## **Supplemental Material**

# **Environmental drivers of spring primary production in Hudson Bay**

Matthes, L.C.1, Ehn, J.K.1, Dalman, L.A.1, Babb, D.G.1, Peeken, I.2, Harasyn, M.1, Kirillov, S.1, Lee, J.3, Bélanger, S.4, Tremblay, J.-É.3, Barber, D.G.1 and Mundy, C.J.1

1 Centre for Earth Observation Science, University of Manitoba, Winnipeg, MB, Canada

2 Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

3 Québec-Océan and Takuvik, Département de Biologie, Université Laval, Québec, QC, Canada

4 Département de Biologie, Chimie et Géographie and BORÉAS, Université du Québec à Rimouski, QC, Canada

*Corresponding author:*

lisa.matthes.1@ulaval.ca

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**Figure S1. *Melosira arctica* growing attached to the bottom of first-year sea ice in central Hudson Bay.** (Photo credit: L. Dalman).

**Table S5.** Historical and measured seasonal primary production of microalgal communities in Hudson Bay presented in Figure 8.

**Table S6.** Seasonal and annual primary production in Hudson Bay.

**Table S1.** Environmental variables of 23 stations sampled in Hudson Bay in June 2018. Variables are the ice concentration (%) retrieved from ice charts, days of open water days prior to sampling (DOW), diffuse vertical attenuation coefficient for downwelling scalar PAR (Kd0), depth of mixed layer (Zm), average temperature of the mixed layer (Tm), average salinity of the mixed layer (Sm), and integrated concentration of nitrate plus nitrite (NOX\_eu), phosphate (PO4\_eu), and silicic acid (Si(OH)4\_eu) over the euphotic zone.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Stationa** | **Ice conc. (tenth)** | **DOW** | **Kd0 (m−1)** | **Zm (m)** | **Tm (°C)** | **Sm** | **NOx\_eu (mmol m−2)** | **PO4\_eu (mmol m−2)** | **Si(OH)4\_eu (mmol m−2)** |
| **5** | 9 | 0 | 0.10 | 22 | -1.57 | 32.7 | 345 | 53.3 | 581 |
| **9** | 1 | 0 | 0.11 | 10 | -1.32 | 32.5 | 188 | 32.1 | 389 |
| **11** | 9.7 | 0 | 0.15 | 35 | -1.65 | 30.7 | 87.9 | 22.5 | 277 |
| **15** | 5 | 1 | 0.10 | 22 | -1.58 | 31.9 | 213 | 45.8 | 487 |
| **16** | 9.7 | 0 | 0.11 | 14 | -1.51 | 31.6 | 128 | 29.2 | 296 |
| **17** | 0 | 23 | 0.18 | 10 | -0.65 | 32.4 | 50.6 | 23.7 | 204 |
| **18** | 0.3 | 23 | 0.17 | 21 | -0.90 | 32.2 | 18.0 | 8.97 | 153 |
| **19** | 0 | 30 | 0.12 | 10 | -0.42 | 32.9 | 1.44 | 28.1 | 4.16 |
| **20** | 0 | 24 | 0.19 | 15 | 0.03 | 32.0 | 17.5 | 19.3 | 127 |
| **21** | 9.7 | 0 | 0.12 | 17 | -1.36 | 31.5 | 74.8 | 27.9 | 202 |
| **22** | 0 | 27 | 0.12 | 4 | 1.76 | 31.6 | 0.41 | 32.3 | 0.65 |
| **23** | 0 | 23 | 0.16 | 33 | 0.16 | 32.6 | 1.53 | 17.2 | 1.77 |
| **24** | 9 | 0 | 0.09 | 22 | -1.33 | 31.1 | 56.3 | 31.5 | 178 |
| **25** | 9 | 0 | 0.17 | 27 | -1.22 | 31.3 | 46.3 | 22.3 | 181 |
| **28** | 0 | 31 | 0.16 | 30 | 0.72 | 32.3 | 21.0 | 21.0 | 51.5 |
| **29** | 9.7 | 9 | 0.13 | 34 | -1.54 | 30.8 | 83.6 | 29.2 | 225 |
| **32** | 9.7 | 0 | 0.19 | 15 | -1.50 | 30.4 | 29.0 | 18.9 | 151 |
| **34** | 9.7 | 0 | 0.27 | 11 | -0.80 | 29.8 | 11.1 | 5.8 | 71.4 |
| **36** | 9.7 | 0 | 0.13 | 4 | -1.57 | 31.5 | 90.2 | 31.6 | 324 |
| **38** | 9.7 | 0 | 0.08 | 17 | -1.54 | 31.9 | 102 | 40.8 | 374 |
| **40** | 9.7 | 0 | 0.19 | 17 | -1.56 | 31.9 | 27.4 | 17.1 | 118 |
| **44** | 0.3 | 14 | 0.11 | 12 | 0.83 | 31.0 | 48.7 | 37.9 | 246 |
| **46** | 0 | 30 | 0.23 | 15 | 1.92 | 29.8 | 12.6 | 14.1 | 84.4 |

aParameters were used in the principal component analysis (PCA) to cluster stations into regions

**Table S2.** Initial and final (after CHEMTAX optimization) pigment to chlorophyll *a* ratios for sea-ice algae.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Class / Pigmenta** | **Chl *c3*** | **Chl *c2*** | **Peri** | **But-Fuco** | **Fuco** | **Allo** | **Lut** | **Chl *b*** | **Neo** | **Chl *a*** |
| Initial ratio matrixb |
| **Diat1** | 0 | 0.189 | 0 | 0 | 0.7 | 0 | 0 | 0 | 0 | 1 |
| **Diat2** | 0.066 | 0.299 | 0 | 0 | 1.1 | 0 | 0 | 0 | 0 | 1 |
| **Crypto** | 0 | 0.2 | 0 | 0 | 0 | 0.229 | 0 | 0 | 0 | 1 |
| **Dino** | 0 | 0.162 | 0.675 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Prasino2** | 0 | 0 | 0 | 0 | 0 | 0 | 0.049 | 0.418 | 0.017 | 1 |
| **Flagel** | 0.145 | 0.08 | 0 | 0.039 | 0.125 | 0 | 0 | 0 | 0 | 1 |
| Final ratio matrix (RMS = 0.12)c |
| **Diat1** | 0 | 0.069 | 0 | 0 | 0.654 | 0 | 0 | 0 | 0 | 1 |
| **Diat2** | 0.050 | 0.363 | 0 | 0 | 1.101 | 0 | 0 | 0 | 0 | 1 |
| **Crypto** | 0 | 0.072 | 0 | 0 | 0 | 0.303 | 0 | 0 | 0 | 1 |
| **Dino** | 0 | 0.180 | 0.713 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Prasino2** | 0 | 0 | 0 | 0 | 0 | 0 | 0.061 | 0.367 | 0.018 | 1 |
| **Flagel** | 0.014 | 0.058 | 0 | 0.150063 | 0.142 | 0 | 0 | 0 | 0 | 1 |

aPigment abbreviations: Chl *c3* = chlorophyll *c3*; Chl *c2* = chlorophyll *c2*; Peri = peridinin; But-Fuco = 19-butanoyl-oxy-fucoxanthin; Fuco = fucoxanthin; Allo = alloxanthin; Lut = lutein; Chl *b* = chlorophyll *b*; Neo = neoxanthin and Chl *a* = chlorophyll *a*

bThe initial matrix was taken from Alou-Font et al. (2013)

cRMS: root mean square error

**Table S3.** Initial pigment to chlorophyll *a* ratio for each phytoplankton group.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Class / Pigmenta** | **Depth** | **Chl *c3*** | **Chl *c2*** | **Peri** | **But-fuco** | **Fuco** | **Pras** | **Hex-fuco** | **Zea** | **Allo** | **Lut** | **Chl *b*** | **Neo** | **Chl *a*** |
| Initial ratio matrixb |
| **Diat** | 0 − 15 m | 0 | 0.192 | 0 | 0 | 0.495 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0 | 0.171 | 0 | 0 | 0.424 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Chloro** | 0 − 15 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.217 | 0.023 | 1 |
| 16 − 50 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.143 | 0.037 | 0.035 | 1 |
| **Crypto** | 0 − 15 m | 0 | 0.075 | 0 | 0 | 0 | 0 | 0 | 0 | 0.201 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0 | 0.079 | 0 | 0 | 0 | 0 | 0 | 0 | 0.162 | 0 | 0 | 0 | 1 |
| **Chryso** | 0 − 15 m | 0.044 | 0.111 | 0 | 0.324 | 0.131 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0.038 | 0.105 | 0 | 0.386 | 0.141 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Dino** | 0 − 15 m | 0 | 0 | 0.285 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 - 50 m | 0 | 0 | 0.375 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Flagel** | 0 − 15 m | 0.145 | 0.08 | 0 | 0.039 | 0.125 | 0 | 0.056 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0.133 | 0.072 | 0 | 0.046 | 0.171 | 0 | 0.11 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Prasino2** | 0 − 15 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.035 | 0 | 0.049 | 0.418 | 0.017 | 1 |
| 16 − 50 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0.424 | 0.03 | 1 |
| **Prasino3** | 0 - 15 m | 0 | 0 | 0 | 0 | 0 | 0.136 | 0 | 0.057 | 0 | 0.005 | 0.222 | 0.043 | 1 |
| 16 − 50 m | 0 | 0 | 0 | 0 | 0 | 0.209 | 0 | 0 | 0 | 0.004 | 0.271 | 0.054 | 1 |
| **Phaeocys** | 0 − 15 m | 0.167 | 0 | 0 | 0 | 0.188 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0.276 | 0.167 | 0 | 0.373 | 0.476 | 0 | 0.684 | 0 | 0 | 0 | 0 | 0 | 1 |

aPigment abbreviations: Chl *c3* = chlorophyll *c3*; Chl *c2* = chlorophyll *c2*; Peri = peridinin; But-Fuco = 19-butanoyl-oxy-fucoxanthin; Fuco = fucoxanthin;Pras *=* Prasinoxanthin; Hex-fuco = 19-hexanoyl-oxy-fucoxanthin; Zea = Zeaxanthin; Allo = alloxanthin; Lut = lutein; Chl *b* = chlorophyll *b*; Neo = neoxanthin and Chl *a* = chlorophyll *a*.

bThe initial matrix was taken from Coupel et al. (2015) and Fragoso et al. (2017)

**Table S4.** Final (after CHEMTAX optimization) pigment to chlorophyll *a* ratio for each phytoplankton group.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Class / Pigmenta** | **Depth** | **Chl *c3*** | **Chl *c2*** | **Peri** | **But-fuco** | **Fuco** | **Pras** | **Hex-fuco** | **Zea** | **Allo** | **Lut** | **Chl *b*** | **Neo** | **Chl *a*** |
| Final ratio matrix (RMS = 0.11 (0 − 15 m), RMS = 0.07 (16 − 50 m))b |
| **Diat** | 0 − 15 m | 0 | 0.174 | 0 | 0 | 0.590 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0 | 0.156 | 0 | 0 | 0.534 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Chloro** | 0 − 15 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.148 | 0.179 | 0.020 | 1 |
| 16 − 50 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.151 | 0.037 | 0.036 | 1 |
| **Crypto** | 0 − 15 m | 0 | 0.092 | 0 | 0 | 0 | 0 | 0 | 0 | 0.256 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0 | 0.078 | 0 | 0 | 0 | 0 | 0 | 0 | 0.188 | 0 | 0 | 0 | 1 |
| **Chryso** | 0 − 15 m | 0.039 | 0.107 | 0 | 0.276 | 0.127 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0.033 | 0.110 | 0 | 0.455 | 0.157 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Dino** | 0 − 15 m | 0 | 0 | 0.365 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 - 50 m | 0 | 0 | 0.361 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Flagel** | 0 − 15 m | 0.106 | 0.084 | 0 | 0.038 | 0.130 | 0 | 0.112 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0.339 | 0.064 | 0 | 0.010 | 0.154 | 0 | 0.016 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Prasino2** | 0 − 15 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.032 | 0 | 0.037 | 0.579 | 0.016 | 1 |
| 16 − 50 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.018 | 0.542 | 0.025 | 1 |
| **Prasino3** | 0 - 15 m | 0 | 0 | 0 | 0 | 0 | 0.158 | 0 | 0.059 | 0 | 0.005 | 0.261 | 0.049 | 1 |
| 16 − 50 m | 0 | 0 | 0 | 0 | 0 | 0.201 | 0 | 0 | 0 | 0.004 | 0.286 | 0.052 | 1 |
| **Phaeocys** | 0 − 15 m | 0.265 | 0 | 0 | 0 | 0.160 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 16 − 50 m | 0.259 | 0.158 | 0 | 0.394 | 0.521 | 0 | 0.760 | 0 | 0 | 0 | 0 | 0 | 1 |

aPigment abbreviations: Chl *c3* = chlorophyll *c3*; Chl *c2* = chlorophyll *c2*; Peri = peridinin; But-Fuco = 19-butanoyl-oxy-fucoxanthin; Fuco = fucoxanthin;Pras *=* Prasinoxanthin; Hex-fuco = 19-hexanoyl-oxy-fucoxanthin; Zea = Zeaxanthin; Allo = alloxanthin; Lut = lutein; Chl *b* = chlorophyll *b*; Neo = neoxanthin and Chl *a* = chlorophyll *a*.

bRMS: root mean square error



**Figure S1. Melosira arctica growing attached to the bottom of first-year sea ice in central Hudson Bay.** (Photo credit: L. Dalman).

**Table S5.** Historical and measured seasonal primary production of microalgal communities in Hudson Bay presented in Figure 8.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Reference** | **Community** | **Region** | **Date** | **Primary productiona (mg m**−**2 d**−**1)** |
| Gosselin et al 1985b | Bottom-ice algae | East | 10-Apr-1982 | 5.5 |
| Bottom-ice algae | East | 10-May-1982 | 15.9 |
| Michel et al. 1993b | Bottom-ice algae | East | 15-Apr-1986 | 8.6 |
| Bottom-ice algae | East | 15-May-1986 | 2.8 |
| Welch et al. 1991b | Bottom-ice algae station 1 | West | 14-Mar-1988 | 3.6 |
| Bottom-ice algae station 1 | West | 14-Apr-1988 | 11.4 |
| Bottom-ice algae station 1 | West | 14-May-1988 | 24.6 |
| Bottom-ice algae station 2 | West | 30-Mar-1988 | 27.8 |
| Bottom-ice algae station 2 | West | 16-Apr-1988 | 101 |
| Bottom-ice algae station 2 | West | 16-May-1988 | 93.5 |
| Bergmann et al. 1991 | Bottom-ice algae | West | 30-May-1988 | 12.0 |
| Legendre et al. 1981b | Under-ice phytoplankton | East | 15-Feb-1978 | 1.3 |
| Under-ice phytoplankton | East | 15-Mar-1978 | 0.7 |
| Under-ice phytoplankton | East | 15-Apr-1978 | 1.0 |
| Under-ice phytoplankton | East | 15-May-1978 | 6.6 |
| Michel et al. 1993b | Under-ice phytoplankton | East | 20-Apr-1986 | 15.3 |
| Under-ice phytoplankton | East | 20-May-1986 | 45.1 |
| Under-ice phytoplankton | East | 20-Jun-1986 | 26.8 |
| This study | Open-water phytoplankton | West | 11-Jun-2018 | 460 |
| Under-ice phytoplankton | West | 20-Jun-2018 | 414 |
| Bottom-ice algae | West | 20-Jun-2018 | 1.8 |
| *Melosira arctica* | West | 18-Jun-2018 | 378 |
| Bélanger et al. 2013 | Open-water phytoplankton | Entire Bay | May 1998 - 2010 | 93 |
| Open-water phytoplankton | Entire Bay | Jun 1998 - 2010 | 154 |
| Open-water phytoplankton | Entire Bay | Jul 1998 - 2010 | 194 |
| Open-water phytoplankton | Entire Bay | Aug 1998 - 2010 | 164 |
| Open-water phytoplankton | Entire Bay | Sep 1998 - 2010 | 128 |
| Ferland et al. 2011 | Open-water phytoplankton | West | 04-Aug-2004 | 244 |
| Open-water phytoplankton | West | 04-Sep-2005 | 236 |
| Open-water phytoplankton | West | 09-Sep-2006 | 485 |
| Lapoussiere et al. 2013 | Open-water phytoplankton | West | 29-Sep-2005 | 100 |
| Open-water phytoplankton | East | 01-Oct-2005 | 337 |

aDaily production rates were extracted from stated references or were calculated as net accumulation from provided Chl a in the references (b)

**Table S6.** Seasonal and annual primary production in Hudson Bay.

|  |  |  |
| --- | --- | --- |
| **Season** | **Mean daily primary production (mg C m−2** **d−1)** | **Seasonal primary productiona (g C m−2)** |
| Winter (Dec−Feb) | 0.0 | 0.0 |
| Early spring (Mar−May) | 85.5 | 7.9 |
| Spring melt (Jun) | 680 | 23.1 |
| Ice-free (Jul−Nov) | 280 | 40.9 |
| **Total annual productionb (g C m−2 yr−1)** | **71.9** |

aSeasonal production was calculated for early spring by multiplying 92 days with the mean daily rate of this season, for the spring melt by multiplying 34 melt days with the mean daily rate, and for the ice-free period by multiplying 146 open water days with the mean daily rate

bTotal annual production is calculated as the sum of seasonal production