Sympagic-pelagic-benthic coupling in Arctic marine ecosystems revealed by stable isotopic and fatty acid tracers

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Short about me

• **Arctic marine ecology** (Field and experimental approach)
  – Community structures (sympagic, pelagic and benthic)
  – Seasonality – winter ecology
  – Population dynamics/Life strategies (*Calanus* spp.)
  – Metabolism
  – Trophic interactions and carbon flow
**CLEOPATRA II:** Climate effects on planktonic food quality and trophic transfer in Arctic Marginal Ice Zones (Norwegian Research Council, 2012-2015)

**COPPY:** Fate of *COPePod secondarY* production in a changing Arctic (Norwegian Research Council, 2012-2015)

http://www.mare-incognitum.no/

‘Mare Incognitum’ umbrella for several research projects.
Outline

• Introduction – Arctic marine ecosystems
• Stable isotope and fatty acid trophic marker techniques
• Case study Svalbard
• Compound specific stable isotopes
• Outlook
Offshore: two food sources in Arctic seas

Ice algae

Phytoplankton

within and on the underside of sea ice

in water
Differences in light regimes according to the angle of the sun

Sea ice and snow cover
Ice algae <1% to 57% of the total primary production in the Arctic

Leu et al. 2011
Carbon sources and trophic structures

- Stable isotopes ($\delta^{13}C; \delta^{15}N$)
- Fatty acid trophic markers (FATM)

Advantages by analysing stable isotopes and FATMs vs. gut contents: time-integrated averages of assimilated food vs. "snapshot" of ingested food
Stable isotope ratios

- Per mill (‰) enrichment relative to international standards

\[
\delta X = \left[ \frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right] \times 1000
\]

Where X is $^{13}\text{C}$ or $^{15}\text{N}$ and R is the corresponding ratio $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$.

Standard $^{13}\text{C}$ Vienna PeeDee Belemnite
Standard $^{15}\text{N}$ atmospheric nitrogen (Air)
Stable isotope techniques
($\delta^{13}C$ and $\delta^{15}N$)

- $^{13}C$ increase little (~0.6‰) per trophic level
- $^{15}N$ increase by ~3.4‰ per trophic level
- Ice algae (Ice-POM) on average 3 to 5‰ more enriched in $^{13}C$ than phytoplankton (P-POM)

(Post 2002; Hobson et al. 1995; Søreide et al. 2006; 2008)
Two-source food web model

Trophic level (TL):

\[
TL_{\text{CONSUMER}} = \frac{1 + (\delta^{15}N_{\text{CONSUMER}} - [\delta^{15}N_{\text{PELAGIC}} - \alpha + \delta^{15}N_{\text{ICE}} * (1 - \alpha)])}{\Delta N}
\]

Carbon source (Pelagic vs. ice):

\[
\alpha = \frac{\Delta N * \delta^{13}C_{\text{CONSUMER}} - \Delta C * \delta^{15}N_{\text{CONSUMER}} + \Delta C * \delta^{15}N_{\text{ICE}} - \Delta N * \delta^{13}C_{\text{ICE}}}{\Delta N * \delta^{13}C_{\text{PELAGIC}} - \Delta N * \delta^{13}C_{\text{ICE}} - \Delta C * \delta^{15}N_{\text{PELAGIC}} + \Delta C * \delta^{15}N_{\text{ICE}}}
\]

Trophic enrichment factors:
\[
\Delta N = 3.4 \%, \quad \Delta C = 0.6 \%
\]

Food web baseline values
\[
\begin{align*}
\delta^{13}C & \quad \delta^{15}N \\
\text{Pelagic-POM} & = -23.5 \pm 0.4 \%o \quad 4.4 \pm 0.4 \%o \\
\text{Ice-POM} & = -18.6 \pm 1.1 \%o \quad 4.1 \pm 0.4 \%o
\end{align*}
\]

Søreide et al. 2006; 2008
Stable isotope baselines in marine food webs: a Pan-Arctic review

Main objectives
1. To determine the natural isotopic variability of food sources in Arctic coastal and offshore marine ecosystems.
2. To describe physical and biological relationships that explain isotopic variability in Arctic marine systems.

Background
Stable isotope analyses of nitrogen (\(\delta^{15}N\)) and carbon (\(\delta^{13}C\)) have the potential to capture trophic complex interactions, including omnivory, and to partition energy flows through ice-associated (sympagic), pelagic and benthic communities. The isotopic signature of the consumer alone, however, is not sufficient to infer its trophic position or major dietary carbon source. An appropriate isotopic baseline is also needed, but difficult to determine.

Challenges
Isotopic baseline signatures are difficult to determine because of spatiotemporal variability in the biochemical composition of primary producers and the challenge of obtaining pure samples of autotrophic material. The interpretation of food web structures and energy flows is further complicated by unknown and/or varying isotopic turnover times for tissues in many Arctic consumers.

Next step
1. Construct a database, which includes physical (light, nutrients and depth) and biological (taxonomic and physiological state) relevant information.
2. Study potential physical and biological relationships explaining the high variability in isotopic baseline values.

Future plans
The output of this joint work (see author list) will be a Pan-Arctic review paper on relevant isotopic baseline data for food web studies in Arctic coastal and offshore marine environments. We aim for a workshop in 2014 to compile all relevant data, discuss their quality/relevance, and to start the writing process. If you would like to contribute, contact Janne E. Søreide (jannes@unis.no).
Arctic marine food web structures

Onisimus
Gammarus
Themisto
Apherusa
Calanus

Ice POM
Pelagic POM
Polar cod
Parasgitta
Thysanoessa

Thysanoessa
Parasgitta
**Trophic level (TL) range:**
- Zooplankton: TL = 1.8 - 3.9
- Ice fauna: TL = 1.9 - 3.7

**Major carbon source:**
- Pelagic-POM (mean 74%)
- Ice-POM (mean 67%)

Based on 263 samples of zooplankton and 63 samples of ice amphipods.

Søreide et al. 2006 PiO
# Polar bear, seals and fish

Stable isotope data from Haakon Hop, NPI

Based on the *Two-source food web model* in Søreide et al. 2006; 2008

<table>
<thead>
<tr>
<th></th>
<th>Trophic level ± SE</th>
<th>α ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar Bear</td>
<td>5.2 ± 0.3</td>
<td>0.4 ± 0.1</td>
</tr>
<tr>
<td>Harp seal</td>
<td>3.7 ± 0.1</td>
<td>0.3 ± 0.0</td>
</tr>
<tr>
<td>Ring seal</td>
<td>3.9 ± 0.4</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>Polar cod &gt; 12 cm</td>
<td>3.6 ± 0.2</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>Polar cod &lt; 11 cm</td>
<td>3.2 ± 0.1</td>
<td>0.8 ± 0.1</td>
</tr>
</tbody>
</table>

Carbon source

\( \alpha = \) proportion of phytoplankton vs. ice algae

Hop & Søreide unpubl. results
Sample preparation effects on stable C and N isotope values: a comparison of methods in Arctic marine food web studies

Janne E. Søreide1,2,*, Tobias Tamelander3,2, Haakon Hop3, Keith A. Hobson4,

Fractionation of stable isotopes in the Arctic marine copepod Calanus glacialis: Effects on the isotopic composition of marine particulate organic matter

Tobias Tamelander a,b,c,* Janne E. Søreide a,b,c, Haakon Hop a, Michael L. Carroll b

Challenges using stable isotopes for estimating trophic levels in marine amphipods

Janne E. Søreide · Henrik Nygård
How important are ice algae?

Scenario 1: Limited Ice

- Phytoplankton
- Ice Algae
- Zooplankton
- Benthos
- Birds
- Fish
- Seals, whales

Scenario 2: Abundant Ice

- Ice Algae
- Phytoplankton
- Zooplankton
- Benthos
- Walrus
- Shrimp

Carroll & Carroll 2003
ORIGINAL ARTICLE

Sympagic-pelagic-benthic coupling in Arctic and Atlantic waters around Svalbard revealed by stable isotopic and fatty acid tracers


Contents lists available at ScienceDirect


Contents lists available at ScienceDirect

Polar Biol
DOI 10.1007/s00300-012-1171-x

ORIGINAL PAPER

Benthic infaunal community variability on the northern Svalbard shelf

Michael L. Carroll · William G. Ambrose Jr.
Study area (2003-04)

I. NW Svalbard dominated by Atlantic water (AtW) and limited seasonal sea ice (3-5 months).

II. N Svalbard dominated by AtW and perennial sea ice (10-12 months).

III. NE Svalbard dominated by Arctic water (ArW) and extensive seasonal sea ice (7-9 months).
Annual primary production (PP)

- NW Svalbard: 106 to 134 g C m\(^{-2}\) yr\(^{-1}\)
- N Svalbard: 54 ± 12 g C m\(^{-2}\) yr\(^{-1}\)
- NE Svalbard: 67 ± 12 g C m\(^{-2}\) yr\(^{-1}\)

Source: Reigstad et al. 2011

But ice algal production is not included here!
Pelagic and Benthic biomass pos. correlated
(y = 0.54x + 7.29; r^2=0.65, p<0.05)
• Coinciding pelagic and benthic biomass «hot spots» only found in Arctic waters, NE Svalbard.
Zooplankton biomass

- **C. finmarchicus**
  - (0.3 – 8.7 g DW m⁻²)

- **C. glacialis**
  - (0.1 – 30.6 g DW m⁻²)

- **C. hyperboreus**
  - (0.1 – 2.6 g DW m⁻²)

Søreide et al. 2008
Carbon flow and trophic levels

H=Herbivores; O=Omnivores C=Carnivores

- H (TL ≤ 2.3)
- O (TL = 2.4-2.8)
- C (TL ≥2.9)

Phytoplankton

Ice algae

δ¹⁵N (‰)

δ¹³C (‰)

POM May

I-POM “young”

I-POM “old”

Ice fauna

Zooplankton

Benthos

I-POM

P-POM

Sediment

H=Herbivores; O=Omnivores C=Carnivores
Carbon flow and trophic levels

- **Zooplankton**: Primarily pytoplankton, BUT *Calanus* spp. utilize ice algae in spring. TL=1.3-3.2

- **Ice fauna**: A mixture BUT herbivores use primarily ice algae. TL=1.2-3.7

- **Benthos**: Primarily ice algae, BUT suspension feeders also phytoplankton. TL=1.3-3.8
Available literature data from Svalbard and N Barents Sea

P-and I-POM: Pelagic and Ice particulate organic matter  
Søreide et al. 2013
Fatty acid trophic markers (FATMs)

- The FA composition of animals’ NL (i.e. storage lipids) largely reflect the FA composition of their diet

- The FA composition of animals’ PL (i.e. structural lipids) is largely determined genetically and thus species specific

- Algal FA composition is determined by their taxonomy, but also their physiological state.

Dalsgaard et al. 2003; Søreide et al. 2008
FATTY ACID (FA) NOMENCLATURE

FA are the major constituents of all lipids. They differ in carbon chain length, and in number and position of double bonds.

18:4n3

This FA has 18 carbon atoms and 4 double bonds, with the first double bond positioned from carbon atom 3.

- FA with no double bond (e.g. 16:0) are termed saturated FA (SFA).
- FA with one double bound (e.g. 16:1n7) are named monounsaturated FA (MUFA).
- FA with two or more double bonds are called polyunsaturated fatty acids (PUFAs).
Fatty acid trophic markers (FATMs)

- **Diatom-FATMs**: \( \Sigma \text{C16PUFAs; 20:5n3; 16:1n7} \)
- **Phaeocystis/dinoflagellate-FATMs**: \( \Sigma \text{C18PUFAs; C22PUFAs} \)
- **Bacteria-FATMs**: \( \Sigma \text{15:0; 17:0; 17:1} \)
- **Calanus-FATMs**: 20:1 and 22:1 FA and fatty alcohols
- **%PUFAs**: herbivore-index
- **18:1n9**: Carnivore-index

Dalsgaard et al. 2003; Søreide et al. 2008
POM fatty acid composition

Phaeocystis

Diatoms

Detritus

Søreide et al. 2008
Ice fauna

Ice algae (diatoms) particularly important for ice amphipods
In addition to Calanus spp. for carnivorous ice fauna
Carnivorous zooplankton

Calanuss spp. important prey for omnivorous-carnivorous zooplankton, except for krill

Diatoms and flagellates equally important
Benthos

Diatom-FATMs on average twice as important as Flagellate-FATMs

Calanus –FATMs prominent in most species
Summary - Biomass

- Pelagic and benthic biomass positively correlated ($r^2=0.66$) and similarly high in AtW (NW) and ArW (NE).

- N Svalbard had particularly low zooplankton and benthic biomass, reflecting the overall low primary production there.

- Biological «hot spots» in NE Svalbard (Rijpfjorden and Hinlopen) most likely due to input of ice-derived organic matter and highly specialized Arctic zooplankton (*C. glacialis*).
Summary – Carbon sources

- Ice algae and phytoplankton are both important carbon sources for ice fauna.

- Phytoplankton is the most important carbon source for zooplankton, but ice algae are important seasonally (spring).

- Ice algae (and/or refractory material) are the most important carbon source for benthic invertebrates.
Summary- Trophic structures and Diet

- 3 to 4 trophic levels (TL) in all three habitats
- Dominance of omnivores (TL = 2.4 to 2.7)
- Diatom FATMs prominent (up to 65%) in ice fauna (mean 39%) and benthic organisms (mean 25%)
- Diatom- and *Phaeocystis/*dinoflagellate FATMs equally high (~15%) in zooplankton.
- *Calanus*-FATMs high in carnivorous ice fauna (up to 28%), zooplankton (up to 38%) and benthic invertebrates (up to 41%)
Conclusion

• Less ice and a subsequent decrease in ice algal production will impact the sympagic and benthic communities, and the pelagic less

• Biological «hot spots» in Arctic waters over the shelves with coinciding high biomass of pelagic and benthic organisms may be lost..........................
Compound Specific Stable Isotopes
Fatty acid and stable isotope characteristics of sea ice and pelagic particulate organic matter in the Bering Sea: tools for estimating sea ice algal contribution to Arctic food web production

Shiway W. Wang, Rolf R. Gra

DOI 10.1007/s00300-014-1470-5

Sourcing fatty acids to juvenile polar cod (Boreogadus saida) in the Beaufort Sea using compound-specific stable carbon isotope analyses

Cory Graham · Laura Oxtoby · Shiway W. Wang · Suzanne M. Budge · Matthew J. Wooller
Compound specific stable isotope analysis

White symbols Ice-POM, solid symbols P-POM

Wang et al. 2014
stable isotope mixing models using $\delta^{13}C_{FA}$ values of diatom FA markers

• show that substantial proportions of these FA originated from sea ice-derived organic matter in the Bering Sea

• Importance of I-POM (FA 16:1n7, 20:5n3, 22:6n3)

  Themisto libellula 36–72%
  Calanus marshallae/glacialis 27–63%
  Thysanoessa raschii 39–71%

* Based on SIAR mixing model, Parnell et al. 2010

Wang et al. In press
CLEOPATRA II

• To estimate the carbon turnover in *Calanus glacialis* in different seasons

• Determine the degree of carbon accumulation in specific fatty acids and alcohols
Feeding experiment with $^{13}$C labeled algae (in 2013)

$T_0 \rightarrow T_1 \rightarrow T_2 \rightarrow T_4 \rightarrow T_8 \rightarrow T_{10} \rightarrow T_{\text{end}}$

Add $^{13}$C enriched phytoplankton ($t0$, $t2$, $t4$, $t8$)

0.125mg/L NaH$^{13}$CO$_3$

Additional Parameter:

BSIA Copepod 1 ind
Cell # 100ml
Chl-a 10ml
BSIA Algae 200ml
BSIA Food add 200ml

Graeve, Søreide, Boissonnot in prep.
$^{13}C$ Exp. Calanus glacialis CIV—May --2013

Graeve, Søreide, Boissonnot in prep.
Outlook

• Bulk stable isotopes and two-source food web model – gives a good overview/food web pattern

• Compound specific stable isotopes – promising tool to ask more specific questions

• $^{15}\text{N}$ and $^{13}\text{C}$ fractionation/turnover information in species/tissues needed to improve data interpretation
Thank you for your attention!

And all who have contributed:

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