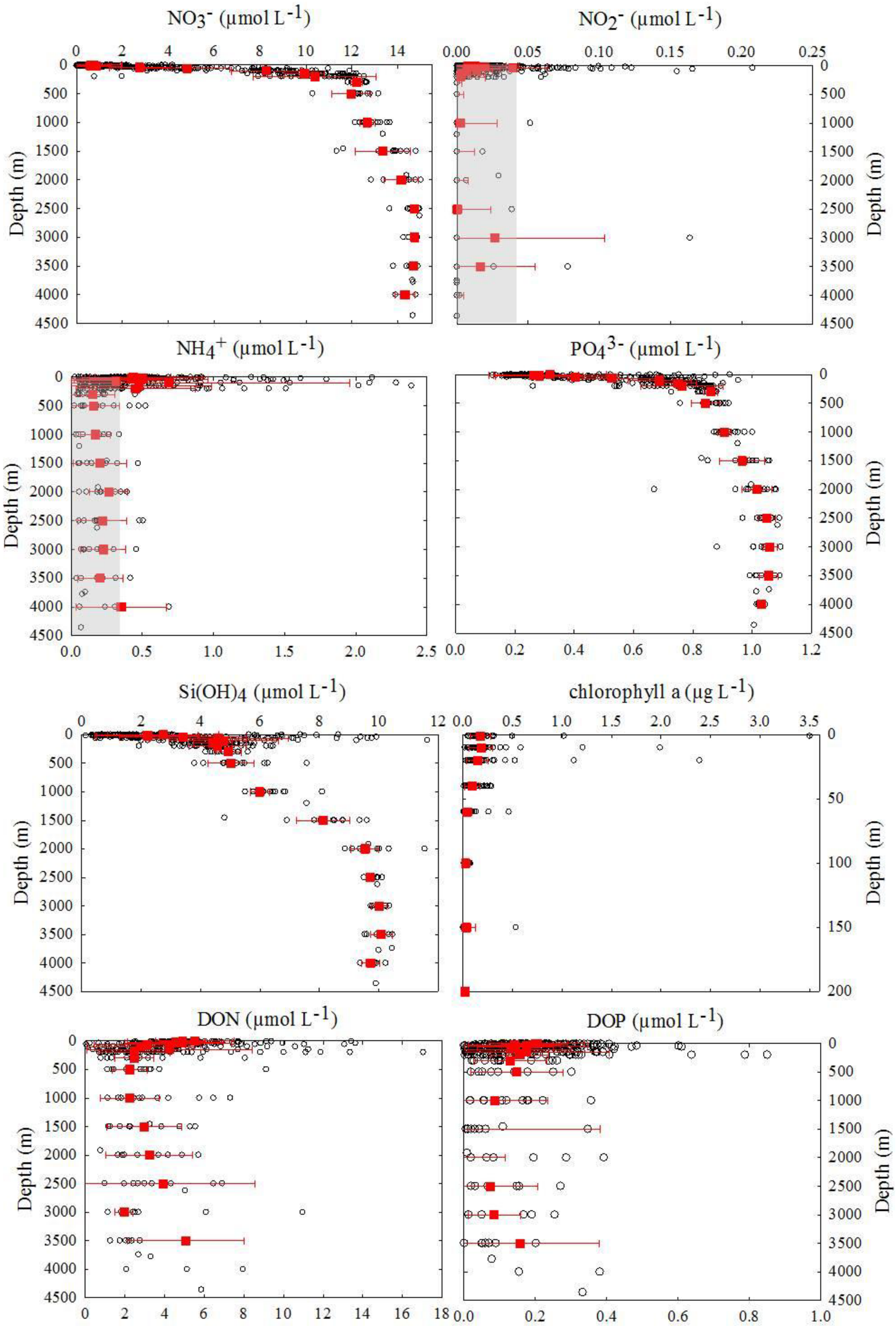
NO3- (µmol L-1)
NO2- (µmol L-1)
NH4+ (µmol L-1)
PO43- (µmol L-1)
Si(OH)4 (µmol L-1)
chlorophyll a (µg L-1)
DON (µmol L-1)
DOP (µmol L-1)
Depth (m)

Fig. 3.