Modelling the effects of changes in sea-ice extent on Arctic marine food webs

Michael Heath¹, Deborah Benkort², Andrew Brierley³, Ute Daewel², Richard Hofmeister², Roland Proud³, Corinna Schrum² and Douglas Speirs¹

¹Department of Mathematics and Statistics, University of Strathclyde, UK
²Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Germany
³School of Biology, University of St Andrews, UK
Retreating Arctic sea-ice cover and increasing primary production

<table>
<thead>
<tr>
<th></th>
<th>1979</th>
<th>2016</th>
<th>decease</th>
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<tbody>
<tr>
<td>winter</td>
<td>15.4</td>
<td>13.7</td>
<td>11%</td>
</tr>
<tr>
<td>summer</td>
<td>7.1</td>
<td>4.5</td>
<td>37%</td>
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</tbody>
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Climate projections indicate continuing loss of ice cover in the future

Increasing Arctic primary production linked to loss of ice cover

Images: National Snow and Ice Data Centre, Univ. Colorado

Arrigo and van Dijken (2011) JGR Oceans
Atlantification of the Barents Sea

Winter ice concentration 1979-2010 (colours), and ice extent (15% conc

From: Arthun et al. (2012). Journal of Climate 25, 4736-4743
See also: Lind et al. (2018). Nature Climate Change 8, 634–639
Borealization of Barents Sea fish communities

Shifting distributions of fish communities

Redrawn from Fossheim et al. 2015 Nature Climate Change DOI:10.1038/NCLIMATE2647
Retreating ice and the prospect of fisheries in polar waters

On 30 November 2017, the EU plus 9 major fishing nations agreed not to develop fisheries in the Central Arctic Ocean for at least the next 16 years, to give time for development of scientific understanding.

Science, 1 Dec 2017. doi:10.1126/science.aar6437
How will increased primary production propagate up the food web in the absence of sea-ice?

Depending on details of the processes, we might see:

- **Enhanced pelagic system**
- **Enhanced benthic system**
StrathE2E food web model - predicting the ecological effects of multiple types of perturbations

Dynamic, mass conserving network model, driven by input data on hydrodynamics, nutrient fluxes, and fishery harvesting rates

Network of coupled ordinary differential equations
- Models flow rates of nitrogen between the living, dead and inorganic components of the food web
- Output at daily intervals
- Computational fitting to observed data

Heath (2012) Prog. Oceanogr. 102, 42-66
Heath et al. (2014) Ecology Letters 17, 101-114
Heath et al. (2014).Nature Communications 5:3893
Barents Sea model – annual cycles of physical driving data

Compare two StrathE2E models for an Arctic shelf sea (Barents Sea)
- (1) Baseline: December-June sea-ice cover; (2) Scenario: year-round ice-free
- Both models – initially, no fishing

Temperature
(0.5°C warmer in the ice-free model)

Light intensity
(ice attenuates incoming light)

Vertical mixing
(ice shields the water column from wind mixing)

Freshwater input
(earlier river runoff in warmer conditions)

Ice-cover baseline model driving data based on 1980’s Barents Sea
Comparison of stationary annual cycle in the ice-cover baseline model with 1980’s observations from Svalbard

- Surface water nitrate
- Surface water ammonia
- Omnivorous zooplankton
- Larval stages of benthos
- Surface water chlorophyll
- Carnivorous zooplankton

Solid lines – Model simulation with ice-cover December - June
Symbols – Monthly averaged 1980’s data from Hornsund, Svalbard
(Węsławski et al. (1988). Polar Research 6, 185-189)
The increase in phytoplankton biomass is amplified as it cascades up the food web.

BUT – sensitive to:
- Temperature
- Attenuation of light and vertical mixing by ice-cover
- Preference parameters defining the accessibility of prey to predators vertically and horizontally

Differences between annual average masses of ecosystem components in the ice-free model and the baseline:

- **Annual primary production:**
  - Ice-cover model: 50.9 gC.m\(^{-2}\).y\(^{-1}\)
  - Ice-free model: 55.4 gC.m\(^{-2}\).y\(^{-1}\)

Less in the ice-free model: Birds & mammals, Demersal Fish, Pelagic fish, Carnivorous zooplankton, Carnivorous benthos, Mesozooplankton, Susp/deposit feeding benthos, Phytoplankton, Water column nitrate, Water column ammonia, Water column detritus, Sediment nitrate, Sediment ammonia, Sediment detritus.

Greater in the ice-free model:
How will increased primary production propagate up the food web in the absence of sea-ice?

**Ice-free scenario:**

Increased draw-down of nitrate and more primary production, as anticipated, but this leads to:

**Enhanced benthic system**

Increased mixing carries spring primary production deeper into the water column where it becomes accessible to filter feeding benthos.
Sensitivity of steady state fisheries yield to ice cover

Modelled fish catches in relation to annual harvest ratio (≡ fishing mortality rate)

- Demersal fish yields are greater in the ice-free model than in the baseline – due to enhanced benthos production

- Pelagic fish yields are smaller in the ice-free model than in the baseline – due to enhanced predation from demersal fish and mammals
Take-home messages

• Loss of winter sea-ice leads to increased primary production

• In this model, increased primary production leads to enhancement of the benthos/demersal fish, rather than the pelagic system.

• Sensitivity analysis and more investigation needed, to better represent the physical and biological effects of ice cover

• Potential impact - strategic guidance related to general policy on future exploitation of Arctic living resources

• Scope for public engagement – digestible results to illustrate the threats and opportunities posed by climate change in the Arctic
MiMeMo
Microbes to Megafauna
Modelling of Arctic Seas
www.changing-arctic-ocean.ac.uk/project/mimemo/

Fishing village with cod-drying racks in the Norwegian Arctic