Impacts of Arctic Sea Ice Melting on the Productivity of the Planktonic Ecosystem

Yvette H. Spitz
Oregon State University, CEOAS

Carin J. Ashjian(1), Robert G. Campbell(2), Michael Steele(3) and Jinlun Zhang(3)

(1) Woods Hole Oceanographic Institution
(2) University of Rhode Island, GSO
(3) University of Washington Applied Physics Laboratory

http://psc.apl.washington.edu/zhang/BIOMAS/index.html
Ice Extent (Sept 1979)

Ice Extent (Sept 2011)
Open Water Days in the Beaufort Sea, 1980 to 2009

NSIDC Courtesy Irina Overseem, University of Colorado Boulder.
Salinity

Salinity of 33.1, characteristic of the core of nutrient CB2 was selected because the data was typical of data collected within the Beaufort Gyre. (b) Map of depth at salinity S = 33.1, which defines the core of the nutrient-bearing Pacific Winter Water. The color scale on right indicates depth.

Deepening of the nutricline and chlorophyll maximum in the Canada Basin interior, 2003–2009 (Fiona A. McLaughlin and Eddy C. Carmack)

Figure 1. (a) Map of salinity at depth 30 m in the Canada Basin, 2003–2009. The colour scale on the right indicates salinity values. Grey lines are contours of dynamic height, calculated with 800 m as the reference depth. Station locations are identified by small black dots and the heavy black dot denotes the location of Station CB2 referred to in the text. Station CB2 was selected because the data was typical of data collected within the Beaufort Gyre. (b) Map of depth at salinity S = 33.1, characteristic of the core of nutrient-bearing Pacific Winter Water. The color scale on right indicates depth.

Figure 3. (a) Continuous profiles of nitrate (ISUS data) at Station CB2a in 2007 (green) and 2009 (red), bottle data are indicated by circles. (b) Time-series plot of basin-averaged values of the depth of the chlorophyll maximum. (c) Time-series plot of the basin-averaged nitrate concentration at the depth of the chlorophyll maximum. The nitrate concentration at each station was determined by fitting a cubic spline fit using AKIMA modifications to the bottle data (red circles) and by determining the depth-axis intercept (blue diamonds). Data from stations with bottom depths greater than 1600m and located from 72.5–78.2°N and 153.5–139°W were included in the basin-averaged calculations.
Exceptional melt pond occurrence in the years 2007 and 2011 on the Arctic sea ice revealed from MODIS satellite data

Anja Rösel1 and Lars Kaleschke1

Received 30 December 2011; revised 23 February 2012; accepted 18 March 2012; published 12 May 2012.

Melt ponds contribute to the ice-albedo feedback as they reduce the surface albedo of sea ice, and hence accelerate the decay of Arctic sea ice. Here, we analyze the melt pond fraction, retrieved from the MODIS sensor for the years 2000–2011 to characterize the spatial and temporal evolution. A significant anomaly of the relative melt pond fraction at the beginning of the melt season in June 2007 is documented. This is followed by above-average values throughout the entire summer. In contrast, the increase of the relative melt pond fraction at the beginning of June 2011 is within average values, but from mid-June, relative melt pond fraction exhibits values up to two standard deviations above the mean values of 30 ± 1.2% which are even higher than in Summer 2007.


Figure 2. Comparison of the spatial melt pond fraction from the data sets of (left) June 18 2007 and (right) June 18 2011.

Figure 3. (a) Multiyear mean relative melt pond fraction (black line) with standard deviation (dashed line) and (b) mean sea ice area covered with melt ponds (black line) with standard deviation (dashed line) for the time period 2000–2011 relative to the sea ice area for the entire Arctic. The light gray lines display the development of melt ponds for the single years. The years 2007 (red) and 2011 (magenta) are highlighted for comparison.
How will this large scale ice melting and changes of water properties (light, temperature, mixing, etc) affect the ecosystem?
BIOMAS’ Circulation Model and Grid

Parallel ocean and sea ice model (Zhang/Rothrock 2003).

=> Multi-category thickness and enthalpy distribution sea ice model.

=> POP (parallel ocean program) ocean model (Smith et al. 1992).

physical open boundary conditions imposed from a global model run
Schematic of BIOMAS' Pelagic Ecosystem Model

Zhang et al. (2010) – based on Nemuro
Changes in PP and plankton in the Arctic Ocean

Satellite derived PP values are from Pabi et al. 2008 and Arrigo et al. 2008

Is that due to a longer growing season? If not, then why?

Is the trend the same for all the Seas?
Arctic Regions for Analysis Purpose

- Bering Sea
- Beaufort Sea
- Chukchi Sea
- ESS+Laptev Sea
- Deep Basin
- Greenland shelf
- Kara Sea
- Nordic Sea
- Barents Sea
- Canada Archipelago

[Map of Arctic Regions]
Start and End of Growing Season (10% above Phytoplankton Winter Value)

Beaufort Sea

Chukchi Sea


Year


100  150  200  250  300  350

Day

Day of Year

Diatom  Flagellate  Chlorophyll

Yea

r

r
Trend of Yearly Maximum (day (black), magnitude (red)) for the Beaufort Sea

Chlorophyll (-21.4783, 0.065443)

Copepods (-10.3043, 0.017287)

Flagellates (-19.4565, 0.054155)

Micro Zooplankton (-7.6957, 0.010566)

Diatoms (-22.9348, -0.0039986)

Predatory Zooplankton (-2.9783, 0.004251)
Maximum of Biomass and Primary Productivity, and Minimum of Nitrate - Change in Day from 1988 to 2010

<table>
<thead>
<tr>
<th></th>
<th>Chukchi Sea</th>
<th>Beaufort Sea</th>
<th>Arctic Deep Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll</td>
<td>-21</td>
<td>-21</td>
<td>-17</td>
</tr>
<tr>
<td>Flagellate</td>
<td>-17</td>
<td>-19</td>
<td>-10</td>
</tr>
<tr>
<td>Diatom</td>
<td>-18</td>
<td>-23</td>
<td>-21</td>
</tr>
<tr>
<td>Microzoo</td>
<td>-16</td>
<td>-8</td>
<td>-17</td>
</tr>
<tr>
<td>Copepod</td>
<td>-12</td>
<td>-10</td>
<td>-9</td>
</tr>
<tr>
<td>Predatory Zoo</td>
<td>-4</td>
<td>-3</td>
<td>-28</td>
</tr>
<tr>
<td>PP</td>
<td>-31</td>
<td>-17</td>
<td>-15</td>
</tr>
<tr>
<td>Ammonium</td>
<td>-26</td>
<td>-13</td>
<td>-2</td>
</tr>
<tr>
<td>Min Nitrate 100m</td>
<td>-12</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Min Nitrate 5m</td>
<td>-12</td>
<td>-2</td>
<td>-1</td>
</tr>
</tbody>
</table>

Change in timing of max. PP is the largest in the Chukchi Sea and the largest change in timing of phytoplankton happens in the Beaufort Sea.

Change in timing of the secondary producer biomass is largest in deep basin, especially for the predatory zooplankton.

Nitrate minimum happens earlier at the surface but later at depth in the Beaufort Sea and Deep Basin.
Maximum of Biomass and Primary Productivity, and Minimum of Nitrate - Change in value from 1988 to 2010

<table>
<thead>
<tr>
<th></th>
<th>Chukchi Sea</th>
<th>Beaufort Sea</th>
<th>Arctic Deep Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll</td>
<td>24%</td>
<td>12%</td>
<td>20%</td>
</tr>
<tr>
<td>Flagellate</td>
<td>12%</td>
<td>39%</td>
<td>129%</td>
</tr>
<tr>
<td>Diatom</td>
<td>31%</td>
<td>-2%</td>
<td>-10%</td>
</tr>
<tr>
<td>Microzoo</td>
<td>9%</td>
<td>33%</td>
<td>79%</td>
</tr>
<tr>
<td>Copepod</td>
<td>8%</td>
<td>12%</td>
<td>69%</td>
</tr>
<tr>
<td>Predatory Zoo</td>
<td>11%</td>
<td>10%</td>
<td>88%</td>
</tr>
<tr>
<td>PP</td>
<td>20%</td>
<td>21%</td>
<td>36%</td>
</tr>
<tr>
<td>Ammonium</td>
<td>-99%</td>
<td>-10%</td>
<td>36%</td>
</tr>
<tr>
<td>Min Nitrate 100m</td>
<td>-100%</td>
<td>-28%</td>
<td>-16%</td>
</tr>
<tr>
<td>Min Nitrate 5m</td>
<td>26%</td>
<td>-114%</td>
<td>-93%</td>
</tr>
</tbody>
</table>

Change in flagellate biomass and PP is the largest in the deep basin. Decrease of diatom biomass in Beaufort and Deep Basin

Change in the secondary producer biomass is the largest in deep basin

Nitrate is decreasing at the surface (except in the Chukchi Sea) and over the first 100m
Summer Mean Primary Productivity (mg C m\(^{-2}\) d\(^{-1}\)) (0-50 m)

- **1988-2000**
  - Integrated (0-50m) Primary Productivity (mg C m\(^{-2}\) d\(^{-1}\)), July-September 1988-2000

- **2001-2006**
  - Integrated (0-50m) Primary Productivity (mg C m\(^{-2}\) d\(^{-1}\)), July-September 2001-2006

- **2007-2011**
  - Integrated (0-50m) Primary Productivity (mg C m\(^{-2}\) d\(^{-1}\)), July-September 2007-2011

- **Increase of PP on the shelves**
  (more of the western Chukchi Sea)

- **Decrease of PP in Beaufort Gyre**
**Summer Mean Chlorophyll-a (mg Chl m\(^{-3}\)) (0-50 m)**

- **1988-2000**
  - Decrease of Chl in Beaufort Gyre

- **2001-2006**
  - Increase of Chl on the shelves (more of the western Chukchi Sea)

- **2007-2011**
  - Decrease of Chl in Beaufort Gyre
Secondary producers appear to follow the same trend as the primary production but not as rapidly.
**Summer Mean Total Nitrogen (mmol N m$^{-3}$) (0-50m)**

- **1988-2000**
  - Decrease of TN in Beaufort Gyre

- **2001-2006**
  - Increase of TN on the shelves (more of the western Chukchi Sea)

- **2007-2011**
  - Decrease of TN in Beaufort Gyre
Summer Mean Kinetic Energy ($cm^2 s^{-2}$) (0-100m)

1988-2000

2001-2006

2007-2011

• Increase of KE at the shelfbreak and edge of the Gyre
100m depth-average currents: Beaufort Gyre region 1988-2010, depths > 1000 m

EOF analysis

Beaufort Gyre (> 1000m)

100 m averaged current

EOF analysis
100 m Integrated Total Nitrogen – Beaufort Sea – 1988-2010

EOF1 (57%) and local contribution (%)

EOF2 (9%) and local contribution (%)

EOF3 (6%) and local contribution (%)

Amplitude

10^1 - mmol N/m^3

Conclusions and future research

• While we found that the maximum of productivity occurs earlier and reaches higher values in general, we did not find a significant trend in the start and end of the growing season.

  But

• The timing, magnitude and pattern of cycles are changing differently from region to region

• Plankton classes respond differently from region to region. Flagellate increase is larger than diatom increase in general. Grazer increase is larger in the Deep Basin.

• There is increase of total nitrogen over the shelves and shelfbreak but decrease at the center of the Beaufort Gyre. This decrease of nitrate could reduce productivity due to nitrogen limitation. On the edge of the gyre, there seems to be an increase of plankton biomass.

• While trends can be found, the complex nature of the Arctic Seas call for cautions when analyzing observations.
**Surface Chlorophyll-a (mg Chl m\(^{-3}\)) – July 04**

**Constant Chl:N**

2003

Chlorophyll-a (mg Chl m\(^{-3}\)) from ICESCAPE regression of Chl and PON

2011
Surface Total Nitrogen (mmol N m$^{-3}$) – July 04

2003

2011