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

Janne E. Søreide
Associate Professor in Marine Biology
The University Centre in Svalbard, UNIS
Janne.soreide@unis.no

AWI colloquium 26 Nov. 2014

Short about me

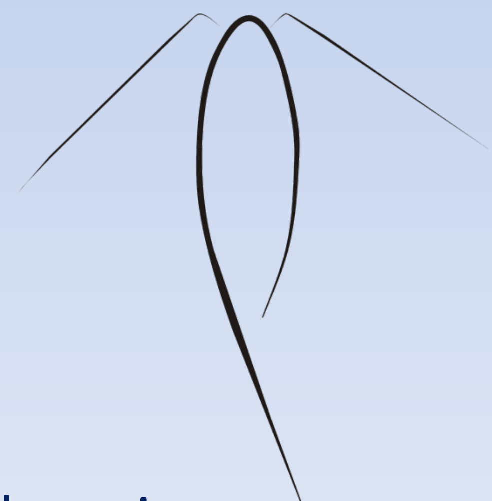
- Arctic marine ecology (Field and experimental approach)
  - Community structures (sympagic , pelagic and benthic)
  - Seasonality – winter ecology
  - Population dynamics/Life strategies (*Calanus* spp.)
  - Metabolism
  - Trophic interactions and carbon flow

Mare incognitum

Unraveling the mysteries of Arctic marine systems

<u>CLEOPATRA II</u>: **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 chancing 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

UNIS

Offshore: two food sources in Arctic seas

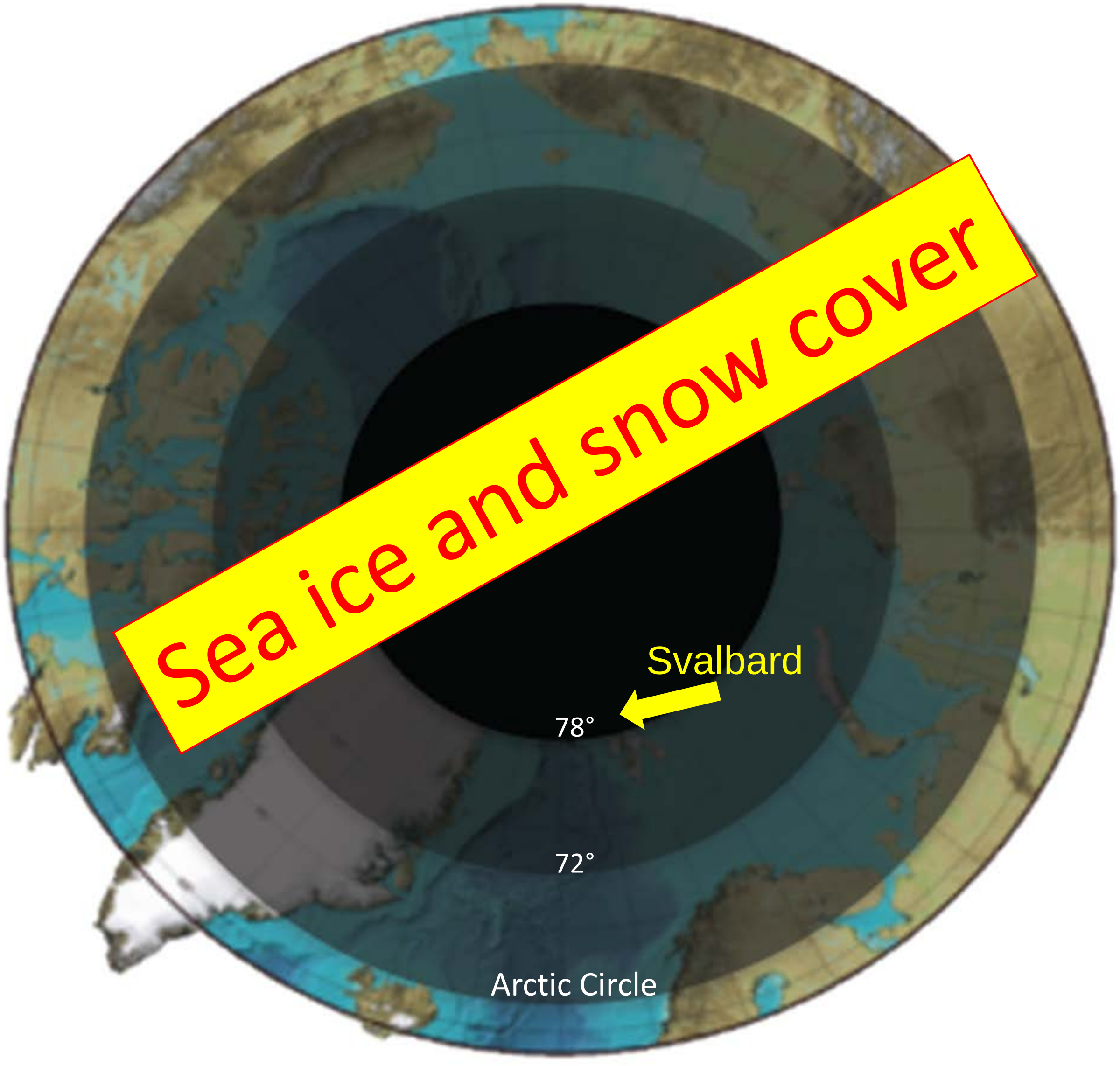
Ice algae

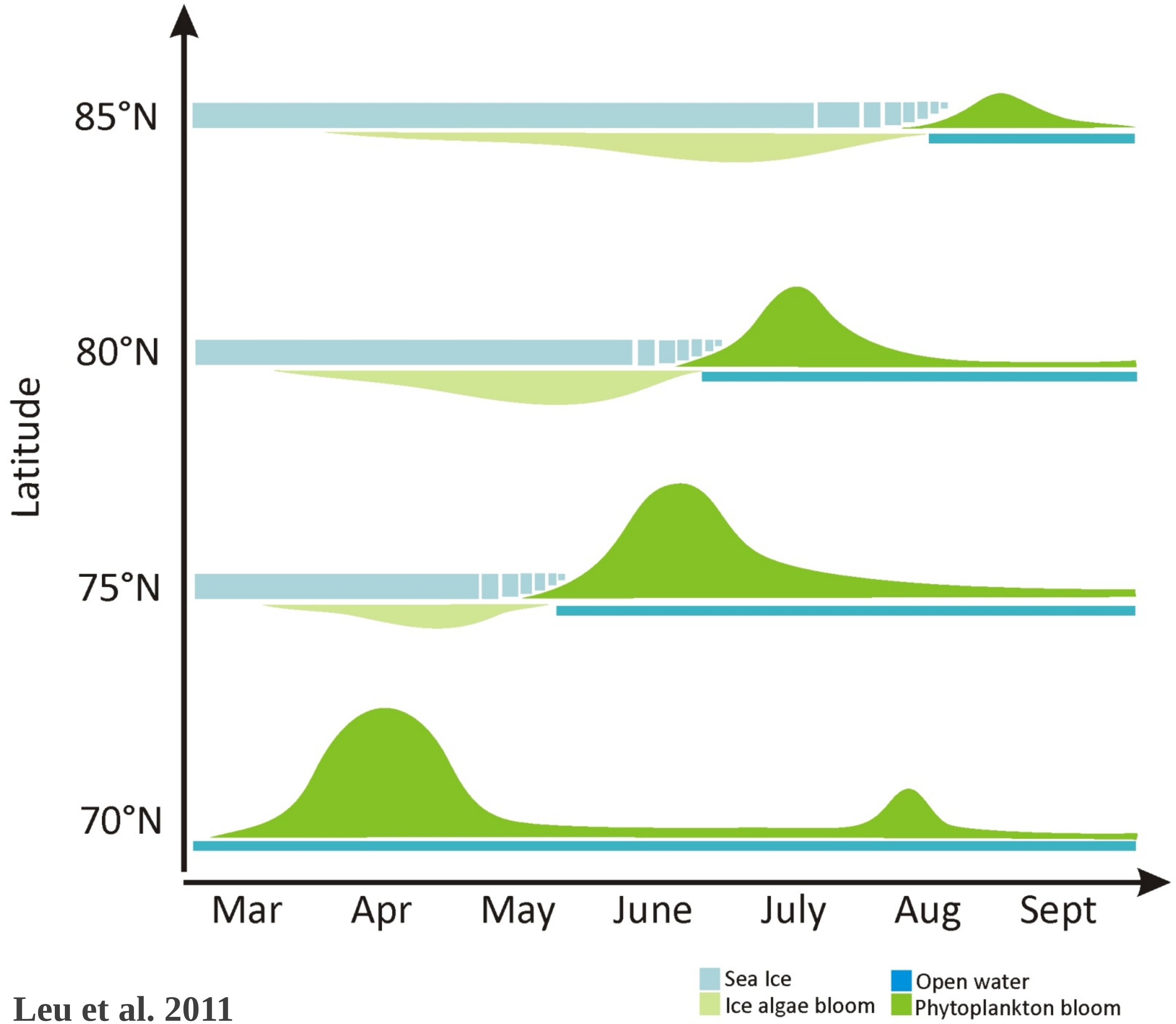
within and on the underside of sea ice

Phytoplankton

in water

Differences in light regimes according to the angle of the sun





Leu et al. 2011

Ice algae <1% to 57% of the total primary production in the Arctic

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

Standard ^{13}C Vienna PeeDee Belemnite
Standard ^{15}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):

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

Carbon source (Pelagic vs. ice):

$$\alpha = \frac{\Delta N * \delta^{13}C_{consumer} - \Delta C * \delta^{15}N_{consumer} + \Delta C * \delta^{15}N_{ICE} - \Delta N * \delta^{13}C_{ICE}}{\Delta N * \delta^{13}C_{PELAGIC} - \Delta N * \delta^{13}C_{ICE} - \Delta C * \delta^{15}N_{PELAGIC} + \Delta C * \delta^{15}N_{ICE}}$$

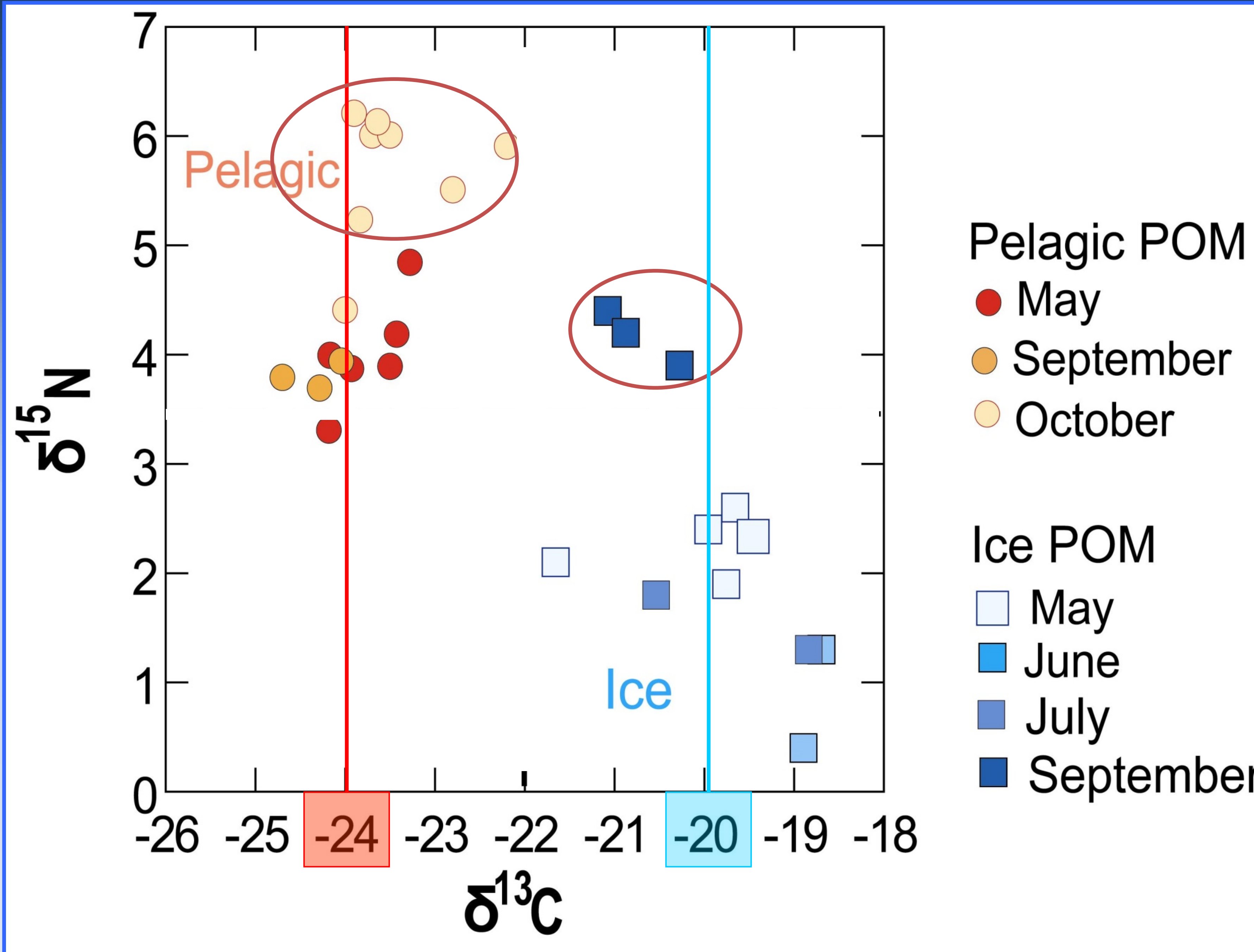
Trophic enrichment factors:

$\Delta N = 3.4$ ‰

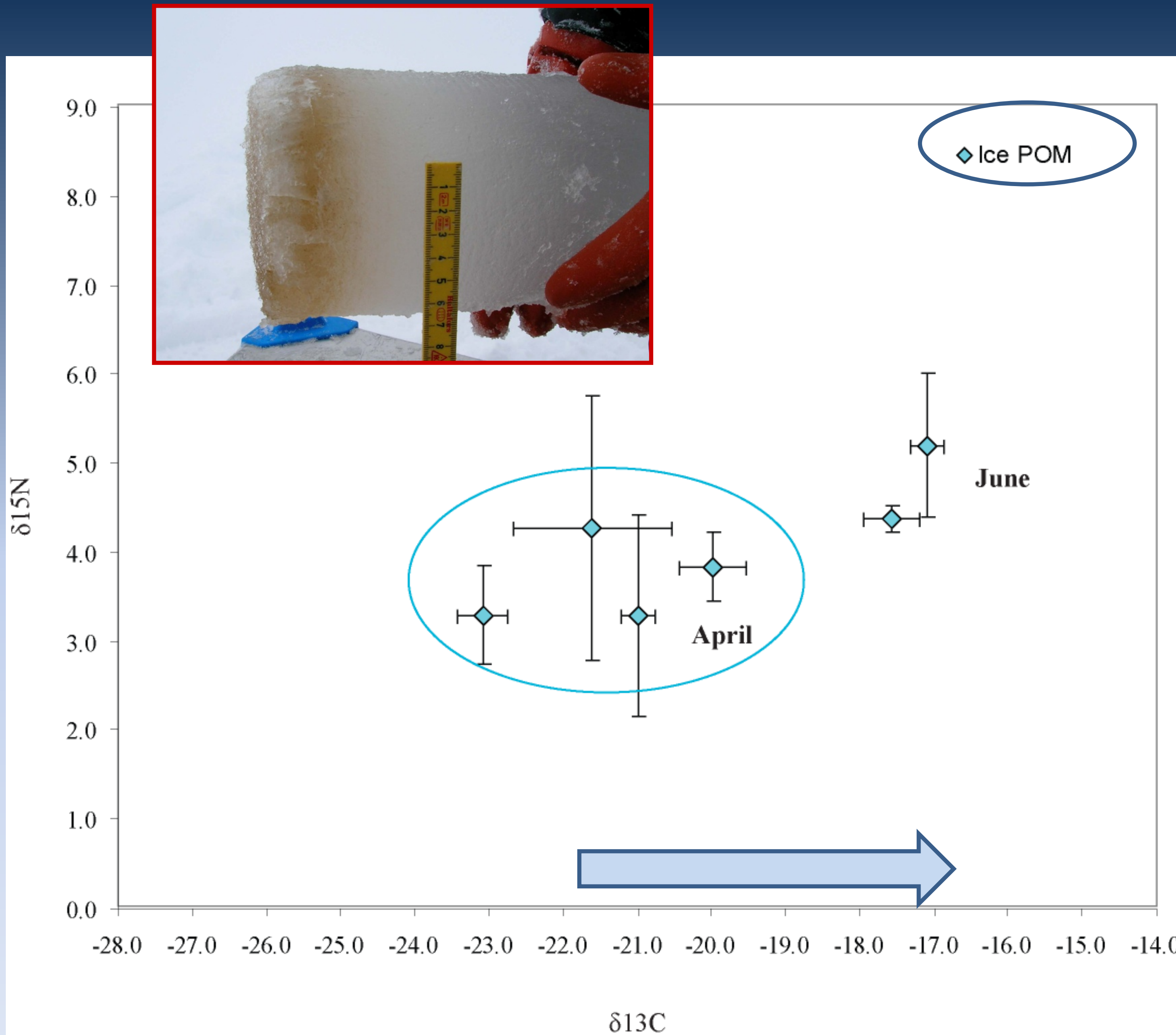
$\Delta C = 0.6$ ‰

Food web baseline values		$\delta^{13}C$	$\delta^{15}N$
Pelagic-POM	=	- 23.5±0.4‰	4.4±0.4‰
Ice-POM	=	-18.6±1.1‰	4.1±0.4‰

Søreide et al. 2006; 2008

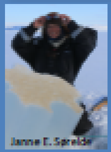


7
6
5
4
3
2
1
0
-26
-25
-24
-23
-22
-21
-20
-19
-18
δ15N
δ13C
Pelagic
Ice
Pelagic POM
May
September
October
Ice POM
May
June
July
September



Leu et al. 2010

Stable isotope baselines in marine food webs: a Pan-Arctic review



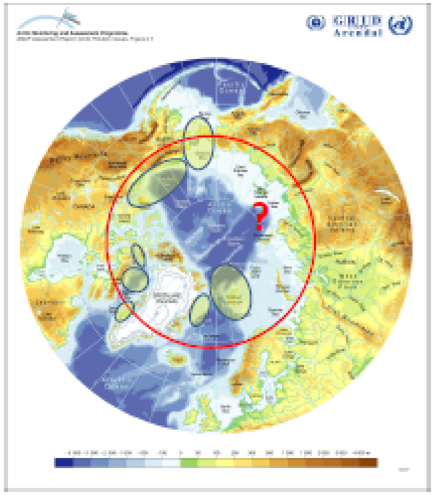
Janne E. Søreide (jannes@unis.no)[1], Katrin Iken[2], Bodil Bluhm[2], Rolf Gradinger[2], Paul E. Renaud[1,3], Tobias Tamelander[4], Jean-Eric Tremblay[5], Haakon Hop[6], Michael L. Carroll[3], William G. Ambrose Jr[3,7]., Kelton McMahon[8], Matthew J. Wooller[2], Kenneth Dunton[9]

Main objectives

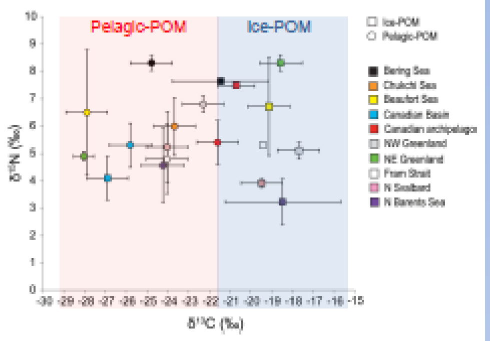
1. To determine the natural isotopic variability of food sources in Arctic coastal and offshore marine ecosystems.
2. Describe physical and biological relationships that explain isotopic baseline variability in Arctic marine systems.

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.



Pan-Arctic investigation area (red circle) for isotopic baseline data in Arctic coastal and offshore marine food webs. Regions with data are high-lighted in yellow, while isotopic data from the remaining Arctic are scarce.



Stable isotope data ($\delta^{13}C$ and $\delta^{15}N$; mean ± SD) of the two main food sources: ice algae (Ice-POM) and phytoplankton (Pelagic-POM) offshore in Arctic seas. Ice-POM is on average 6‰ more enriched in ^{13}C than Pelagic-POM, while Ice-POM and Pelagic-POM are similar in $\delta^{15}N$. However, the variability is high which complicates food web interpretations.

Ice algae comprise up to 57% of the primary production in the Arctic. Their importance as food can be traced by stable isotope analyses since $\delta^{13}C$ changes little as carbon moves through food webs. In contrast, a consumer is typically enriched in ^{15}N by 3-4‰, relative to its diet, providing a marker of trophic position.

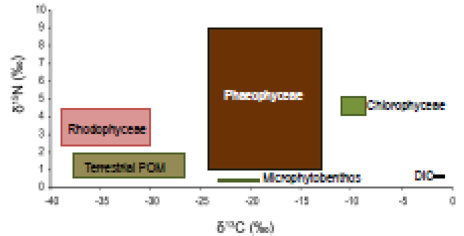
Challenges

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 flow is further complicated by unknown and/or varying isotopic turnover times for tissues in many Arctic consumers.

Next step

1. Construct a database, which include 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.



In progress: mapping of stable isotope data (ranges) of Arctic macroalgae, microphytobenthos ($\delta^{15}N$ not determined) and terrestrial POM. Dissolved inorganic carbon (DIC) shown for comparison.

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).

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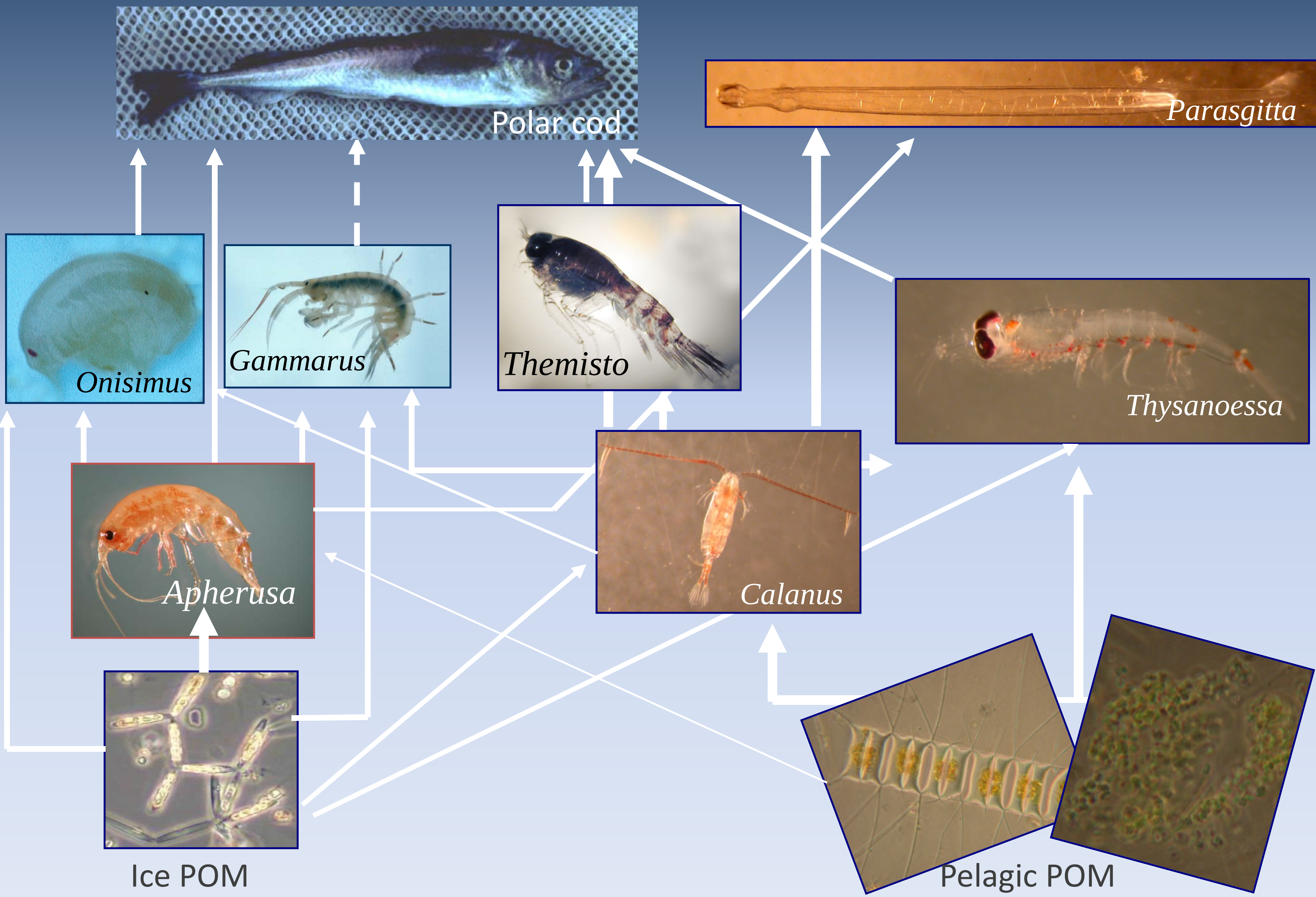
Arctic marine food web structures



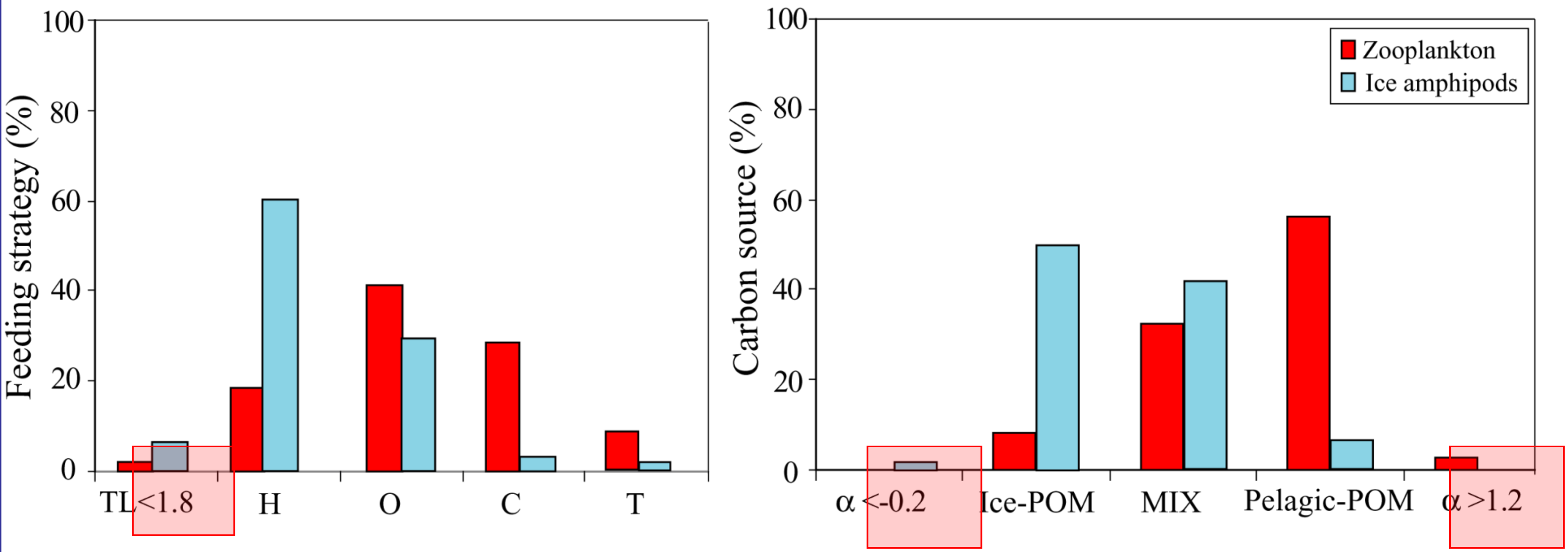
Trophic level (TL) range:

Zooplankton	TL = 1.8 - 3.9
Ice fauna	TL = 1.9 - 3.7

Major carbon source:

Pelagic-POM (mean 74%)

Ice-POM (mean 67%)



H: Herbivore	TL = 1.8-2.3
O: Omnivore	TL = 2.4-2.8
C: Carnivore	TL = 2.9-3.3
T: "Top"-canivore	TL = 3.4-3.8

Ice-POM	α = –0.2–0.3
MIX	α = 0.4–0.6
Pelagic-POM	α = 0.7–1.2

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

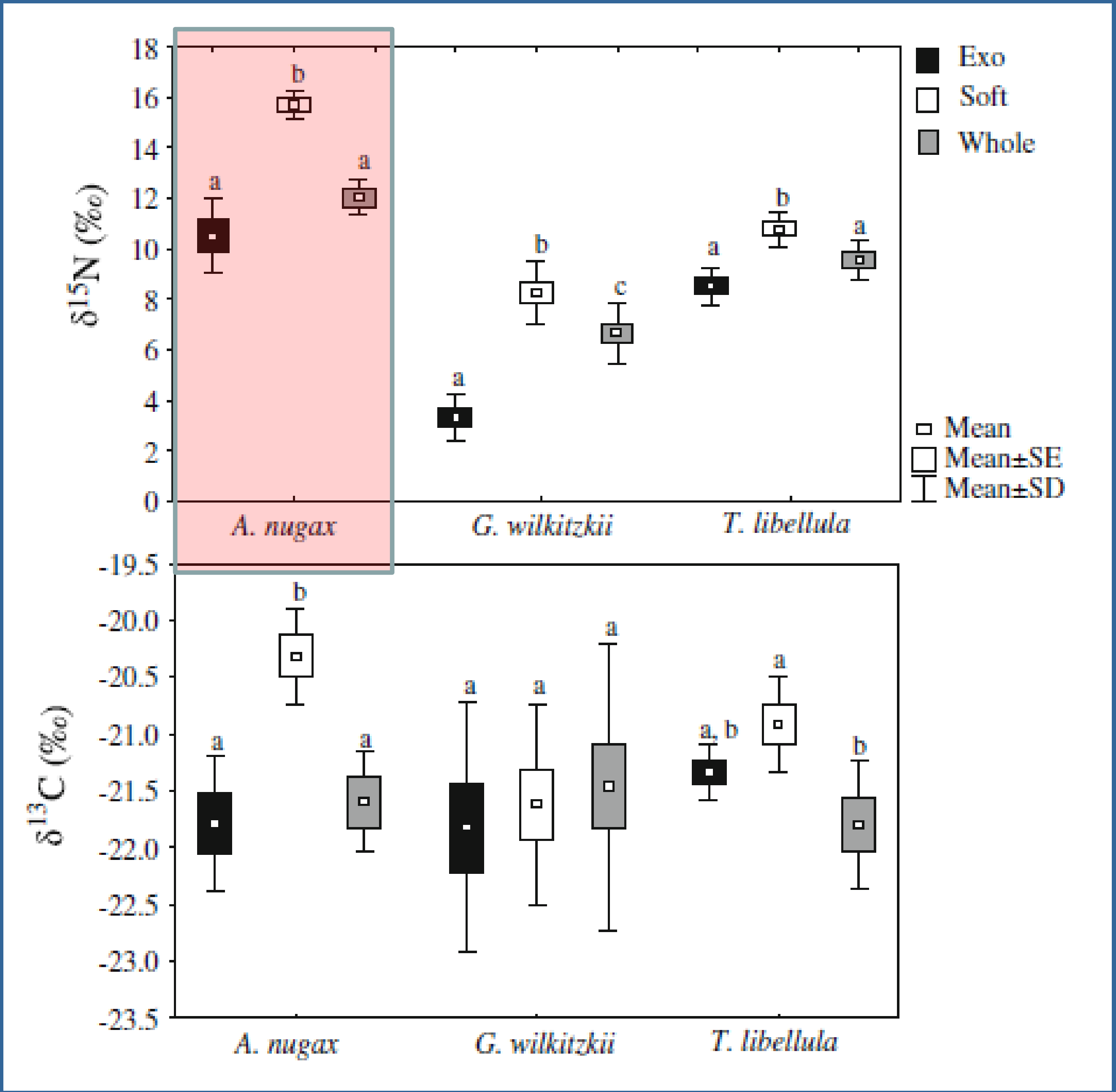
Based on the *Two-source food web model* in Søreide et al. 2006; 2008

	Trophic level	α
Polar Bear	5.2 ± 0.3	0.4 ± 0.1
Harp seal	3.7 ± 0.1	0.3 ± 0.0
Ring seal	3.9 ± 0.4	0.5 ± 0.1
Polar cod > 12 cm	3.6 ± 0.2	0.5 ± 0.1
Polar cod < 11 cm	3.2 ± 0.1	0.8 ± 0.1

<u>Carbon source</u>

α = proportion of phytoplankton vs. ice algae

Hop & Søreide unpubl. results



Søreide & Nygård 2012

Vol. 328: 17–28, 2006 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published December 20

Sample preparation effects on stable C and N isotope values: a comparison of methods in Arctic marine food web studies

Janne E. Søreide[1,2,*], Tobias Tamelander[3,2], Haakon Hop[3], Keith A. Hobson[4],

ELSEVIER

Journal of Experimental Marine Biology and Ecology 333 (2006) 231–240

Journal of EXPERIMENTAL MARINE BIOLOGY AND ECOLOGY

www.elsevier.com/locate/jembe

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]

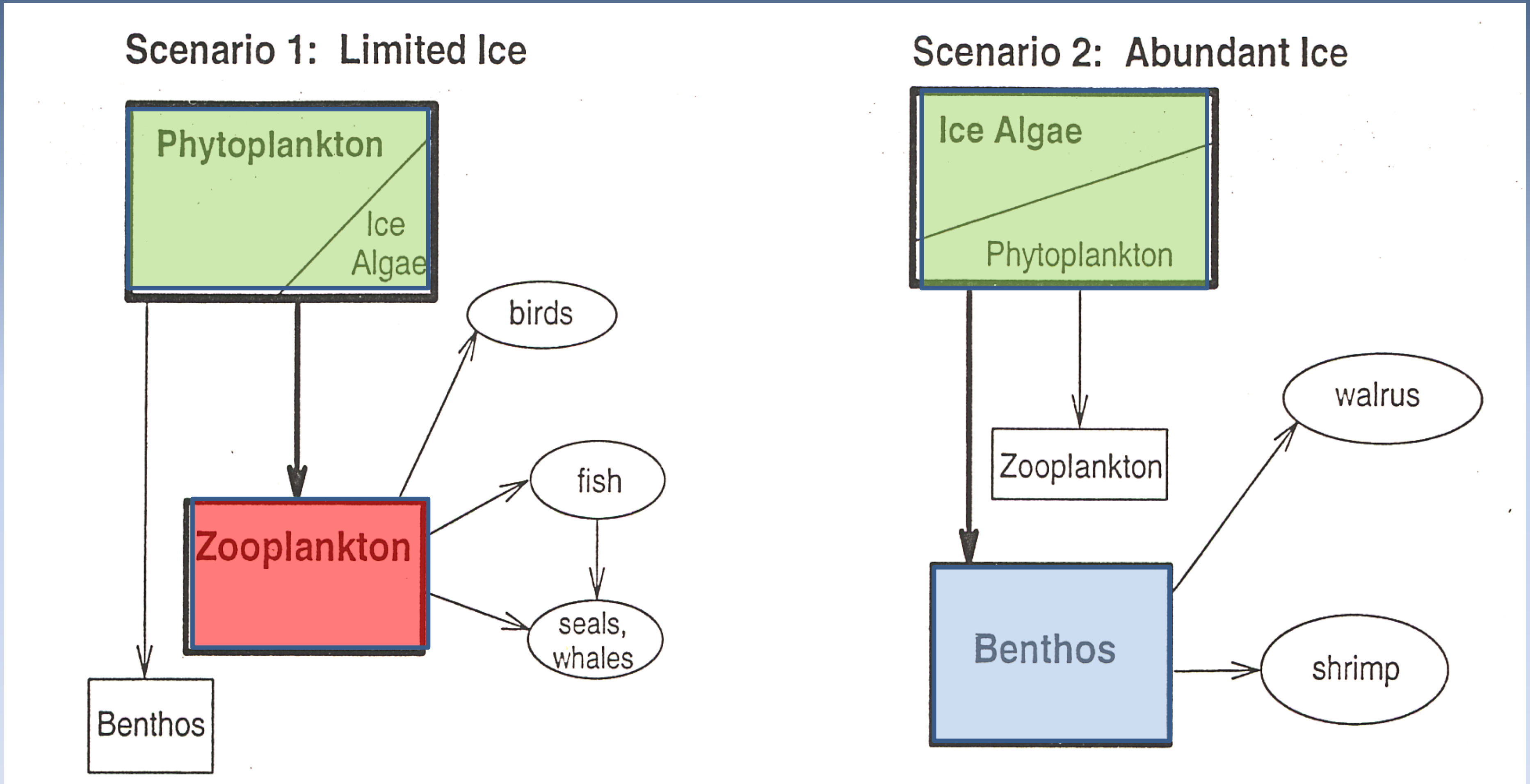
Polar Biol (2012) 35:447–453
DOI 10.1007/s00300-011-1073-3

SHORT NOTE

Challenges using stable isotopes for estimating trophic levels in marine amphipods

Janne E. Søreide · Henrik Nygård

How important are ice algae?



Carroll & Carroll 2003

Marine Biology Research, 2013
Vol. 9, No. 9, 831–850, http://dx.doi.org/10.1080/17451000.2013.775457

ORIGINAL ARTICLE

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

Deep-Sea Research II 55 (2008) 2210–2224

Deep-Sea Research II 55 (2008) 2292–2307

Deep-Sea Research II 55 (2008) 2225–2244

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

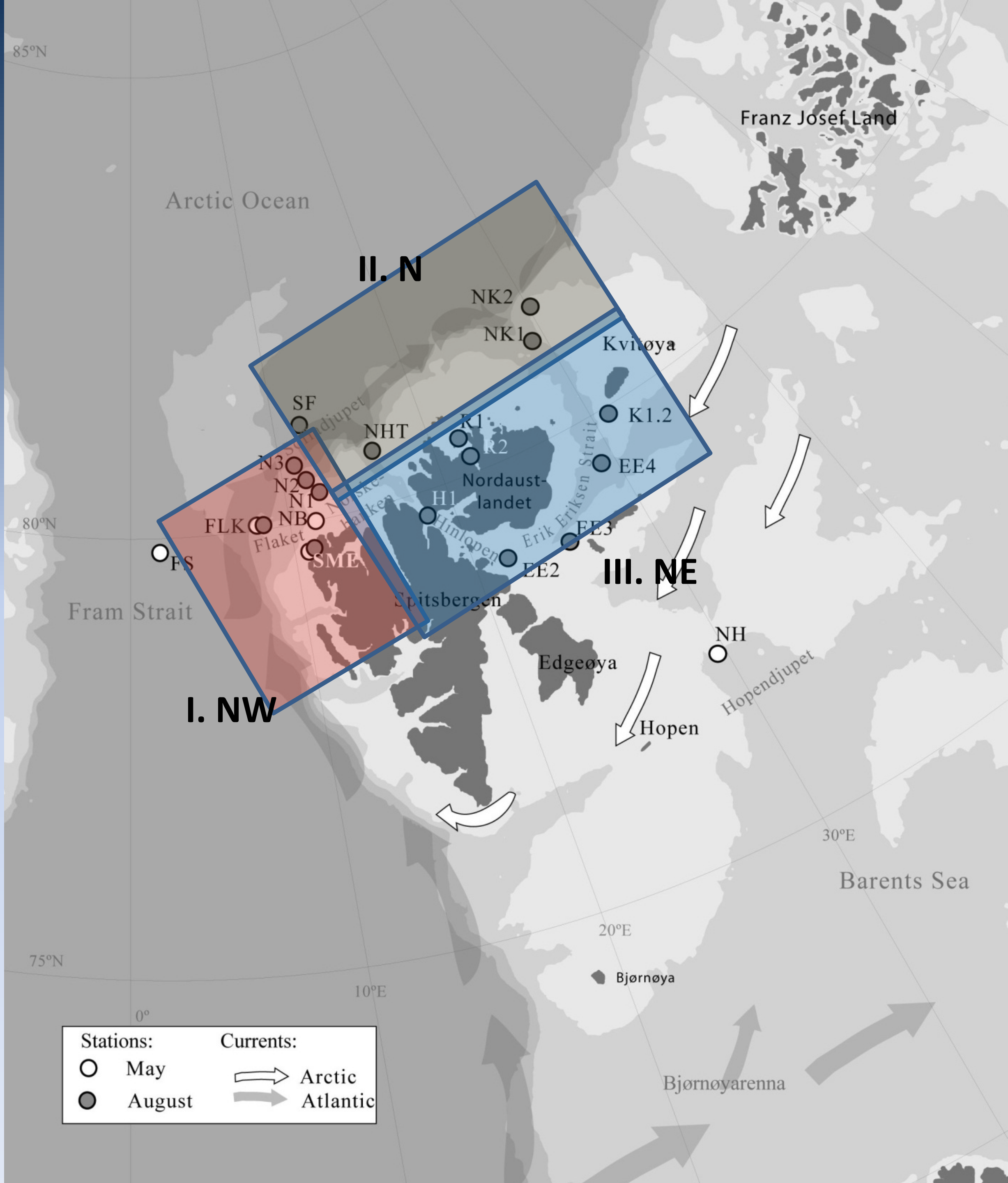
Michael L. Carroll · William G. Ambrose Jr.

Study area
(2003-04)

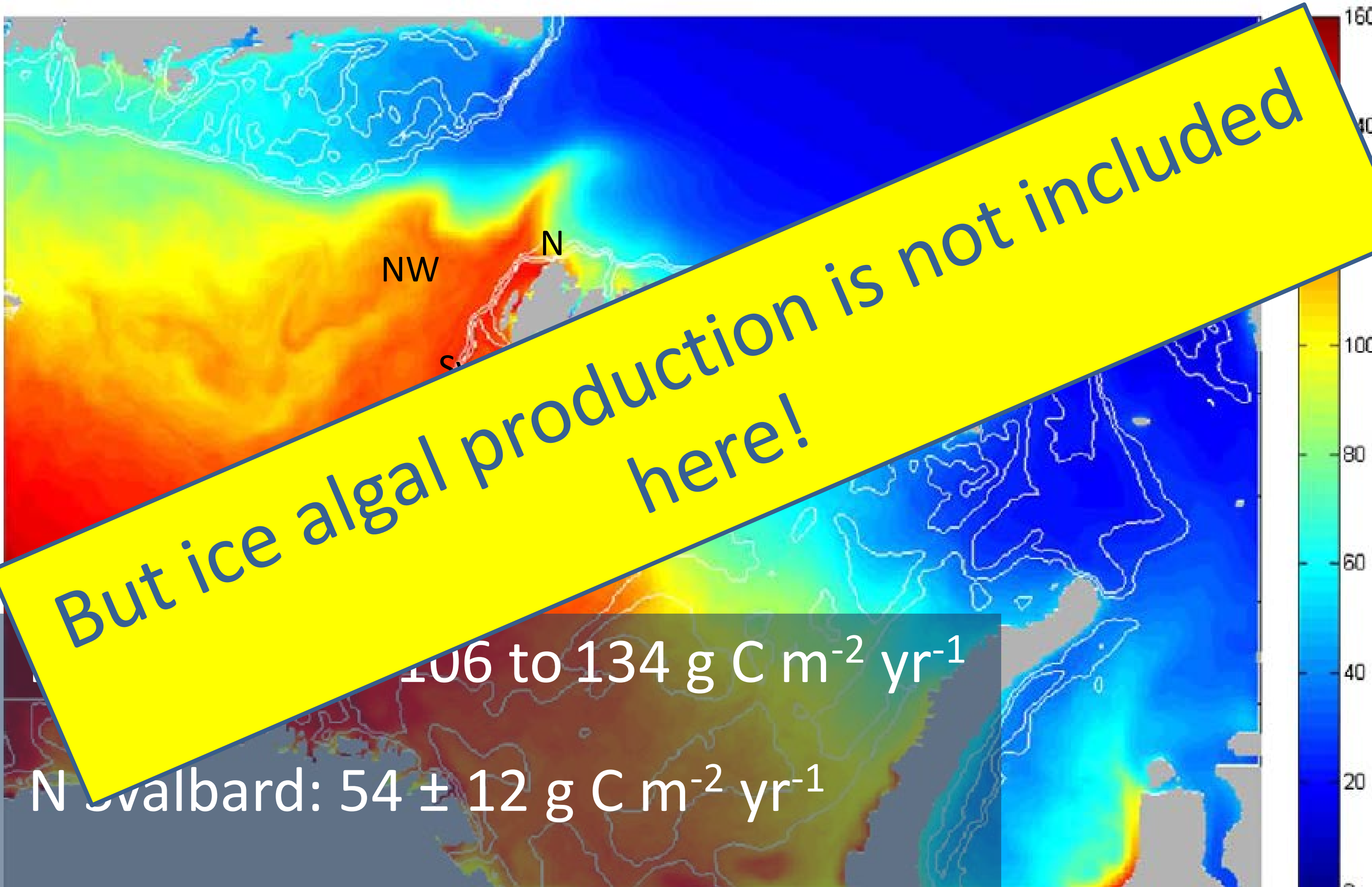
I. **NW Svalbard dominated by Atlantic water (AtW) and limited seasonal sea ice (3-5 months).**

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)

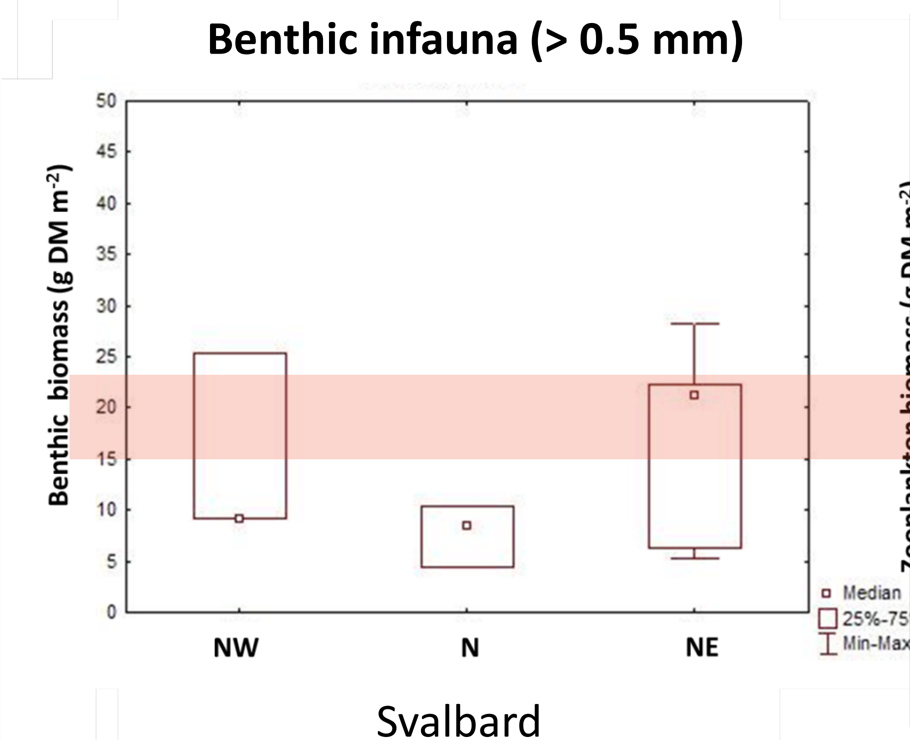


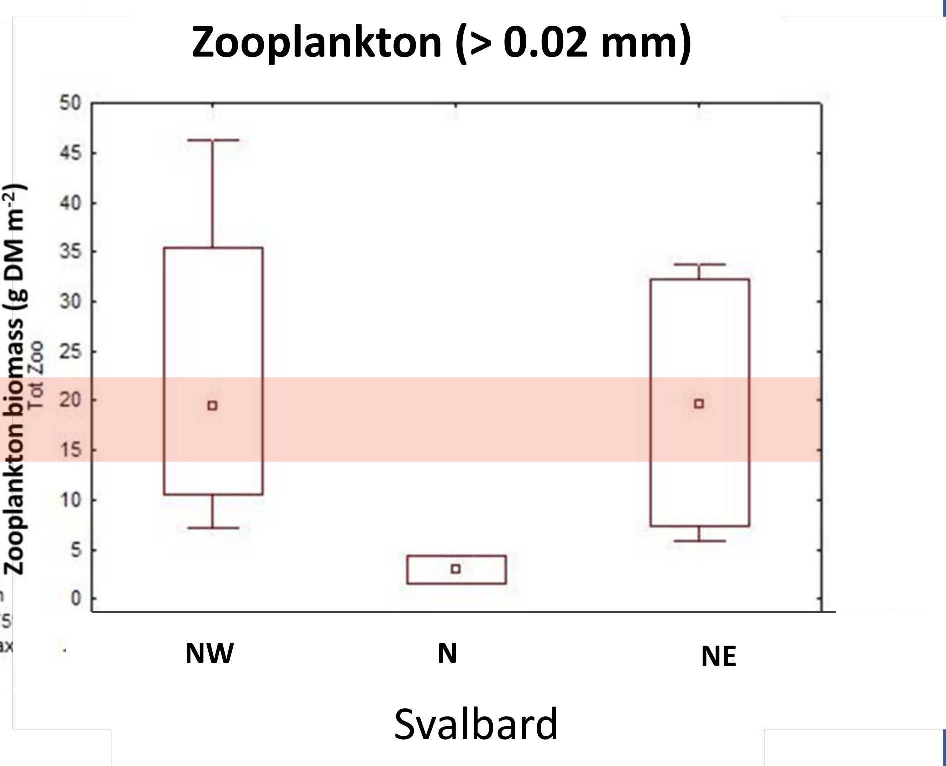
But ice algal production is not included here!

- 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

Biomass (g DM m^{-2})

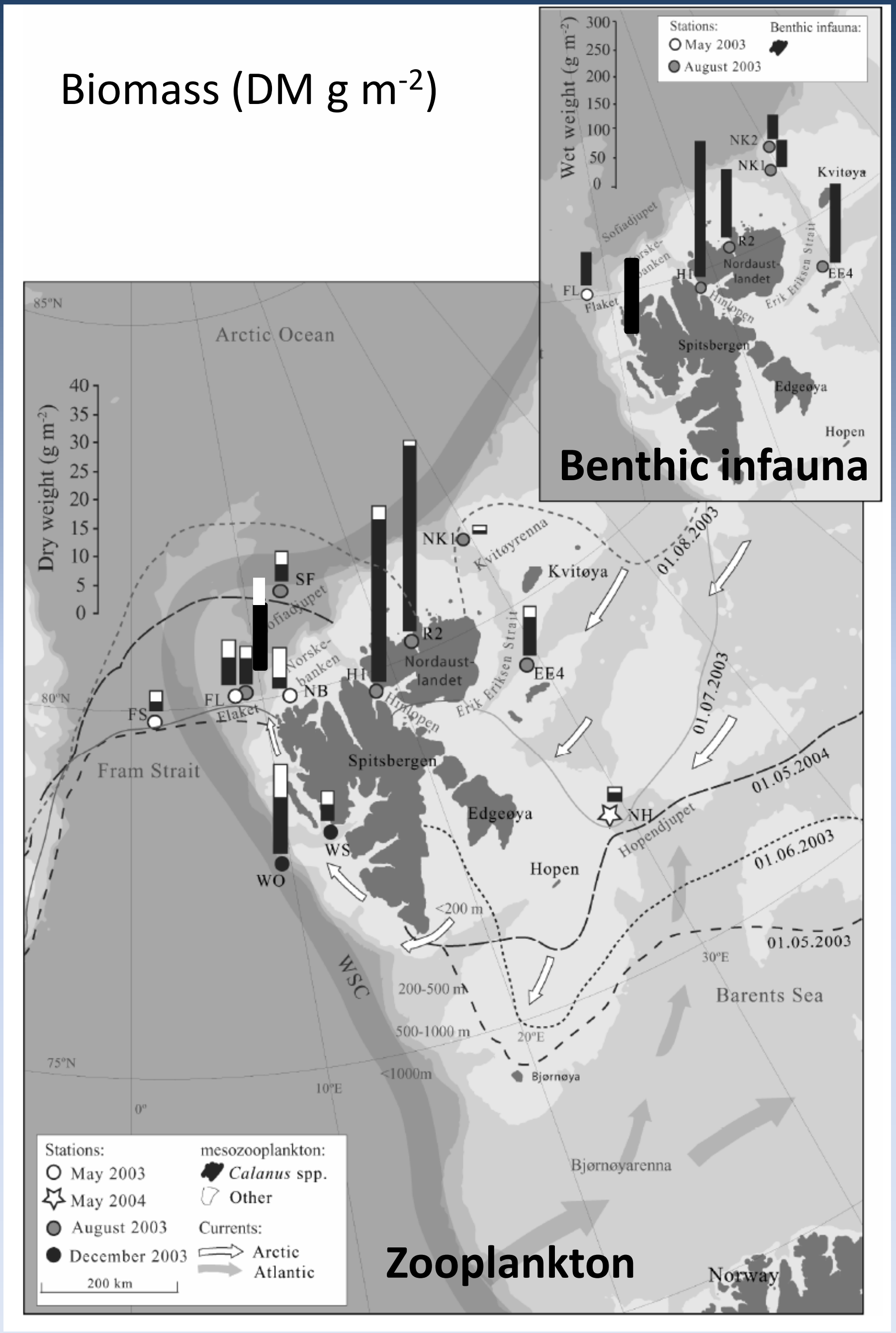




Pelagic and Benthic biomass pos. correlated

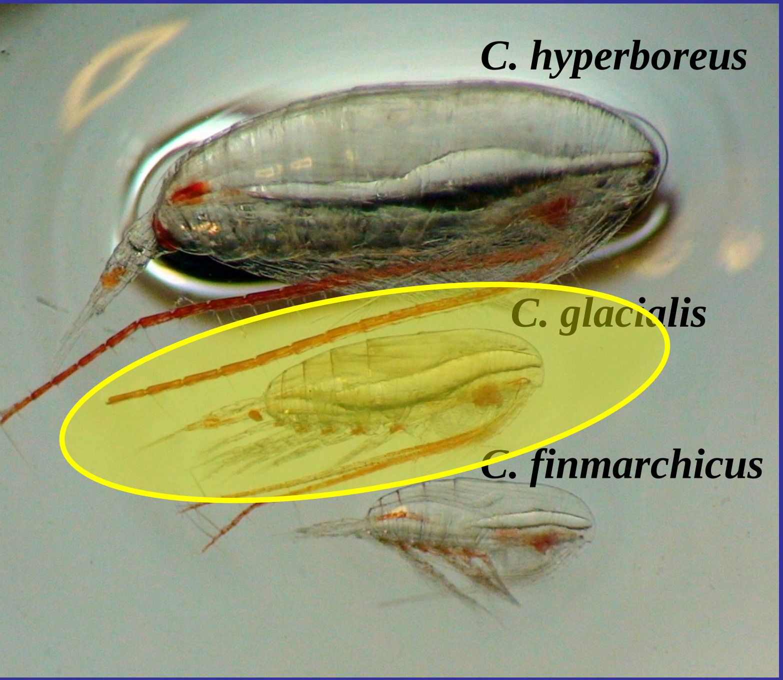
($y = 0.54x + 7.29$; $r^2=0.65$, $p<0.05$)

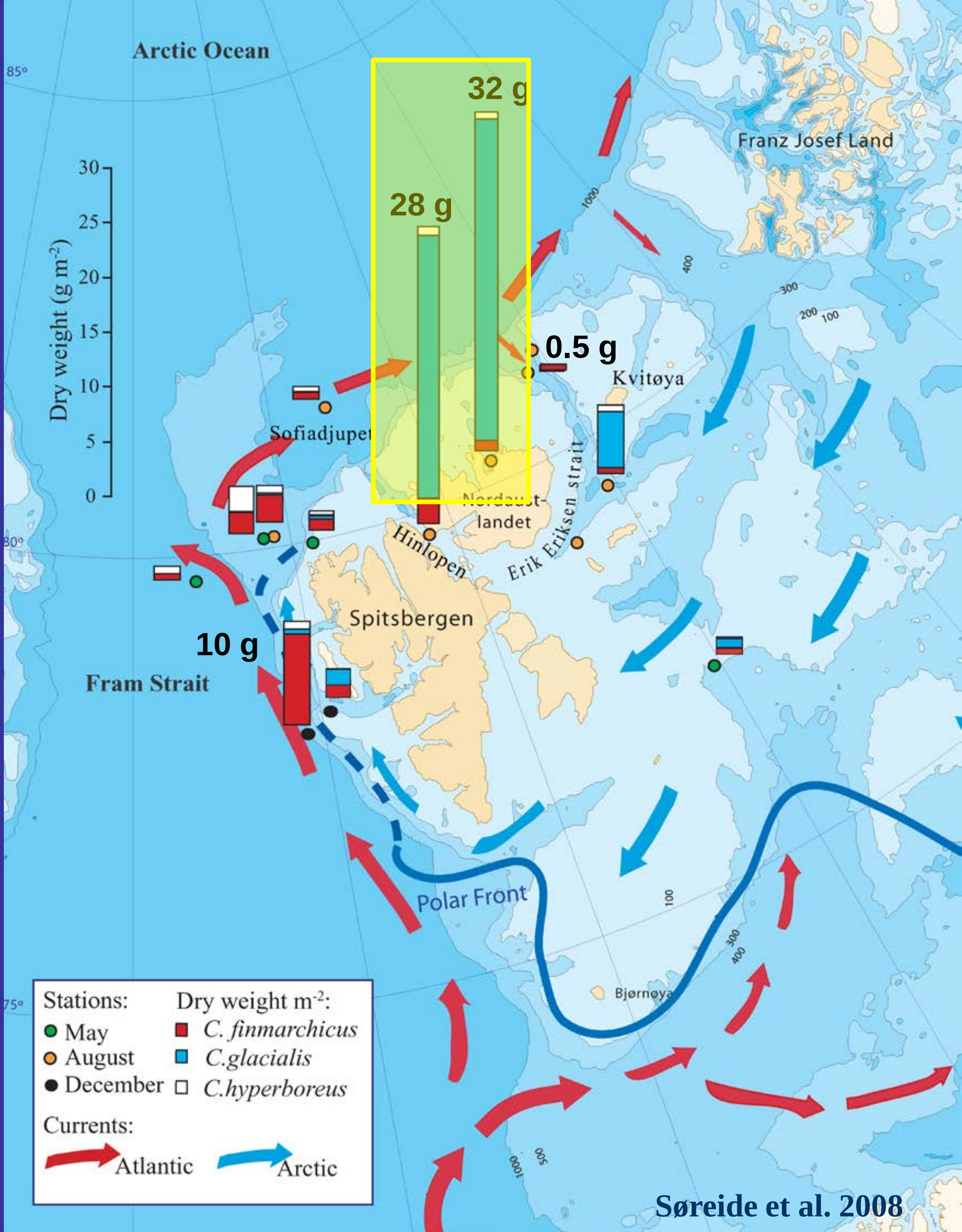
- Coinciding **pelagic** and **benthic** biomass «hot spots» only found in Arctic waters, NE Svalbard.



Zooplankton biomass

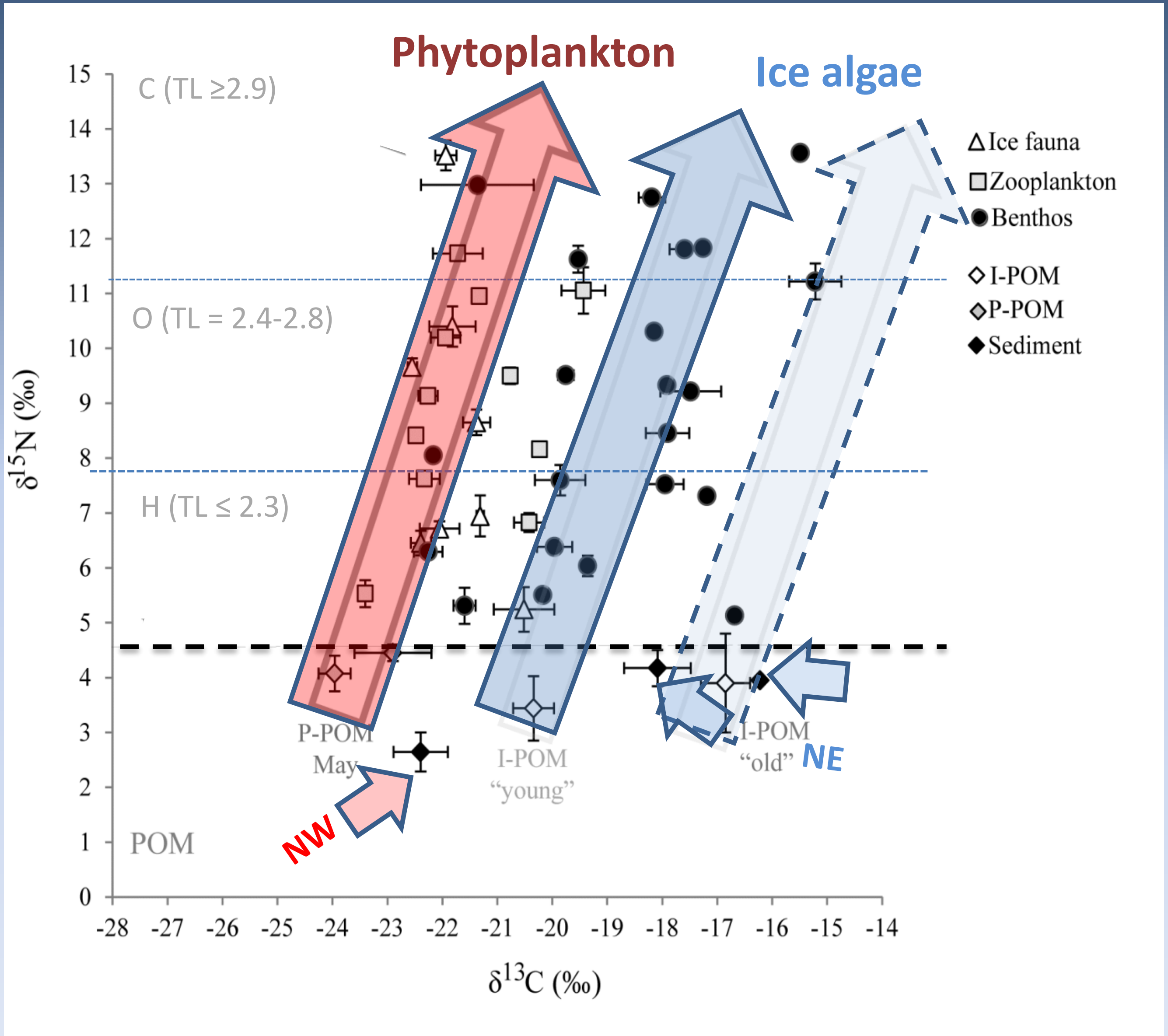
- *C. finmarchicus* (0.3 – 8.7 g DW m^{-2})
- *C. glacialis* (0.1 – 30.6 g DW m^{-2})
- *C. hyperboreus* (0.1 – 2.6 g DW m^{-2})





Søreide et al. 2008

Carbon flow and trophic levels



H=Herbivores; O=Omnivores C=Carnivores

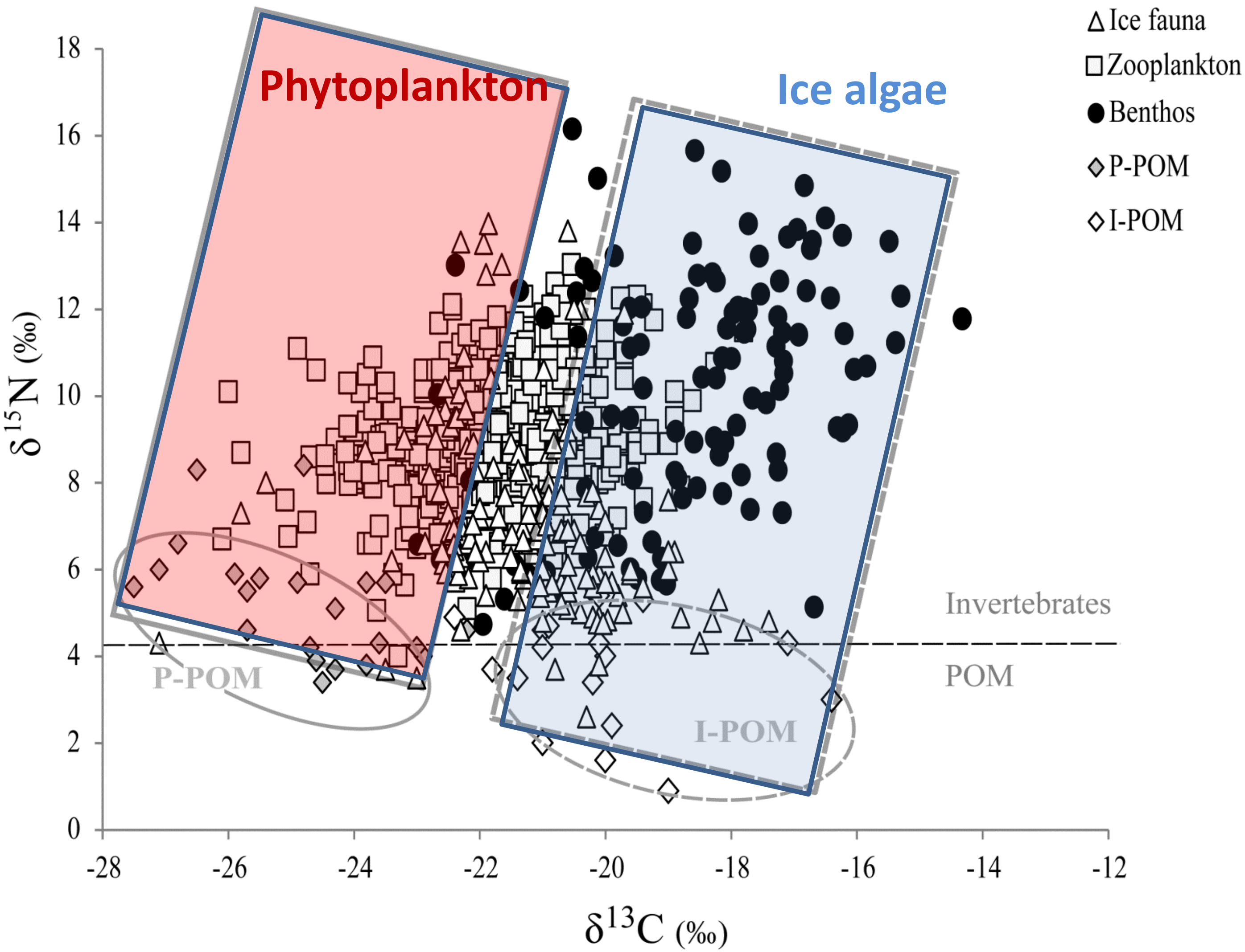
Carbon flow and trophic levels

- **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

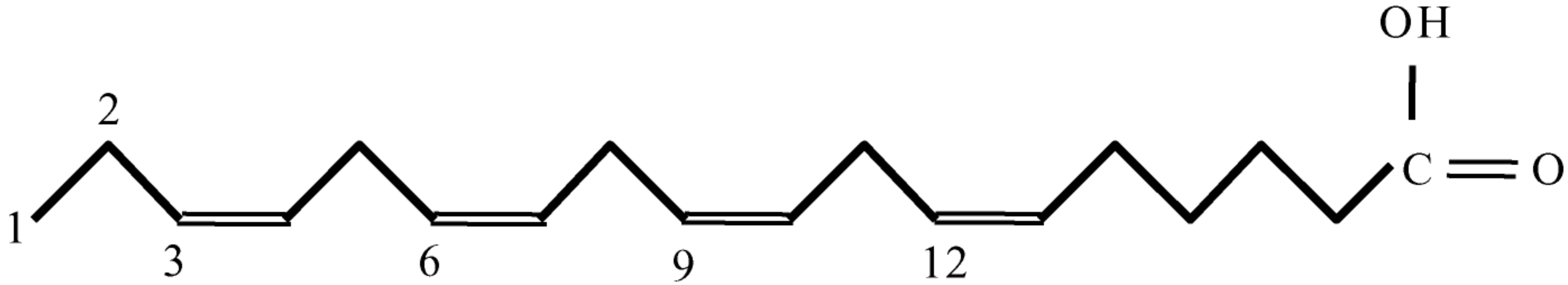
Fatty acid trophic markers (FATMs)

- **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

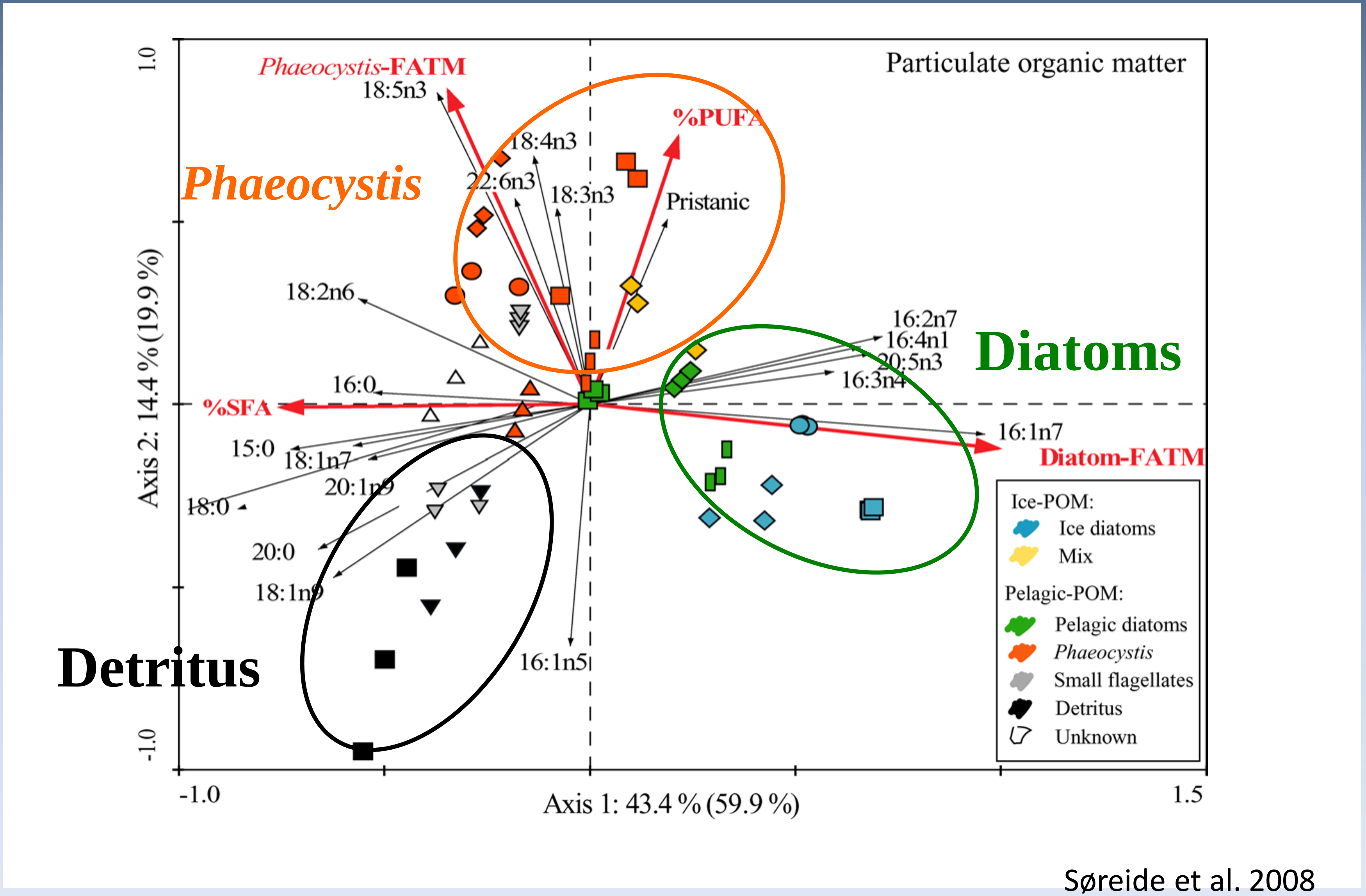
- FA with no double bond (e.g. 16:0) are termed saturated FA (SFA)
- FA with one double bound (e.g. 16:1n7) are named monounsaturated FA
- (MUFA)
- FA with two ore more double bonds are called polyunsaturated fatty acids (PUFAs)

Fatty acid trophic markers (FATMs)

- Diatom-FATMs: ΣC16PUFAs; 20:5n3; 16:1n7
- Phaeocystis/dinoflagellate-FATMs: ΣC18PUFAs; C22PUFAs
- Bacteria-FATMs: Σ15:0; 17:0; 17:1
- *Calanus*-FATMs: 20:1 and 22:1 FA and fatty alcohols
- %PUFAs: herbivore-index
- 18:1n9: Carnivore-index

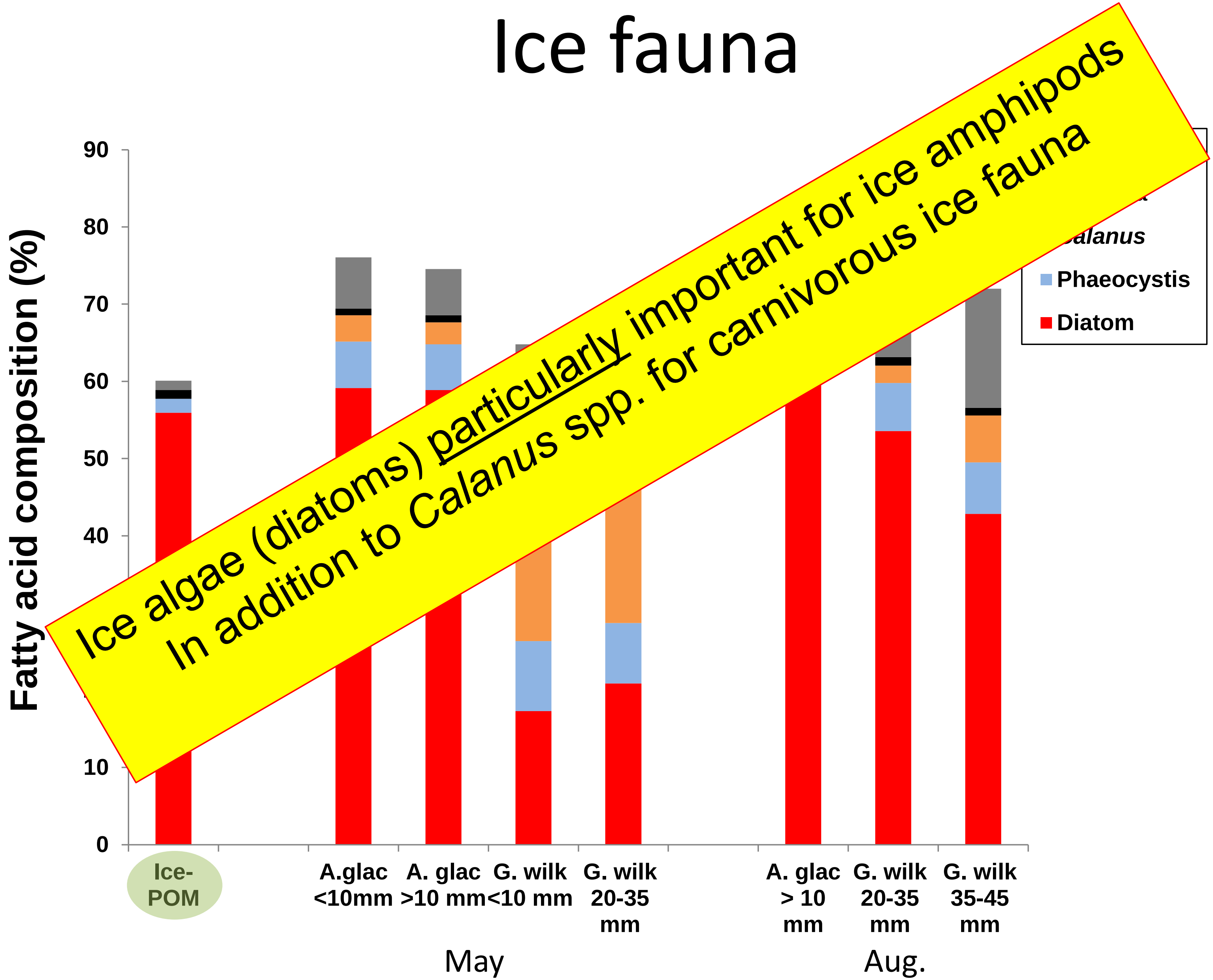
Dalsgaard et al. 2003; Søreide et al. 2008

POM fatty acid composition



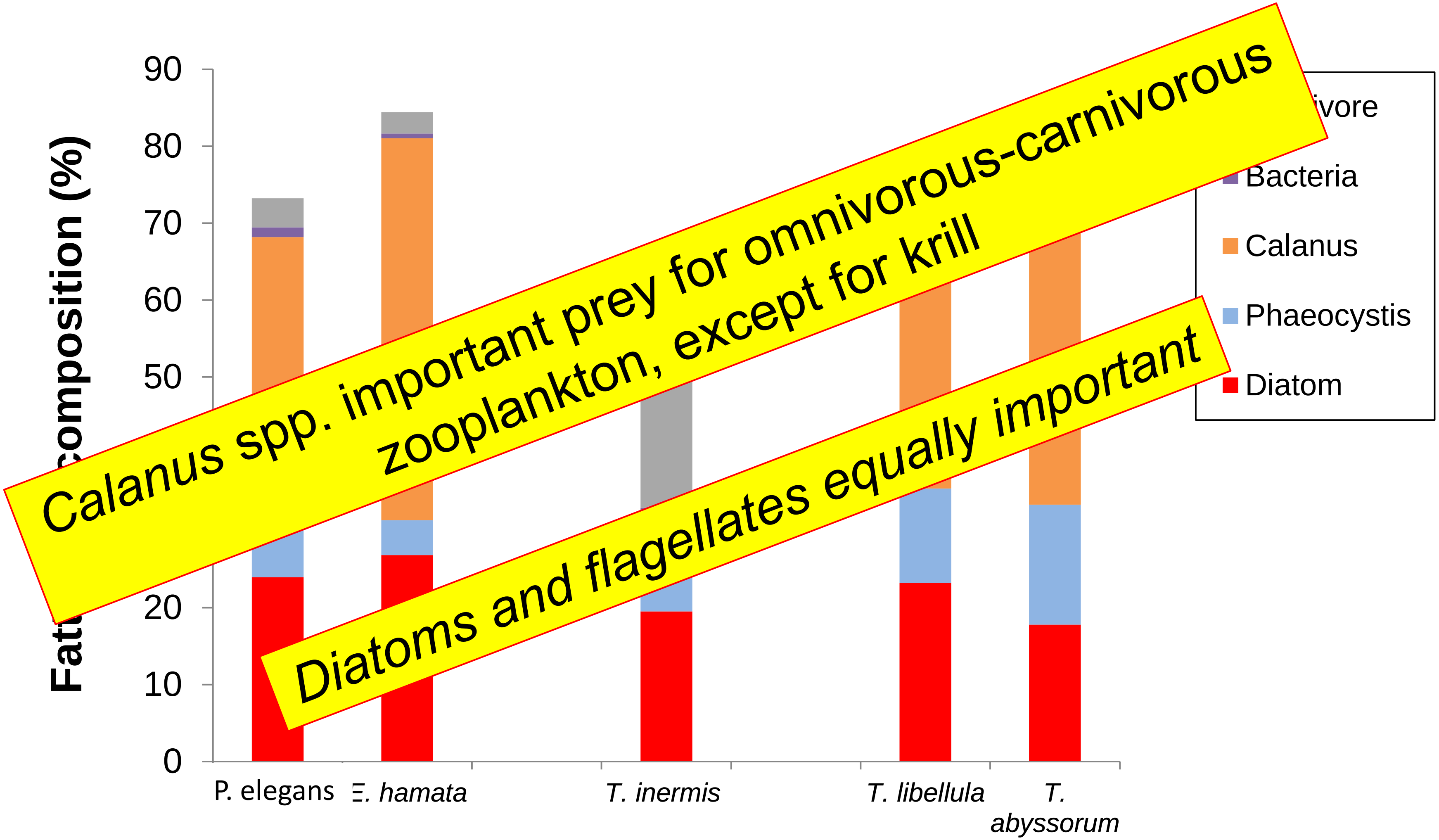
Søreide et al. 2008

Ice fauna

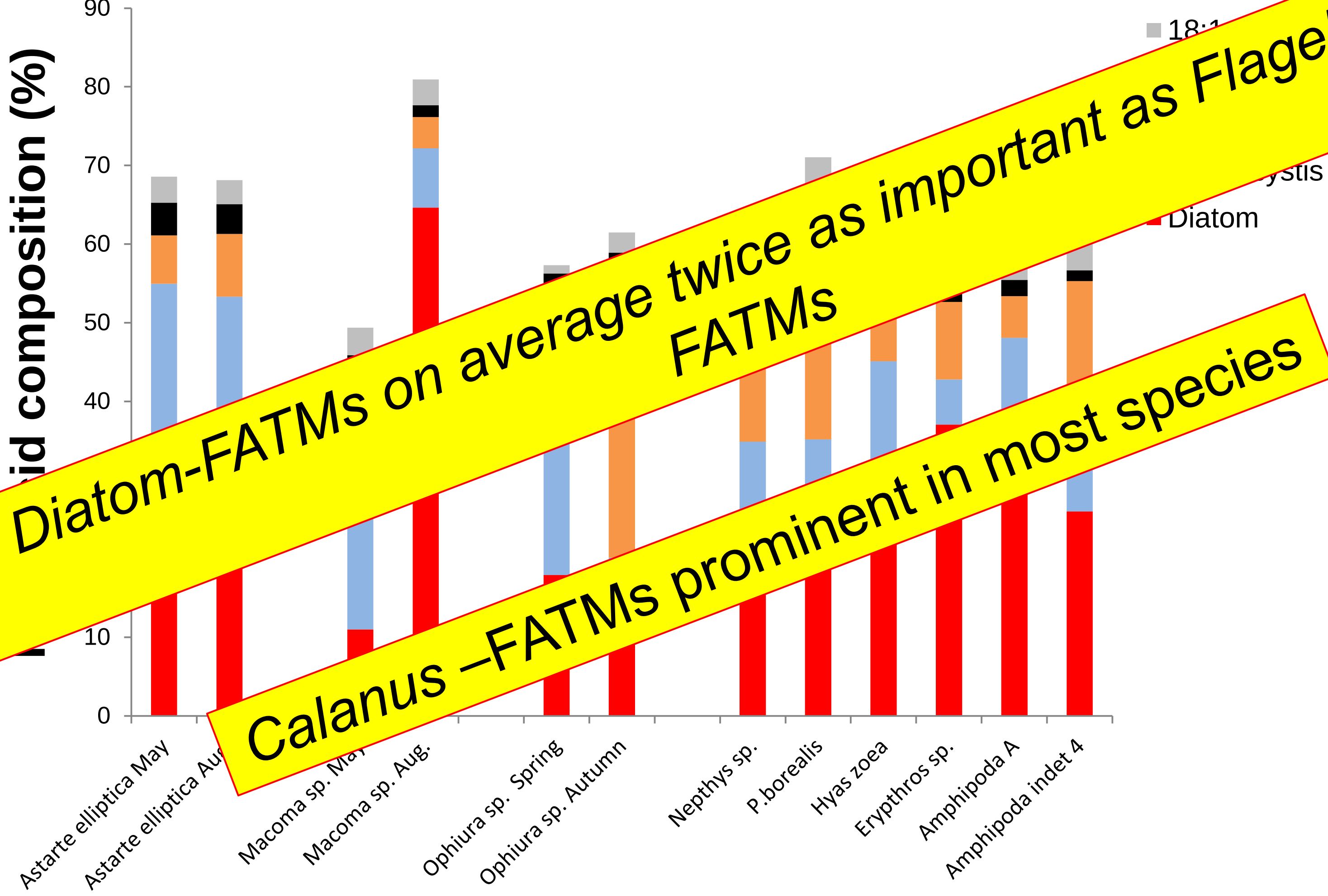


Ice algae (diatoms) particularly important for ice amphipods
In addition to *Calanus* spp. for carnivorous ice fauna
Fatty acid composition (%)
90
80
70
60
50
40
10
0
Calanus
Phaeocystis
Diatom
Ice-POM
A.glac <10mm
A. glac >10 mm
G. wilk <10 mm
G. wilk 20-35 mm
A. glac > 10 mm
G. wilk 20-35 mm
G. wilk 35-45 mm
May
Aug.

Carnivorous zooplankton



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

Oecologia (2008) 157:117–129
DOI 10.1007/s00442-008-1053-7

ECOSYSTEM ECOLOGY - ORIGINAL PAPER

Oecologia (2014) 174:699–712
DOI 10.1007/s00442-013-2832-3

PHYSIOLOGICAL ECOLOGY - ORIGINAL RESEARCH

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.
Rolf R. Gra

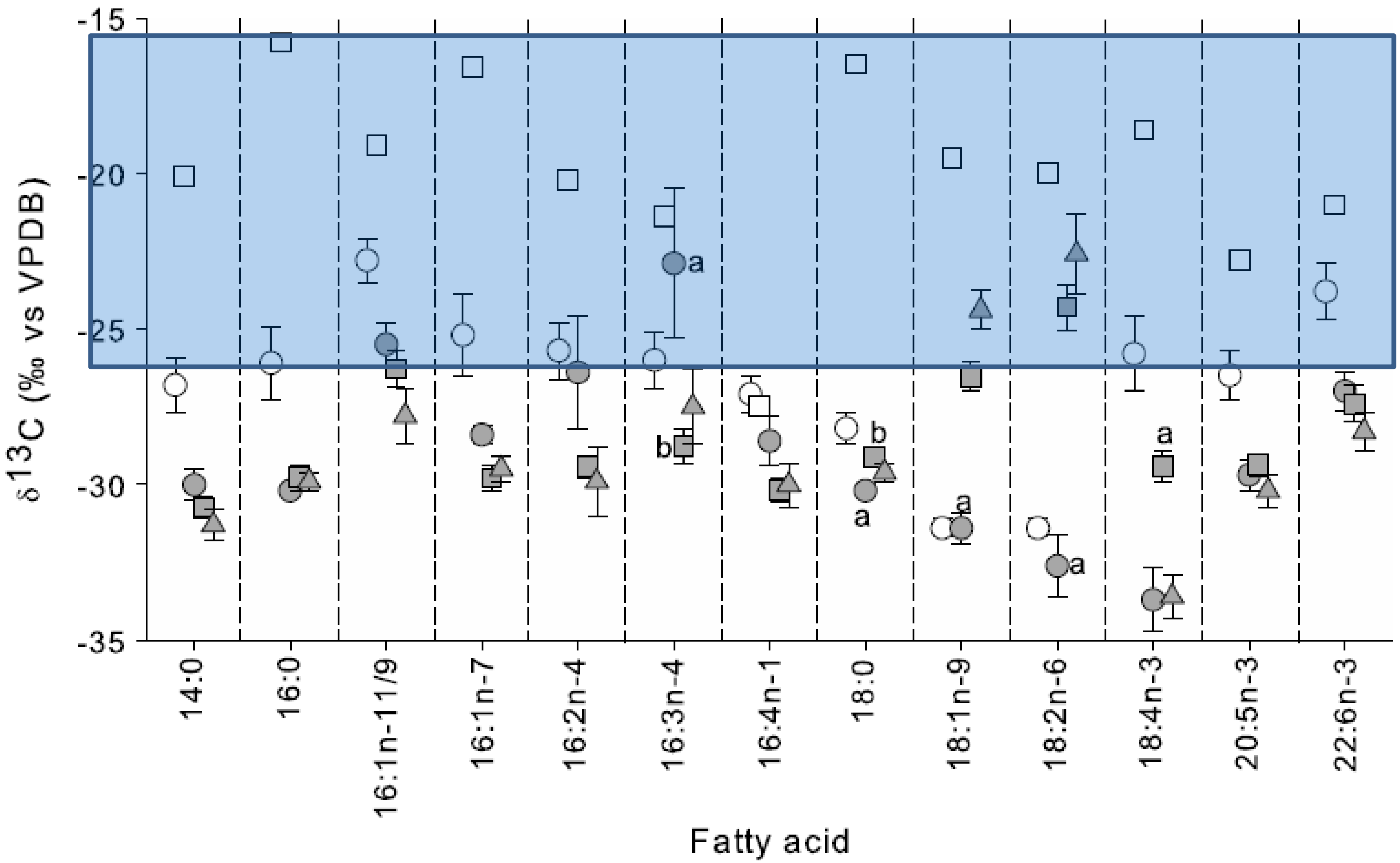
Polar Biol (2014) 37:697–705
DOI 10.1007/s00300-014-1470-5

ORIGINAL PAPER

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%

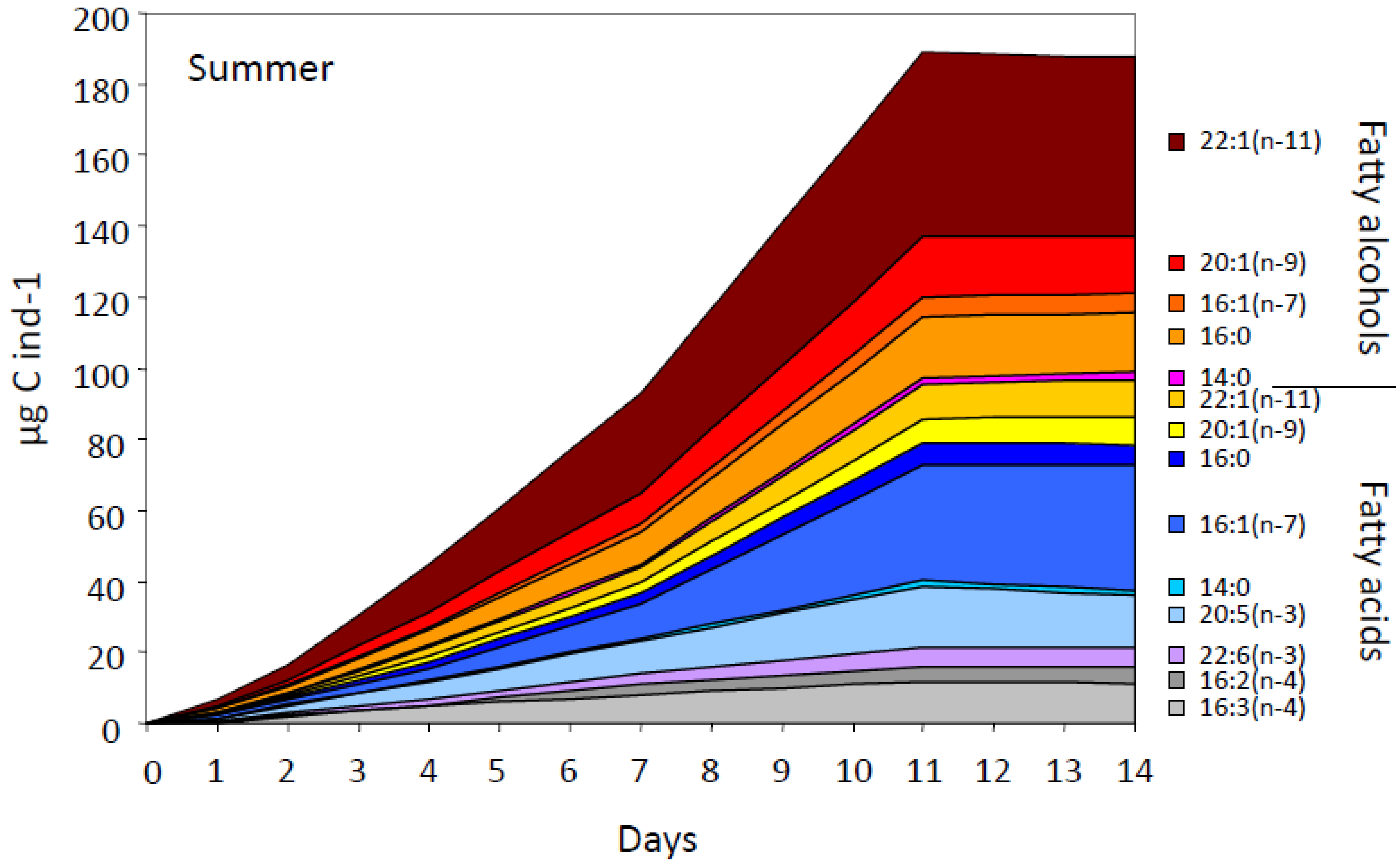
* Based on SIAR mixing model, Parnell et al. 2010

Wang et al. *In press*

CLEOPATRA II

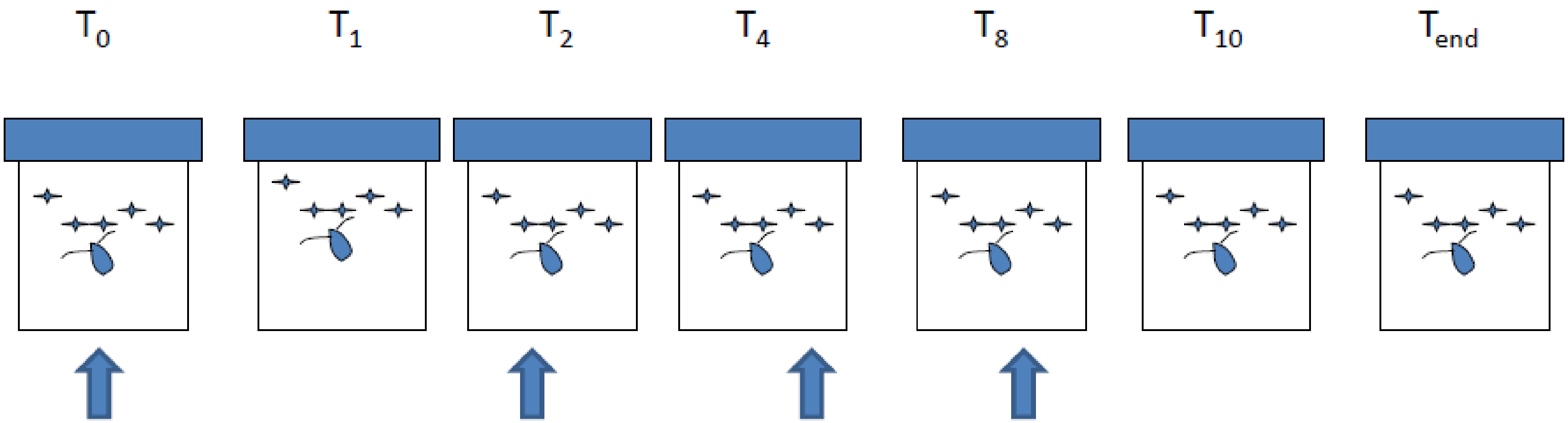
- To estimate the carbon turnover in *Calanus glacialis* in different seasons
- Determine the degree of carbon accumulation in specific fatty acids and alcohols

Calanus hyperboreus CV (^{13}C assimilation)



Graeve et al. 2005

Feeding experiment with ^{13}C labeled algae (in 2013)



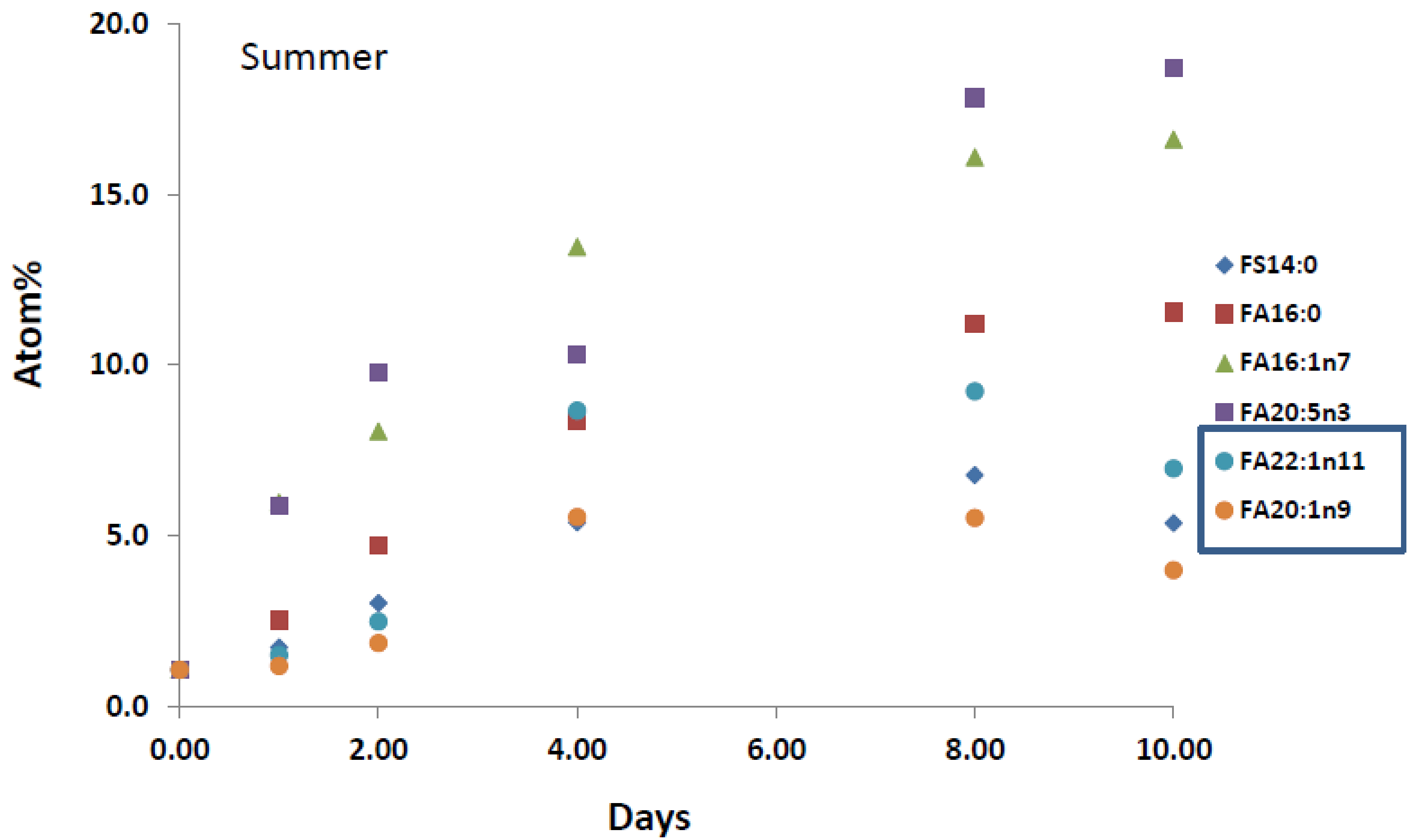
→ Add ^{13}C enriched phytoplankton (t0, t2, t4, t8)

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}N and ^{13}C fractionation/turnover information in species/tissues needed to improve data interpretation

Thank you for your attention!

And all who have contributed :

Martin Graeve (AWI), Eva Leu (APN), Tobias Tamelander (UiT), Michael Carroll (APN), Stig Falk-Petersen (APN), Haakon Hop (NPI), Malin Daase (UiT), Else Hegseth (UiT), Finlo Cottier (SAMS), Colin Griffiths (SAMS), Arild Sunfjord (NPI), Olga Pavlova (NPI), Keith Hobson. Ingar Johansen, (IFE), Henrik Nygård (UNIS), Jørgen Berge (UiT/UNIS)

Billefjorden in January © M. Daase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