Food web structure in Antarctica in a context of global climate change: a stable isotope perspective

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Course "Etude des isotopes stables et applications au milieu marin"

Sea ice in Antarctica

Sea ice is a major environmental driver of ecological processes in Antarctica

- Water column mixing
- Benthic-pelagic coupling
- Niche partitioning
- Benthic community structure
- …

Image: NASA

Sea ice in Antarctica

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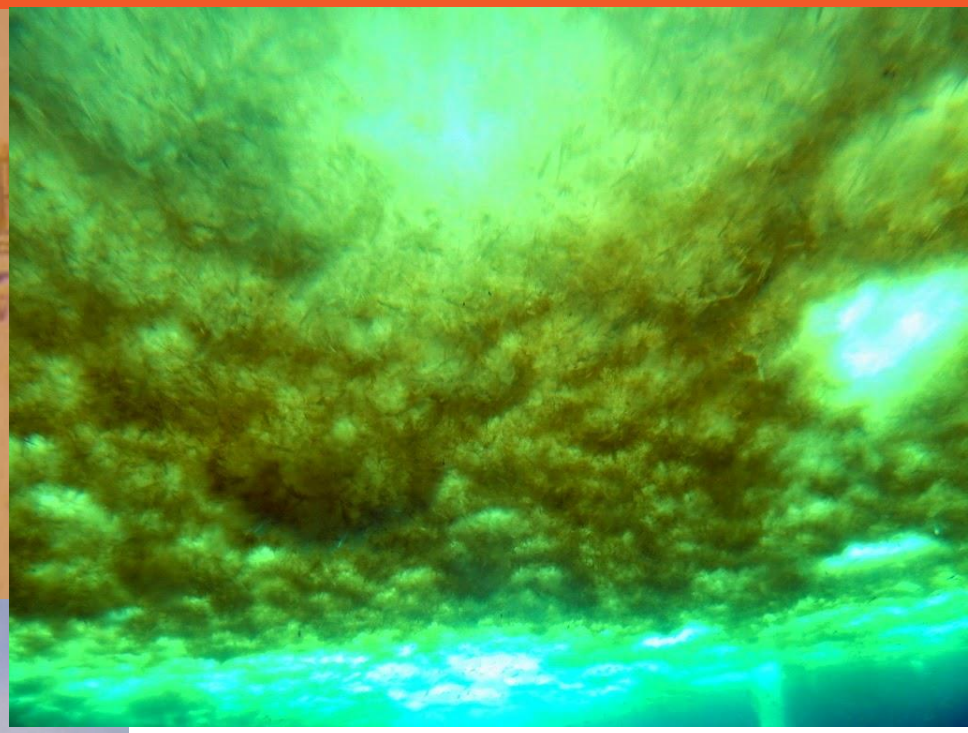
Sea ice hosts sympagic algae

Image: NASA

Sea ice in Antarctica



Source: Australian Antarctic Division

Sympagic algae:
Mostly diatoms
Form thick mats
Filaments up to several cm

Sea ice in Antarctica

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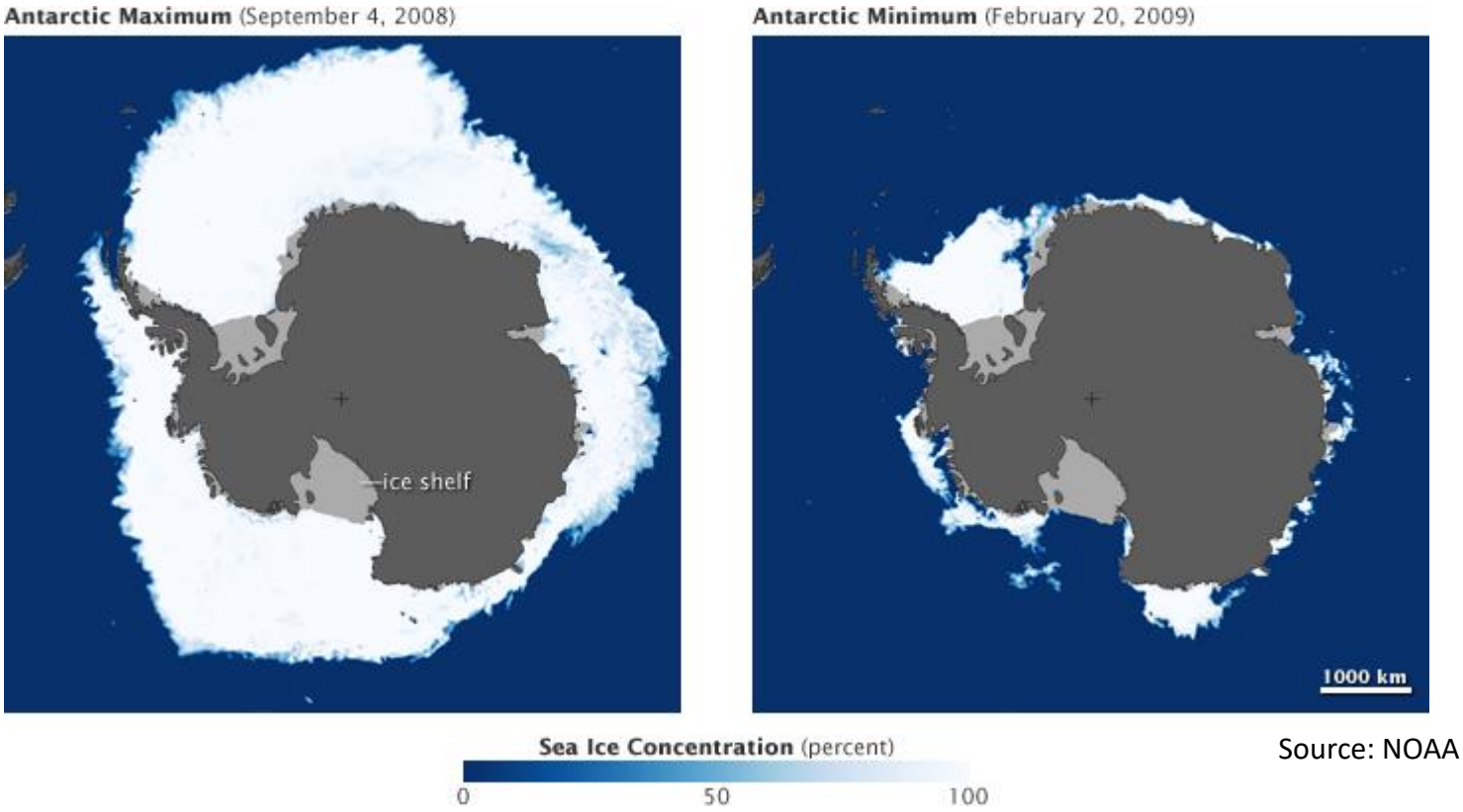
- …

Sea ice hosts sympagic algae

Sea ice is a highly dynamic system

Image: NASA

Seasonal patterns of sea ice cover



Source: NOAA

Normal cycle:

Austral winter

Thick sea ice cover

Austral summer

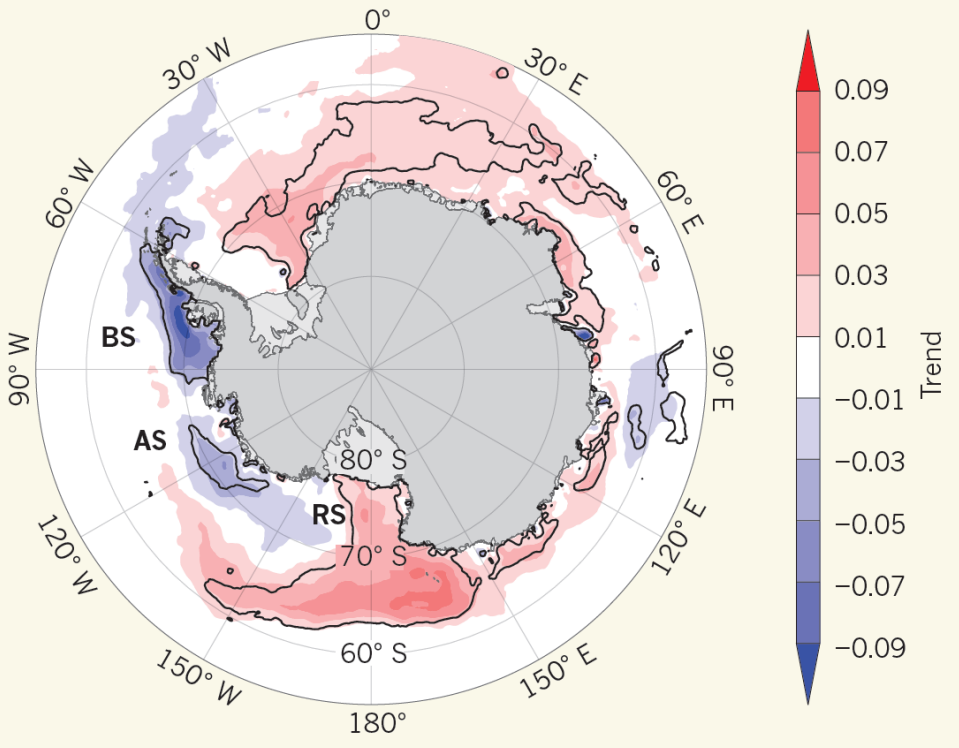
Thinning and breakup of sea ice

Changes in Antarctic sea ice cover

Climate change causes contrasted changes in sea ice cover in Antarctica

Spatial extent

Changes in sea ice concentration



From King (2014), Nature 505: 491-492.
(Data 1979-2012)

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Climate change causes contrasted changes in sea ice cover in Antarctica

Spatial extent

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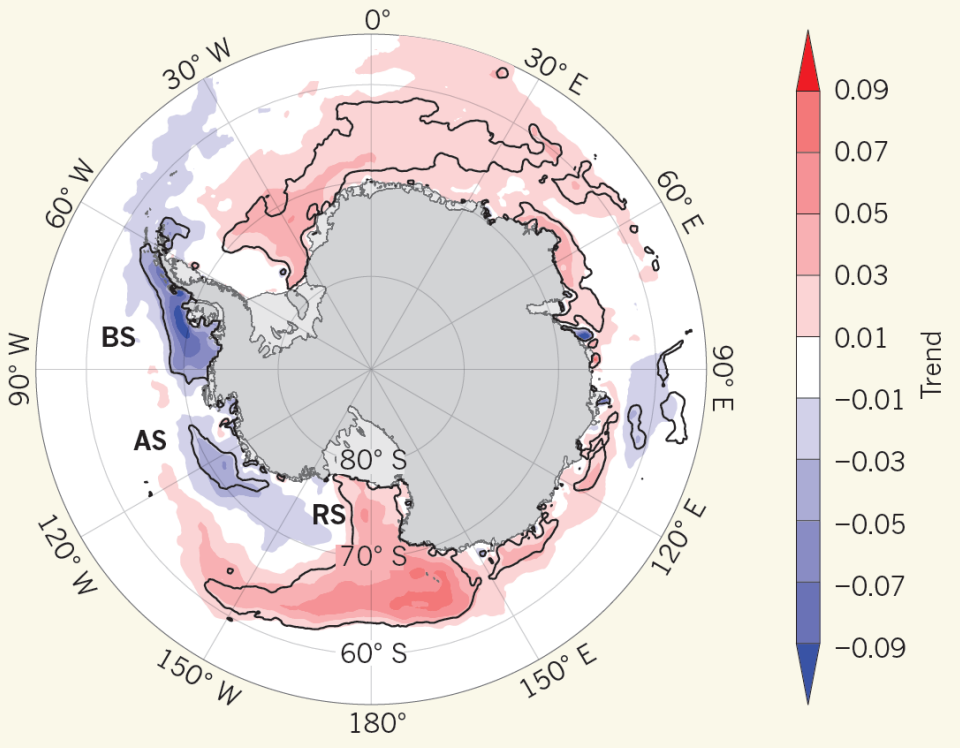

From King (2014), Nature 505: 491-492.
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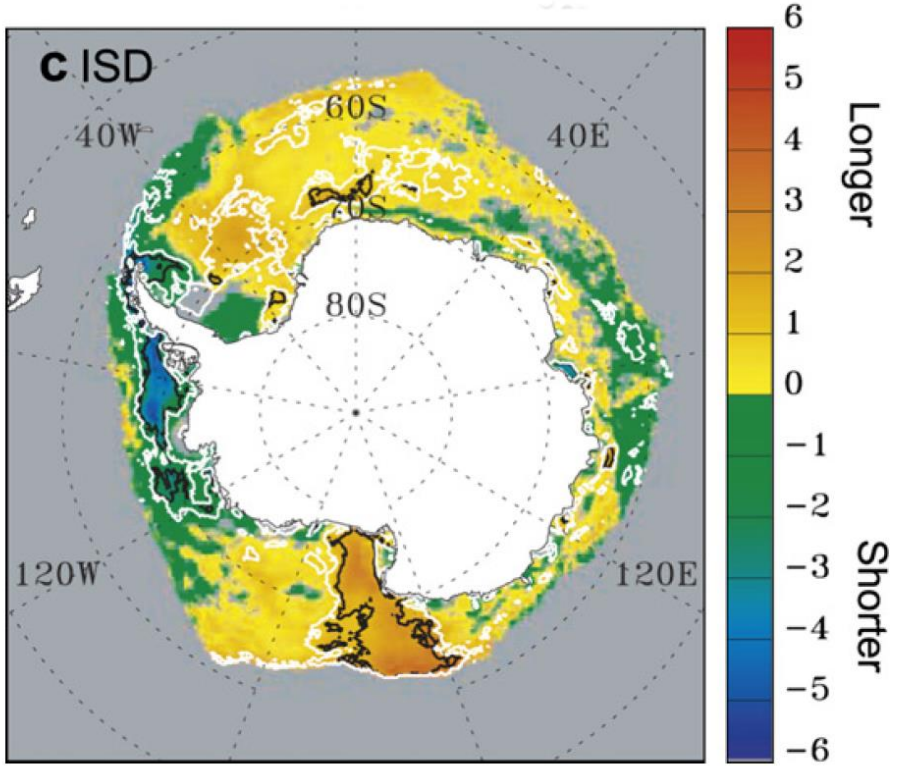
Temporal extent

Changes in sea ice season duration



From Massom & Stammerjohn (2010), Pol . Sci. 4: 149-186
(Data 1979 -2004)

Study site: Dumont d'Urville station

East Antarctica, Adélie Land
Petrels Island

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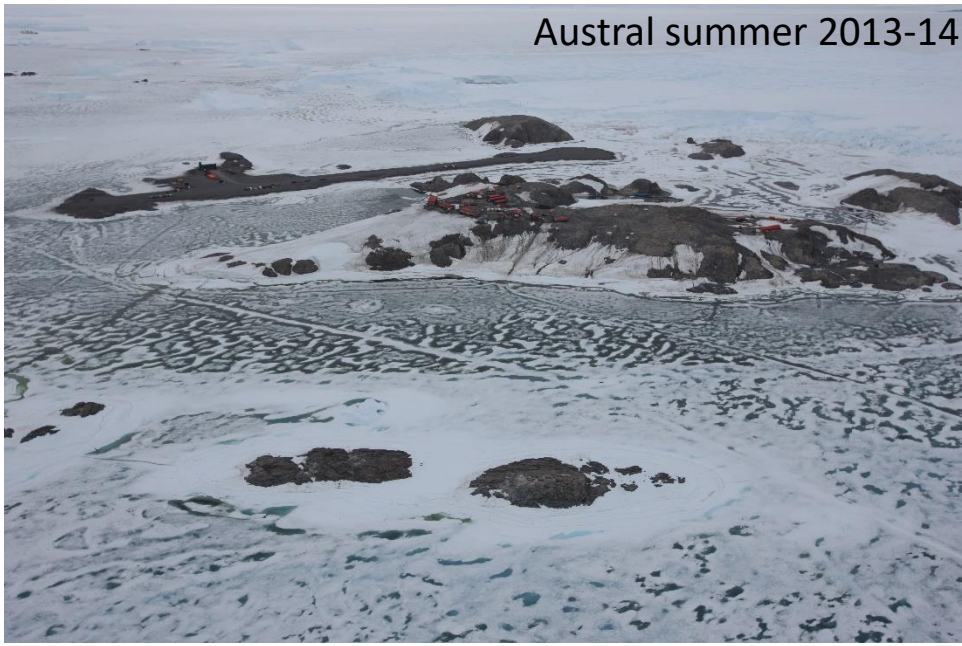
East Antarctica, Adélie Land
Petrels Island

2013-2015: Event of high spatial and temporal sea ice coverage

No seasonal breakup during austral summers 2013-14 and 2014-15



Study site: Dumont d'Urville station

Time of sampling : Austral summer 2014-15

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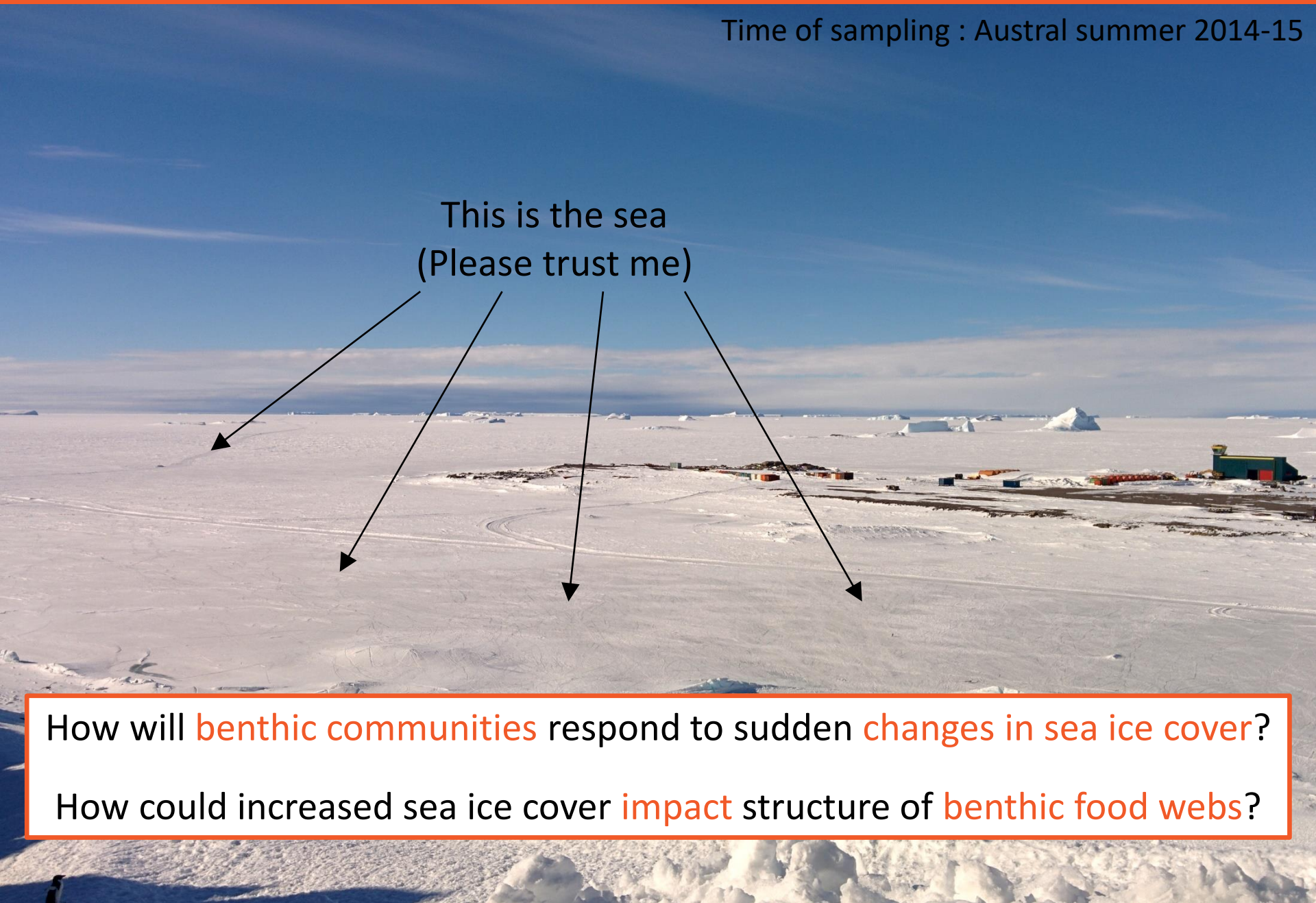


How will benthic communities respond to sudden changes in sea ice cover?

How could increased sea ice cover impact structure of benthic food webs?

Food web structure in natural ecosystems

Food web: natural interconnection of food chains and a graphical representation of what-eats-what in an ecological community. Network formed by entirety of trophic interactions found in a given ecosystem.

Food webs are complex ecological networks, but a lot of that complexity can be summarized using two dimensions, leading to their classical depiction as 2D diagrams

Charles Sutherland Elton (1900-1991)

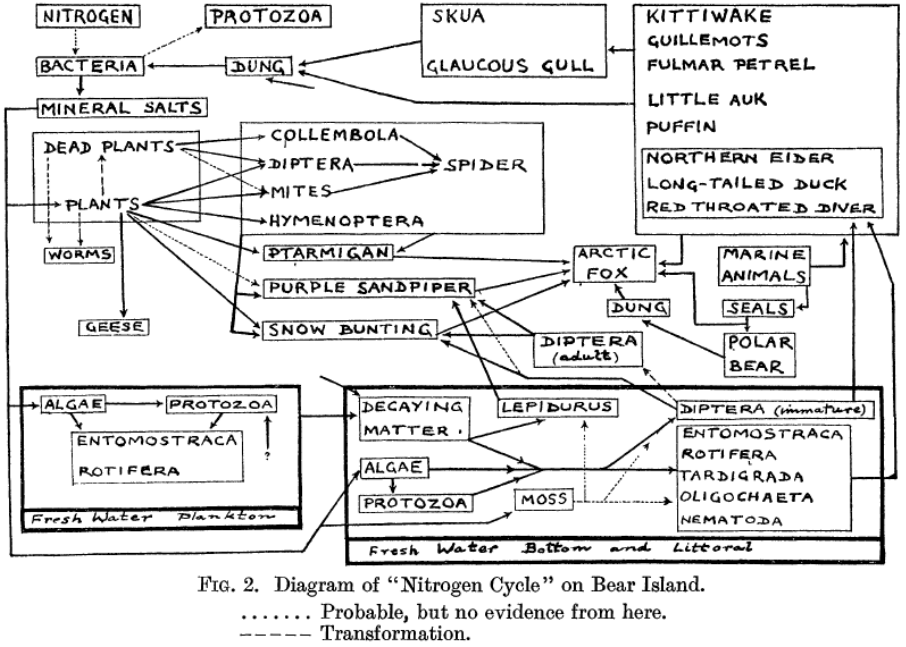
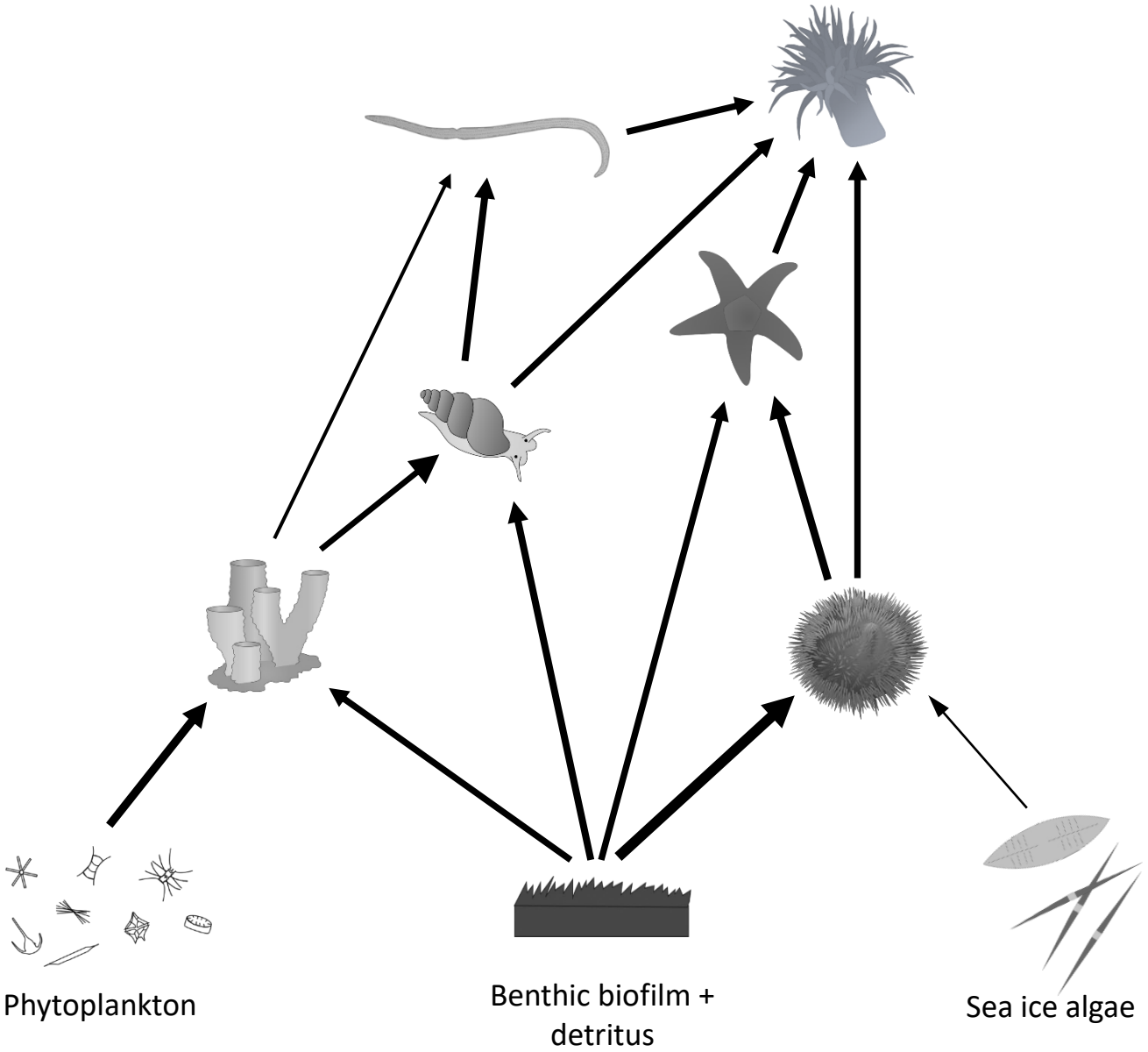


FIG. 2. Diagram of "Nitrogen Cycle" on Bear Island.
..... Probable, but no evidence from here.
----- Transformation.

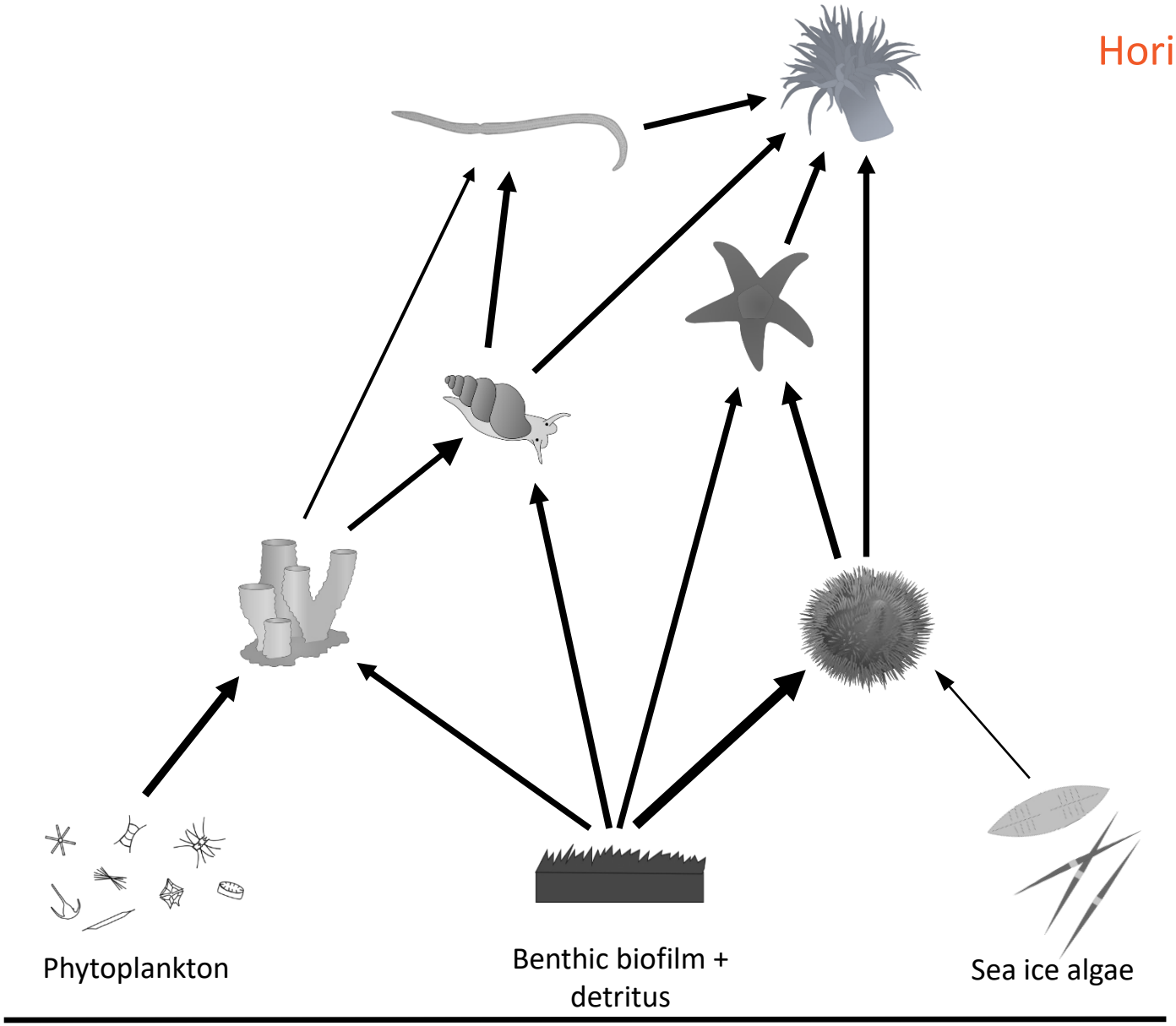
Summerhayes & Elton (1923): J. Animal Ecol. 11(2): 216-233

Food web structure in natural ecosystems



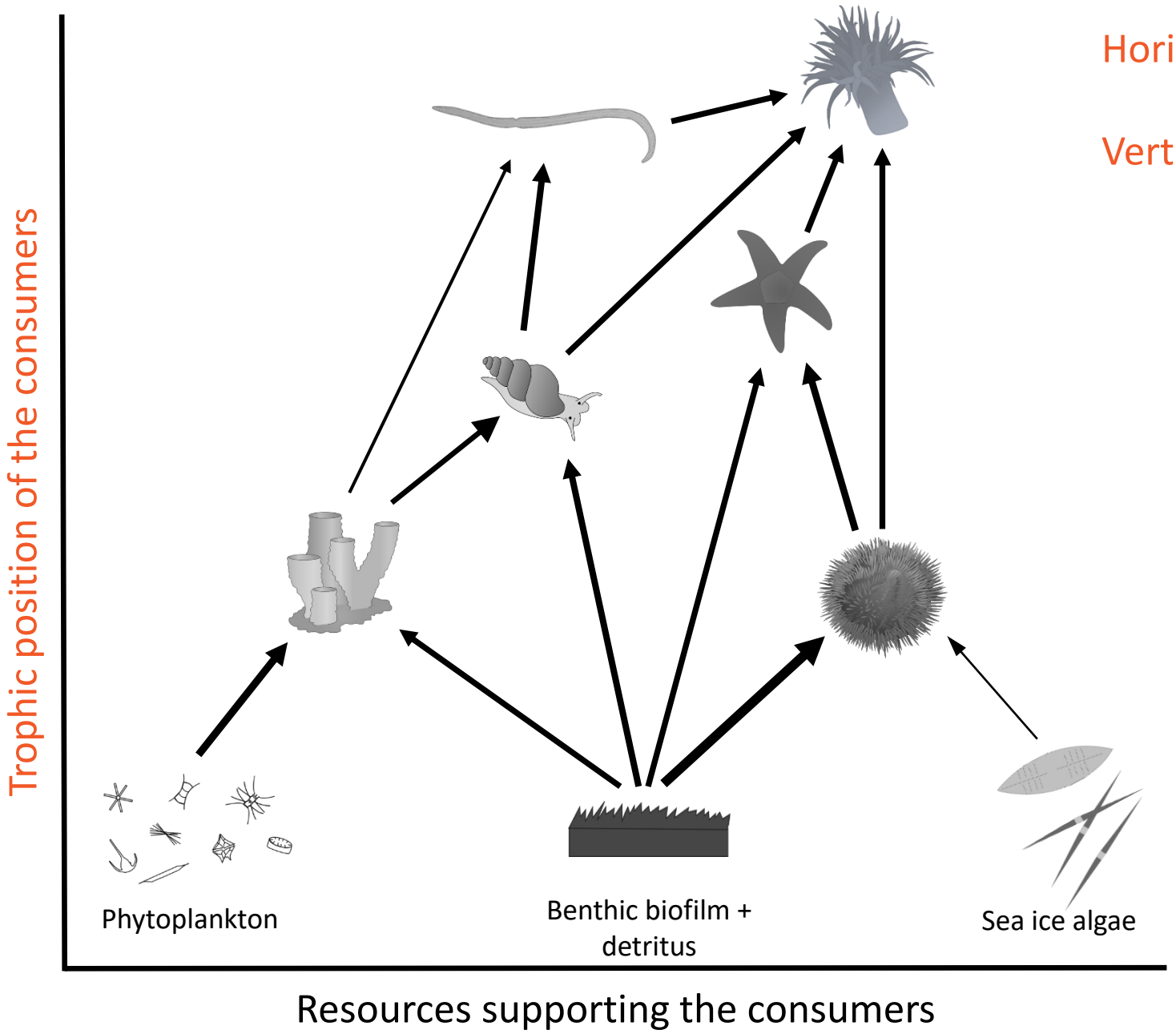
Food web structure in marine ecosystems

Horizontal dimension



Resources supporting the consumers

Food web structure in marine ecosystems



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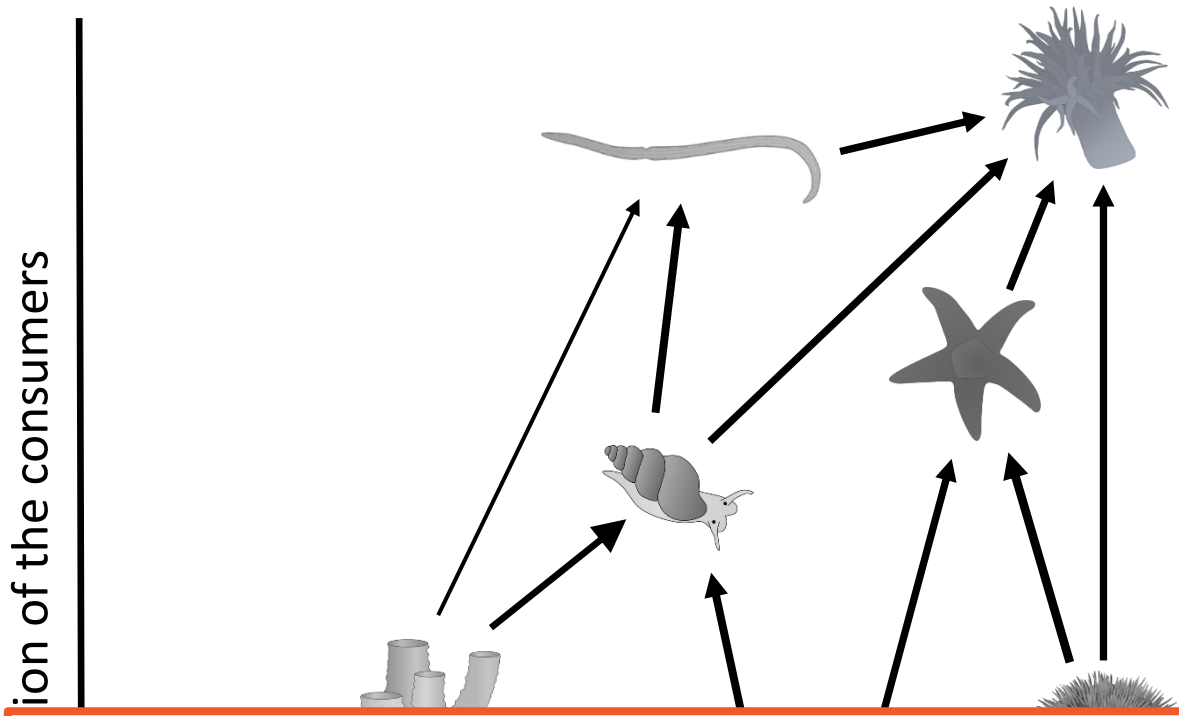


ion of the consumers

Horizontal dimension

Vertical dimension

Here: models based on trophic markers (stable isotope ratios) were used to as proxies of both food webs dimensions

Horizontal dimension: use of a mixing model (SIAR) to identify main food items of consumers

Vertical dimension: use of a trophic position model (tRophicPosition)

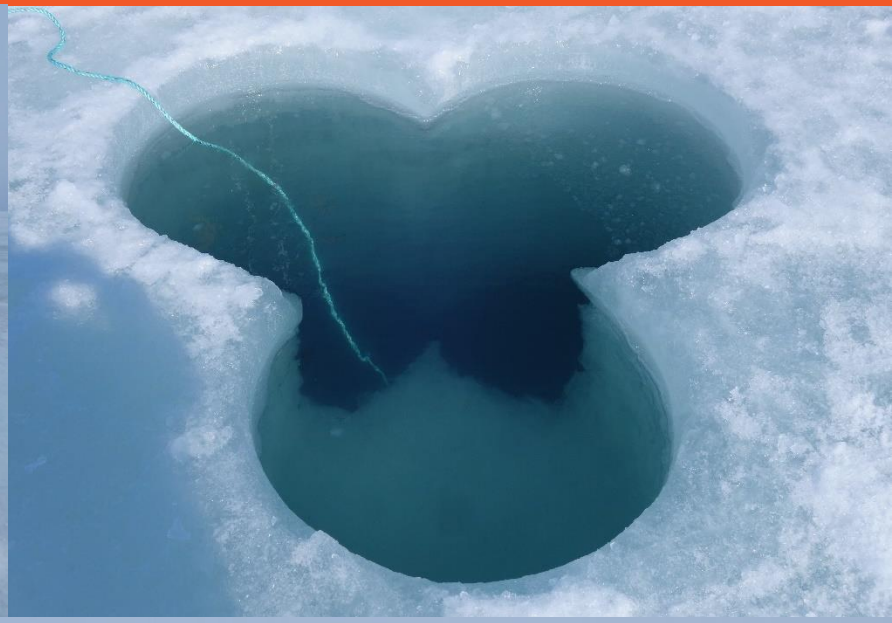
Phytoplankton

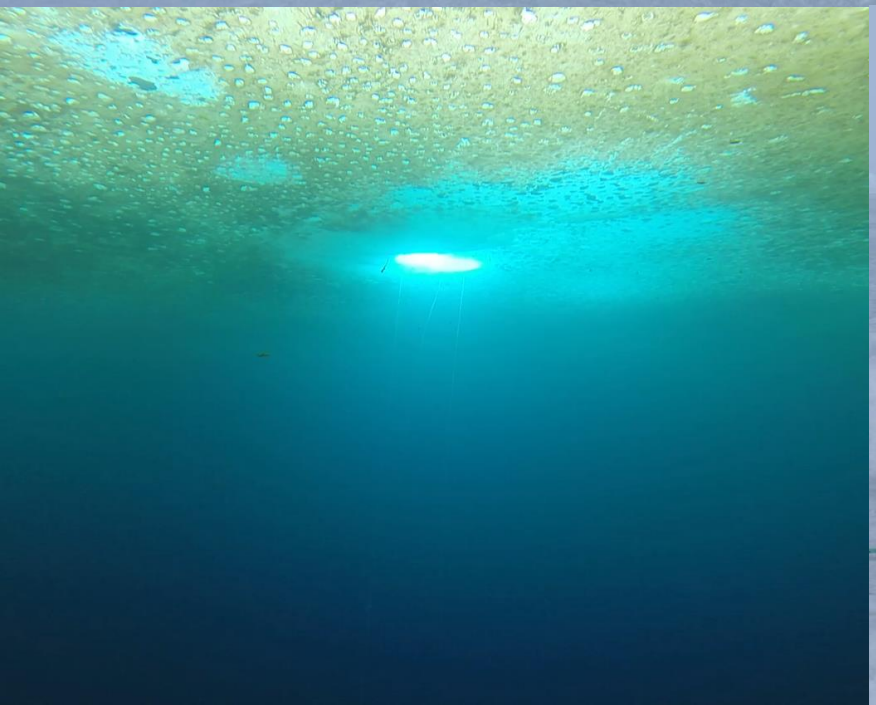
Benthic biofilm + detritus

Sea ice algae

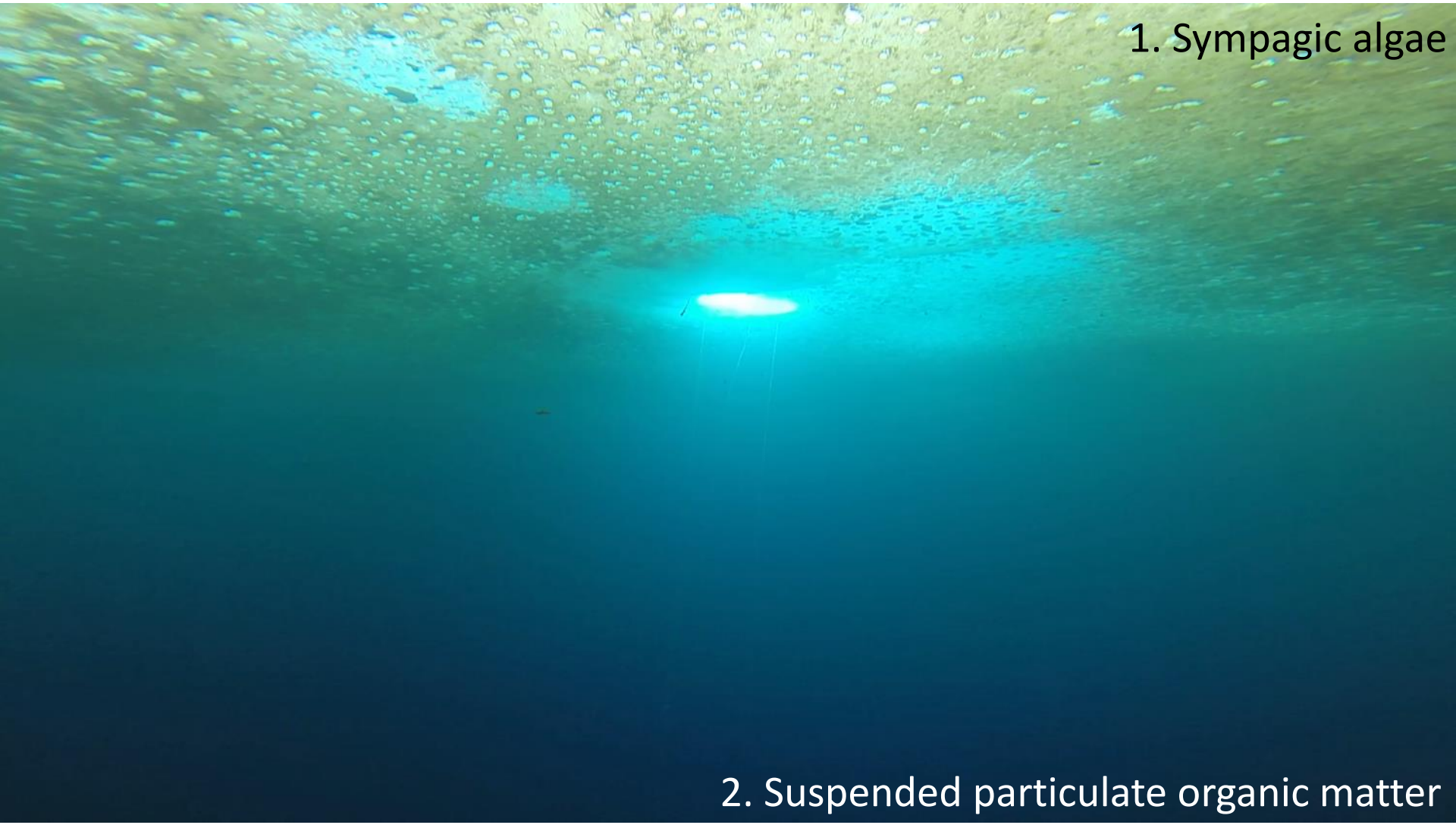
Resources supporting the consumers

Sampling: under ice SCUBA diving





Sampling: food items

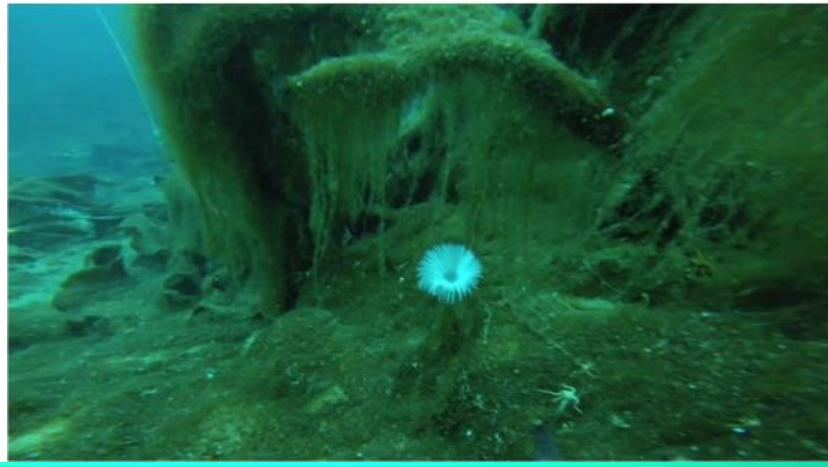


Sampling: food items

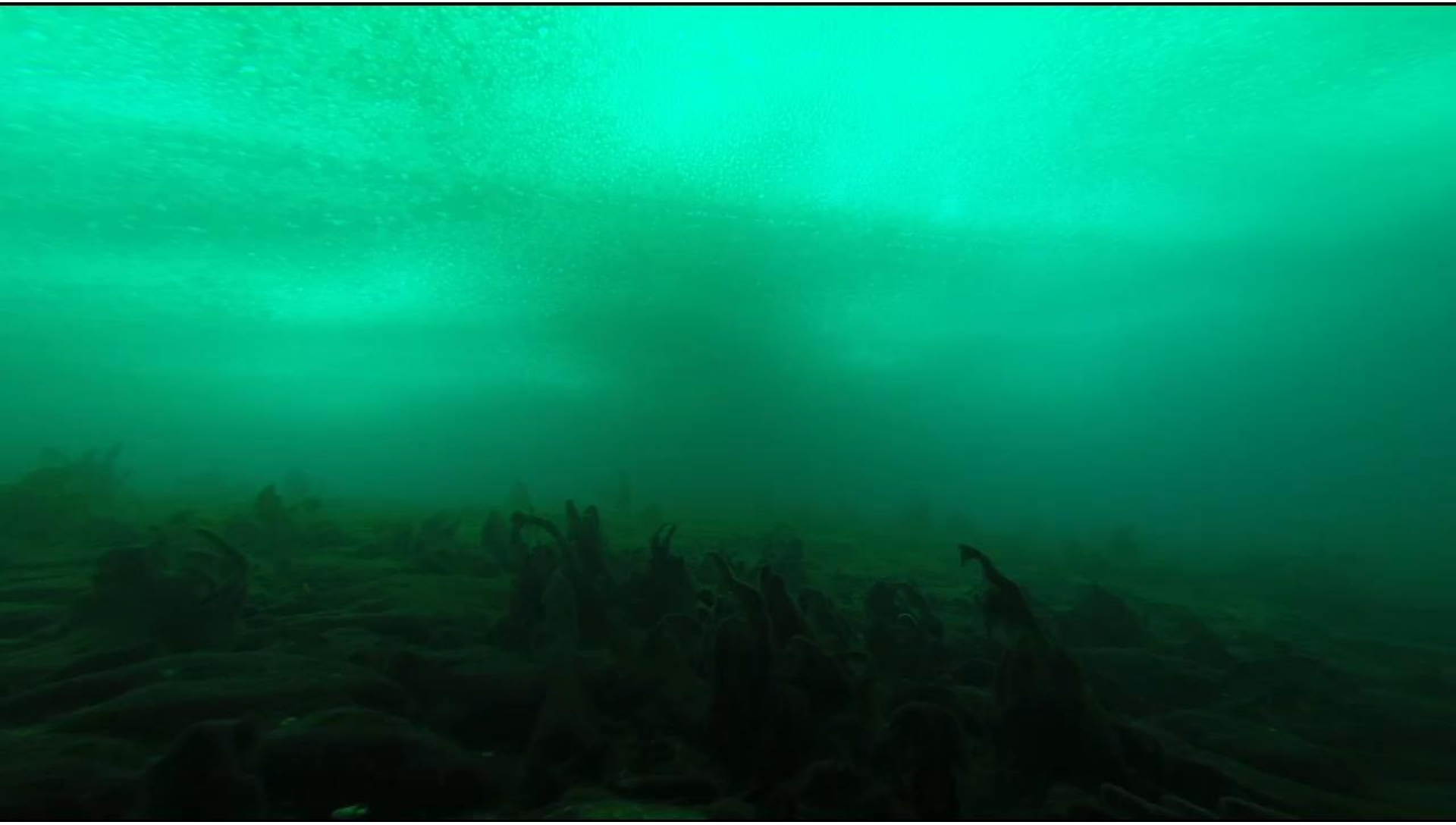
3. Benthic brown algae *Himantothallus grandifolius*

Sampling: food items

4. Benthic biofilm
(heterogeneous mix of microalgae, bacteria, amorphous material and detrital items)

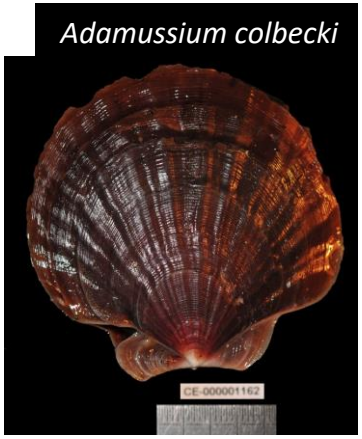


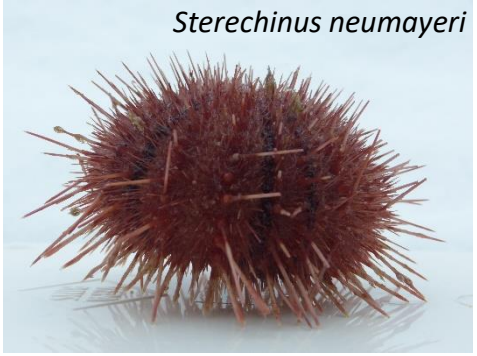
Sampling: food items

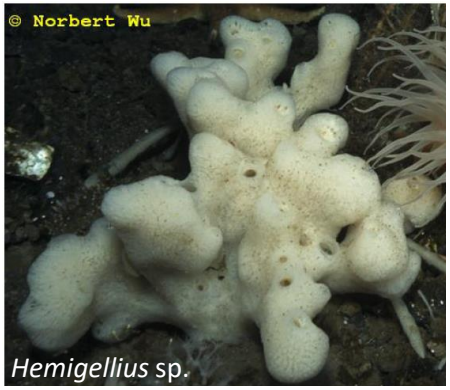


Sampling video at www.youtube.com/watch?v=fTNziVltIYE

Some sampled consumers







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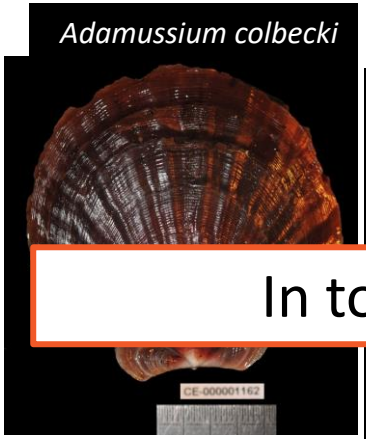
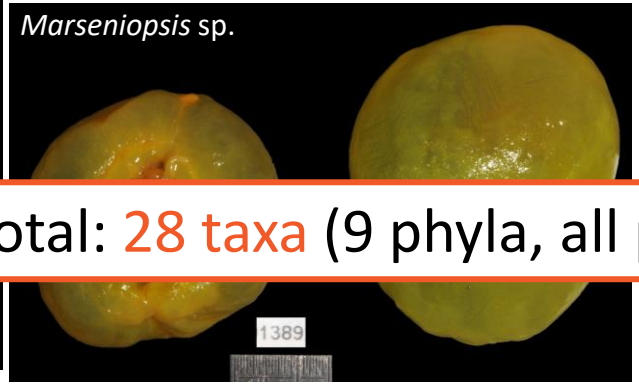
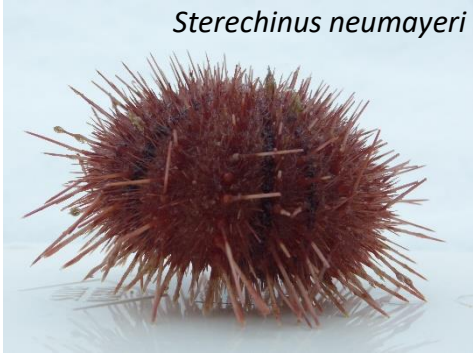
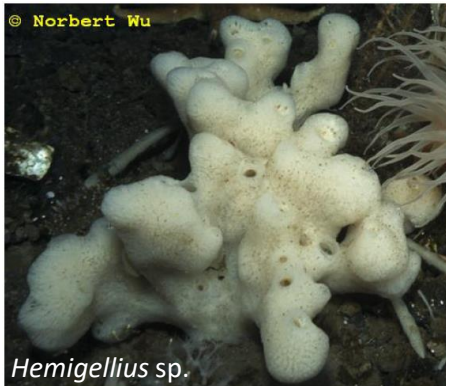




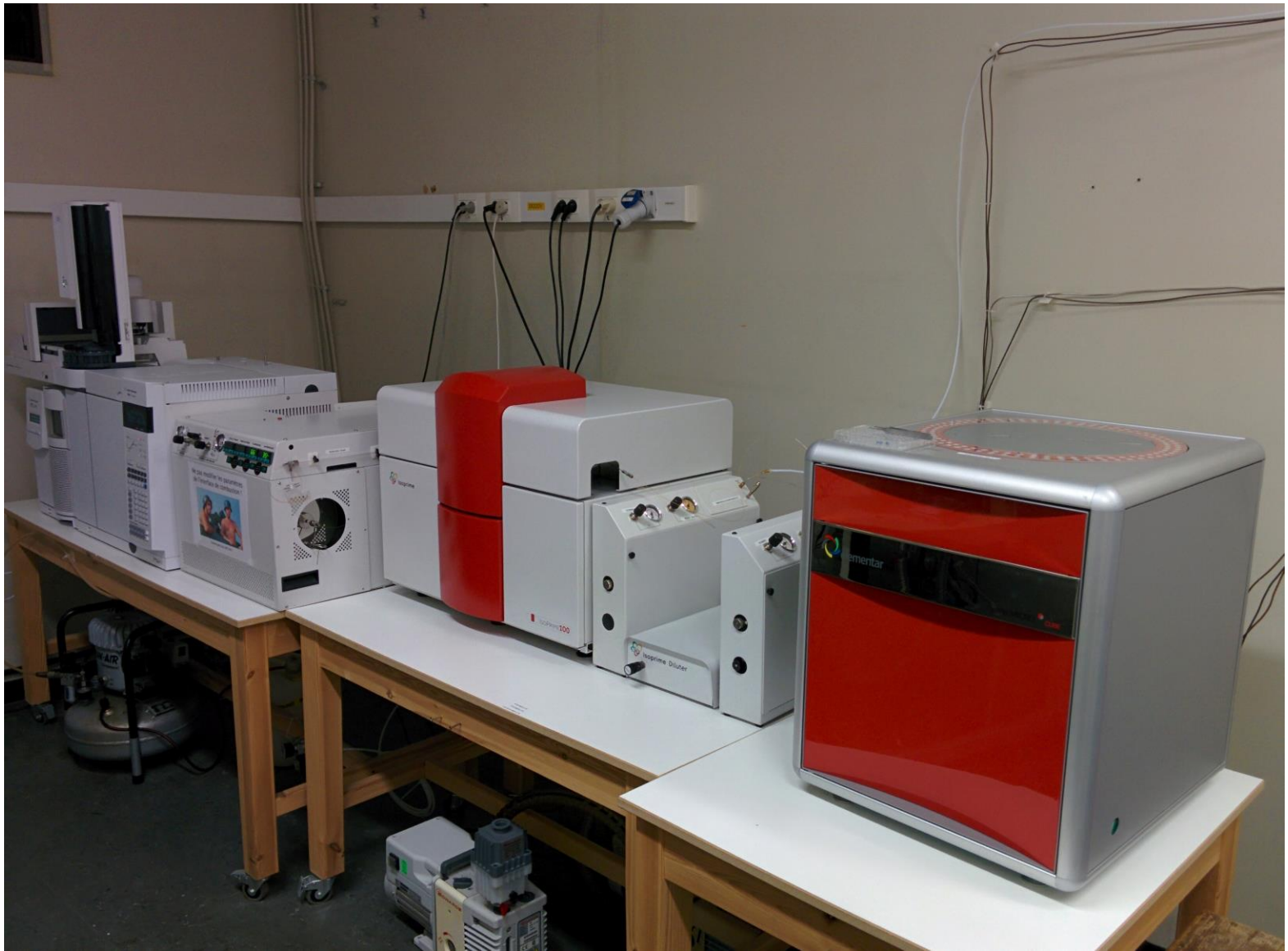
In total: 28 taxa (9 phyla, all present functional guilds)



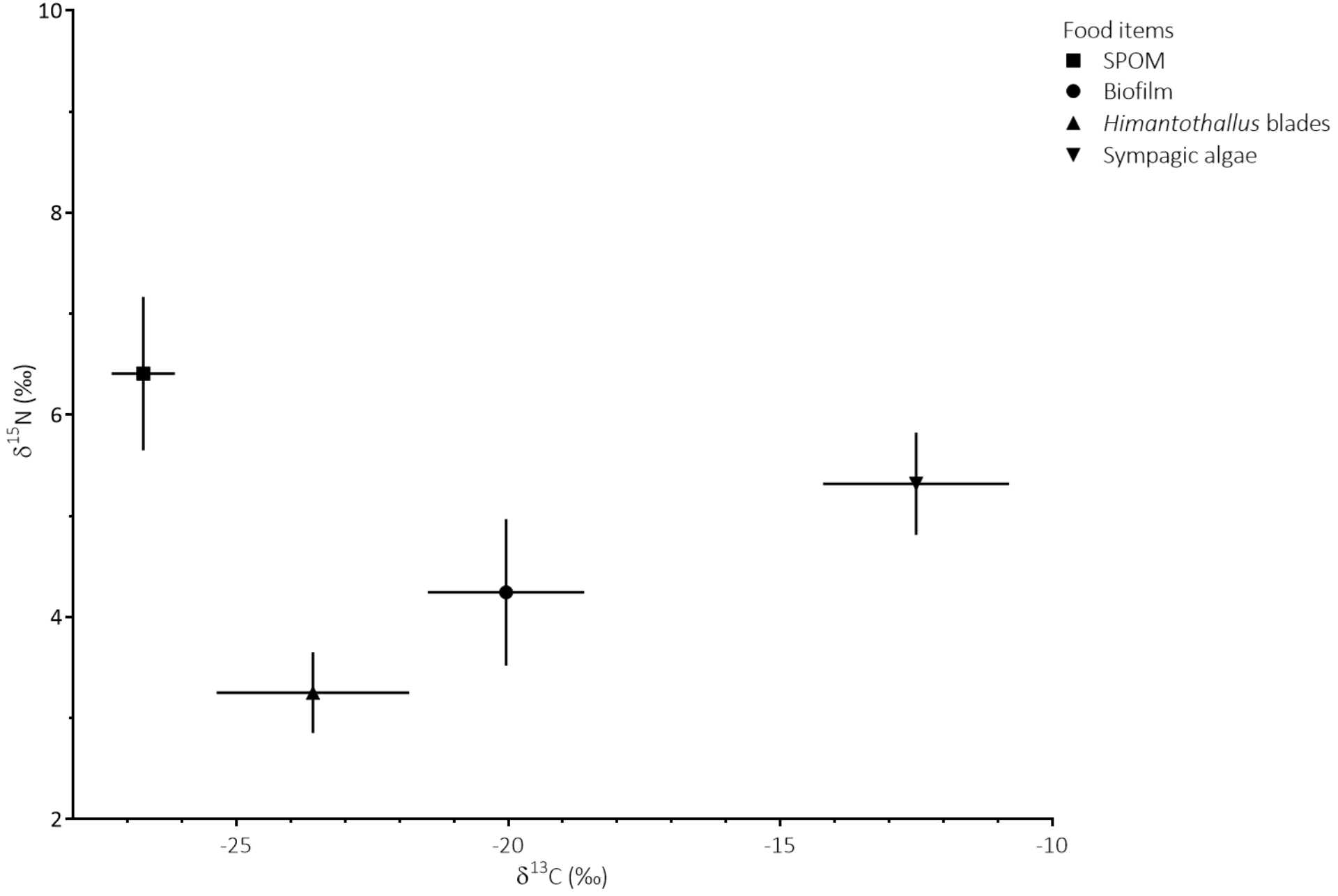


Material & methods: analysis

University of Liège's setup:
Vario MICRO cube EA coupled to an Isoprime 100 IRMS



Results: isotopic biplot



Results: isotopic biplot

Harmothoe sp.

Food items
- SPOM
- Biofilm
- *Himantothallus* blades
- Sympagic algae

Polychaetes
- *Harmothoe* sp.
- *Flabelligera mundata*
- *Polycirrus* sp.
- *Perkinsiana* sp.

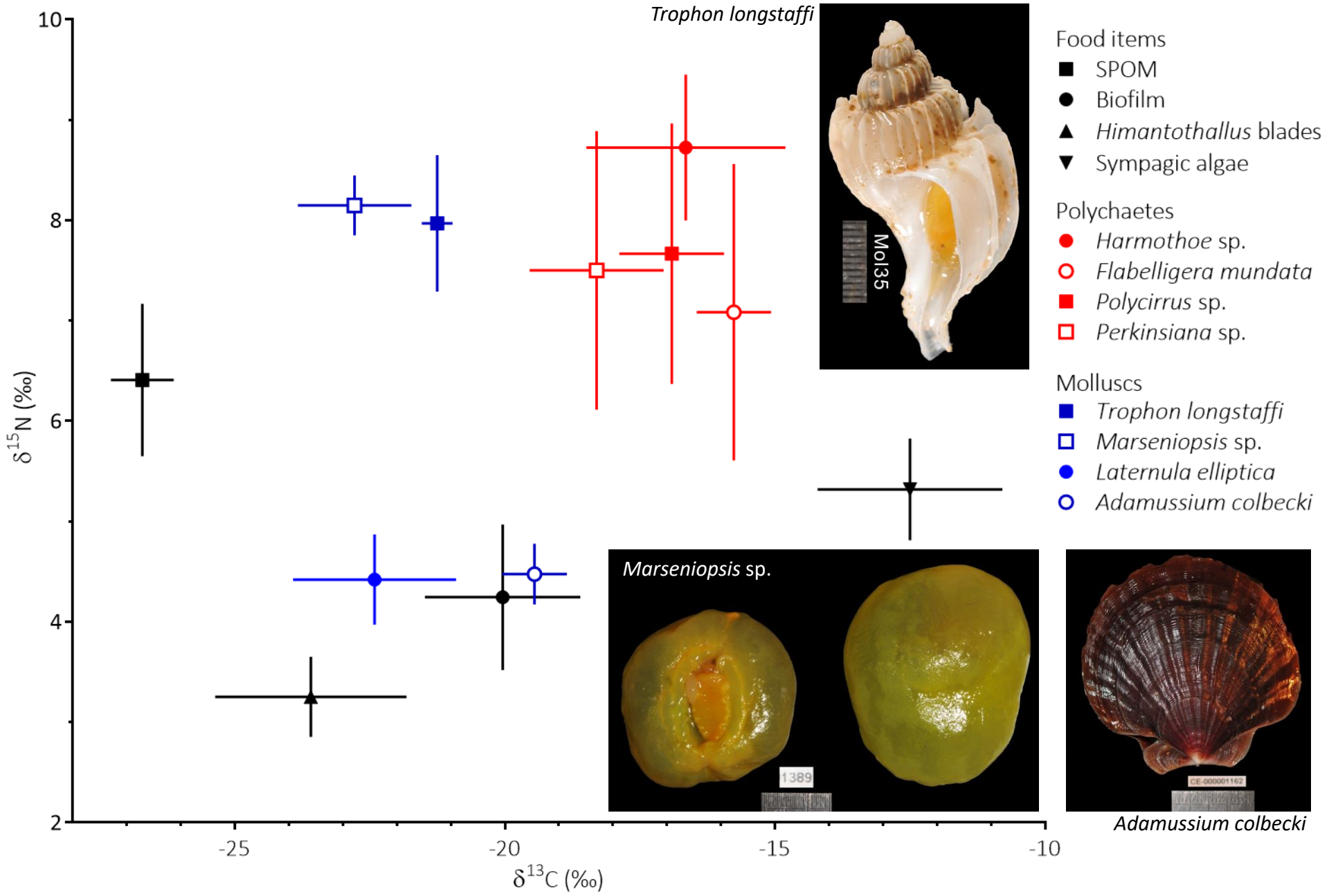
$\delta^{15}N$ (‰)

10
8
6
4
2

-25
-20
-15
-10

$\delta^{13}C$ (‰)

Results: isotopic biplot



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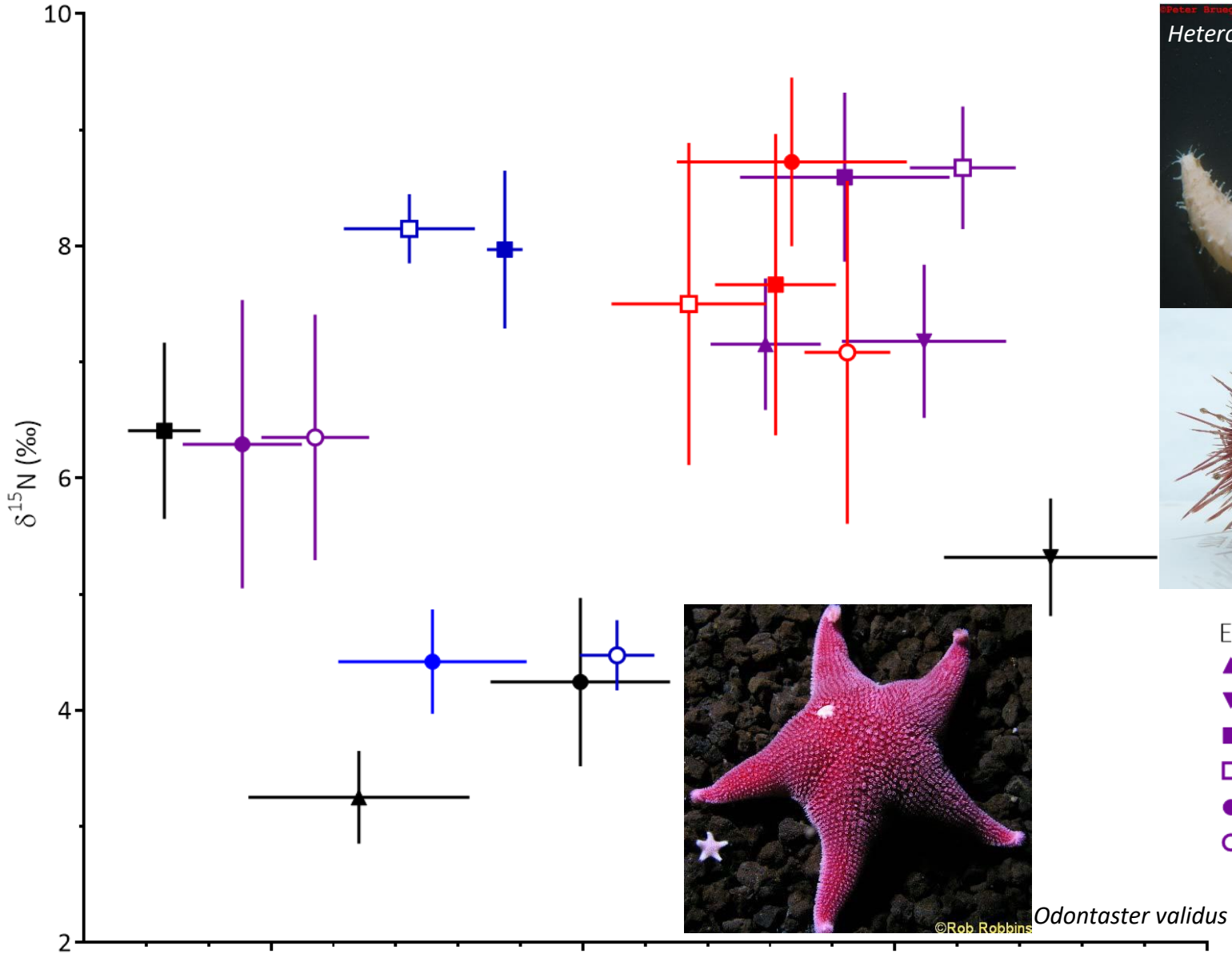
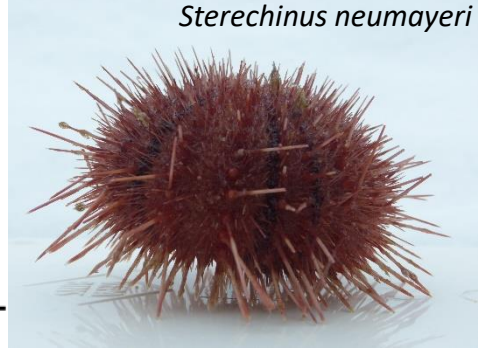


Sterechinus neumayeri

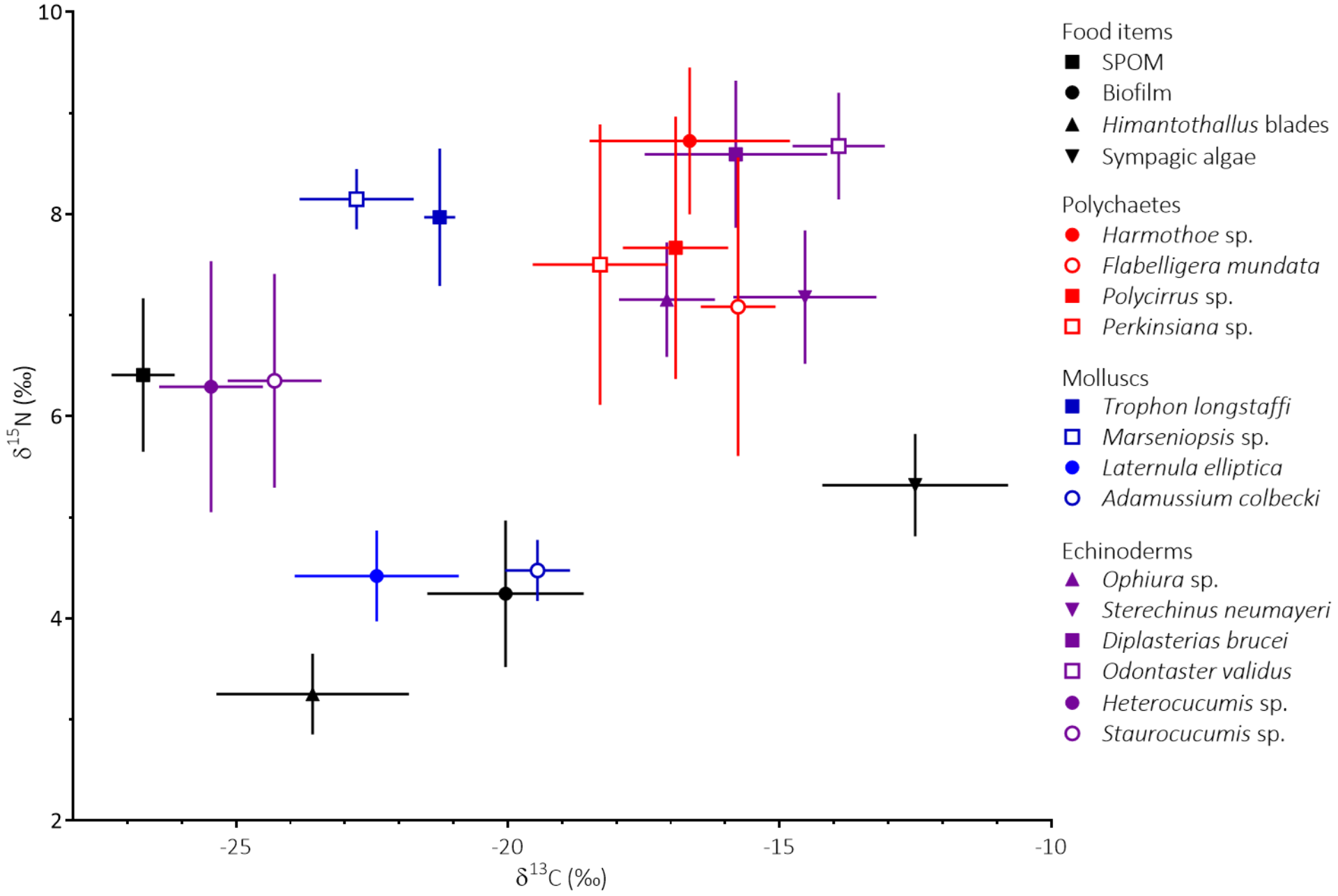


Odontaster validus

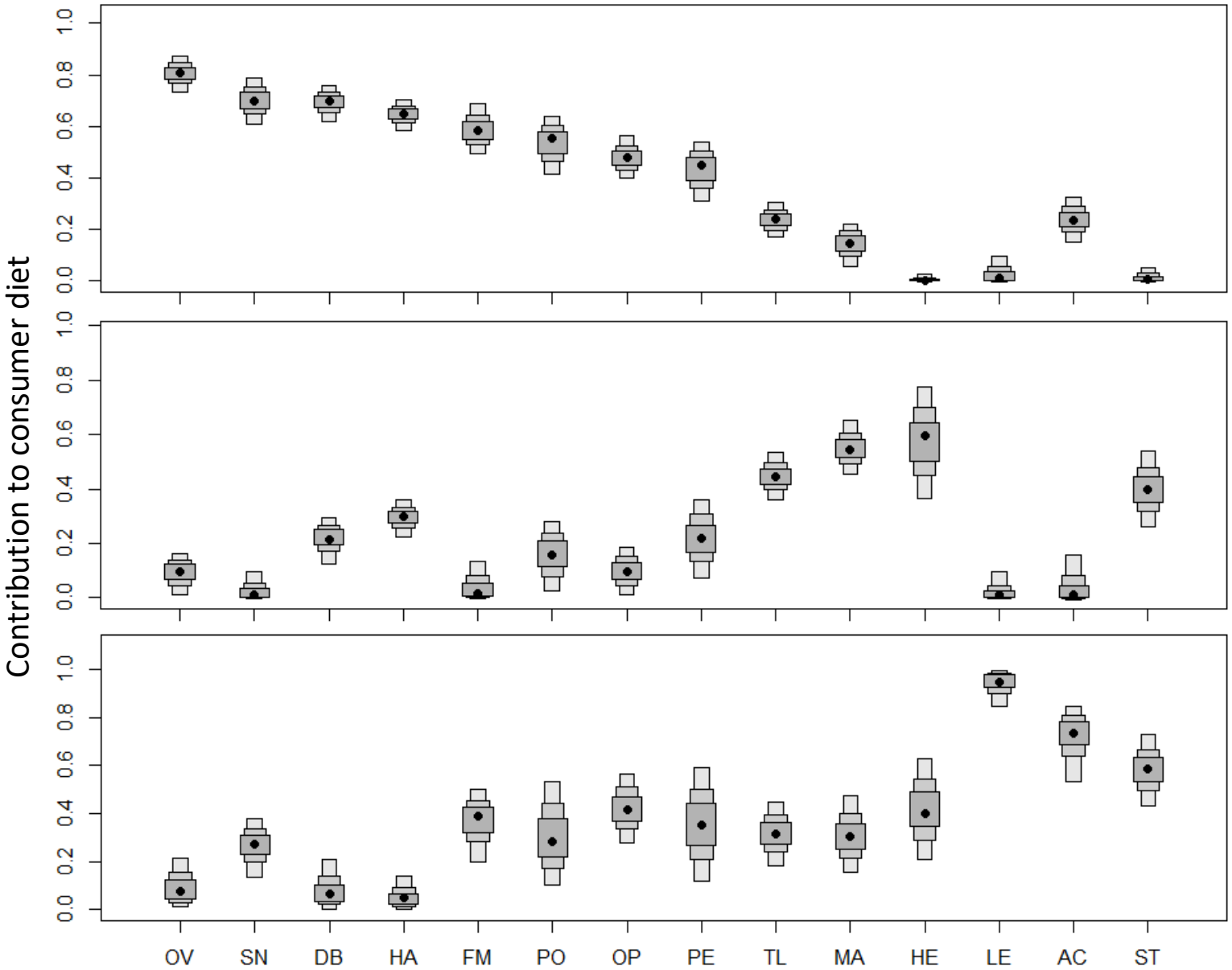
Echinoderms

- ▲ *Ophiura* sp.
- ▼ *Sterechinus neumayeri*
- ■ *Diplasterias brucei*
- □ *Odontaster validus*
- ● *Heterocucumis* sp.
- ○ *Staurocucumis* sp.

Results: isotopic biplot



Results - SIAR modelling



Sympagic algae

Suspended Particulate Organic Matter (SPOM)

Benthic algae + Biofilm

OV: *O. validus*; SN: *S. neumayeri*; DB: *D. brucei*; HA: *Harmothoe* sp.; FM: *F. mundata*; PO: *Polycirrus* sp.; OP: *Ophiura* sp.; PE: *Perkinsiana* sp.; TL: *T. longstaffi*; MA: *Marsienopsis* sp.; HE: *Heterocucumis* sp.; LE: *Laternula elliptica*; AC: *Adamussium colbecki*; ST: *Staurocucumis* sp.

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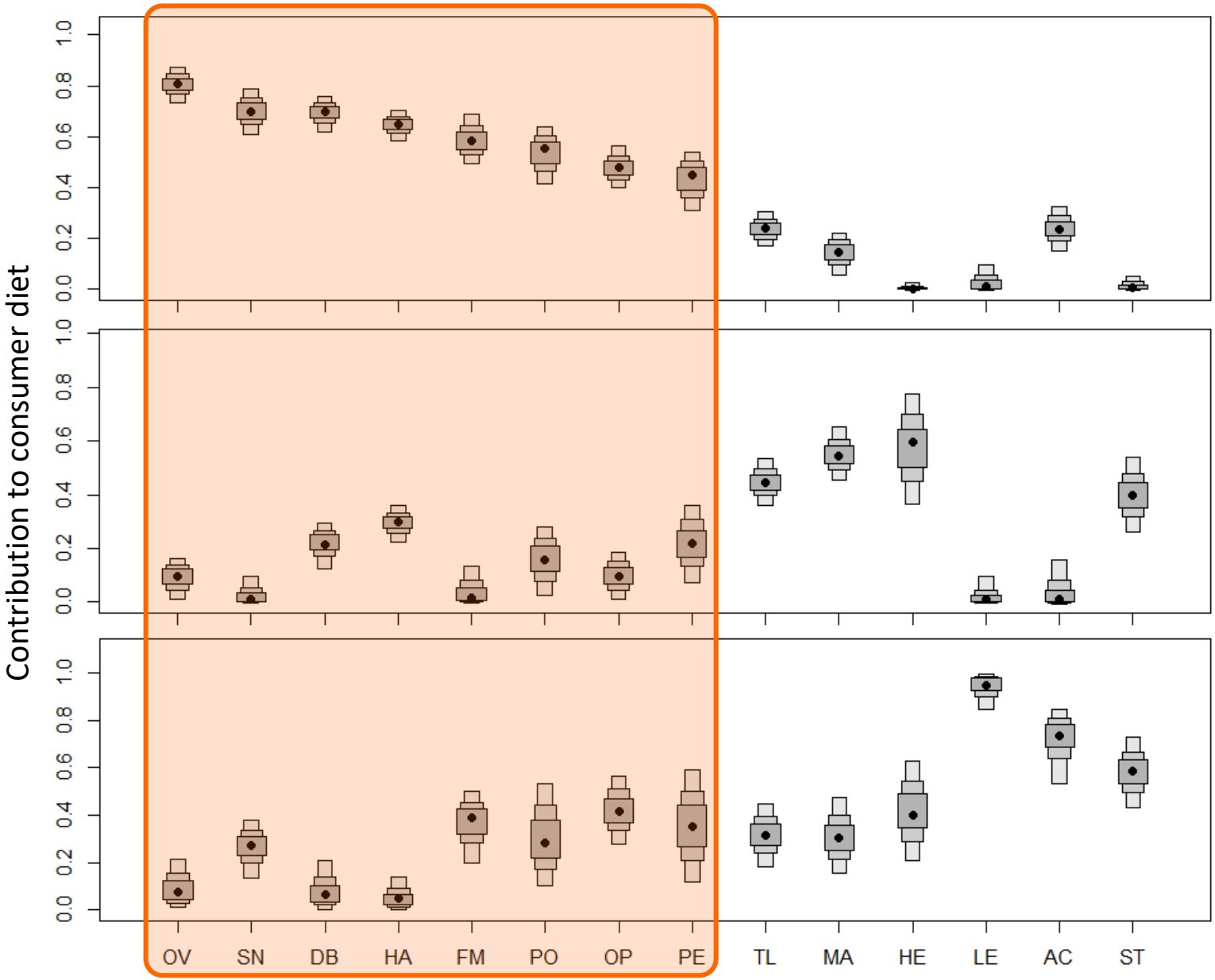

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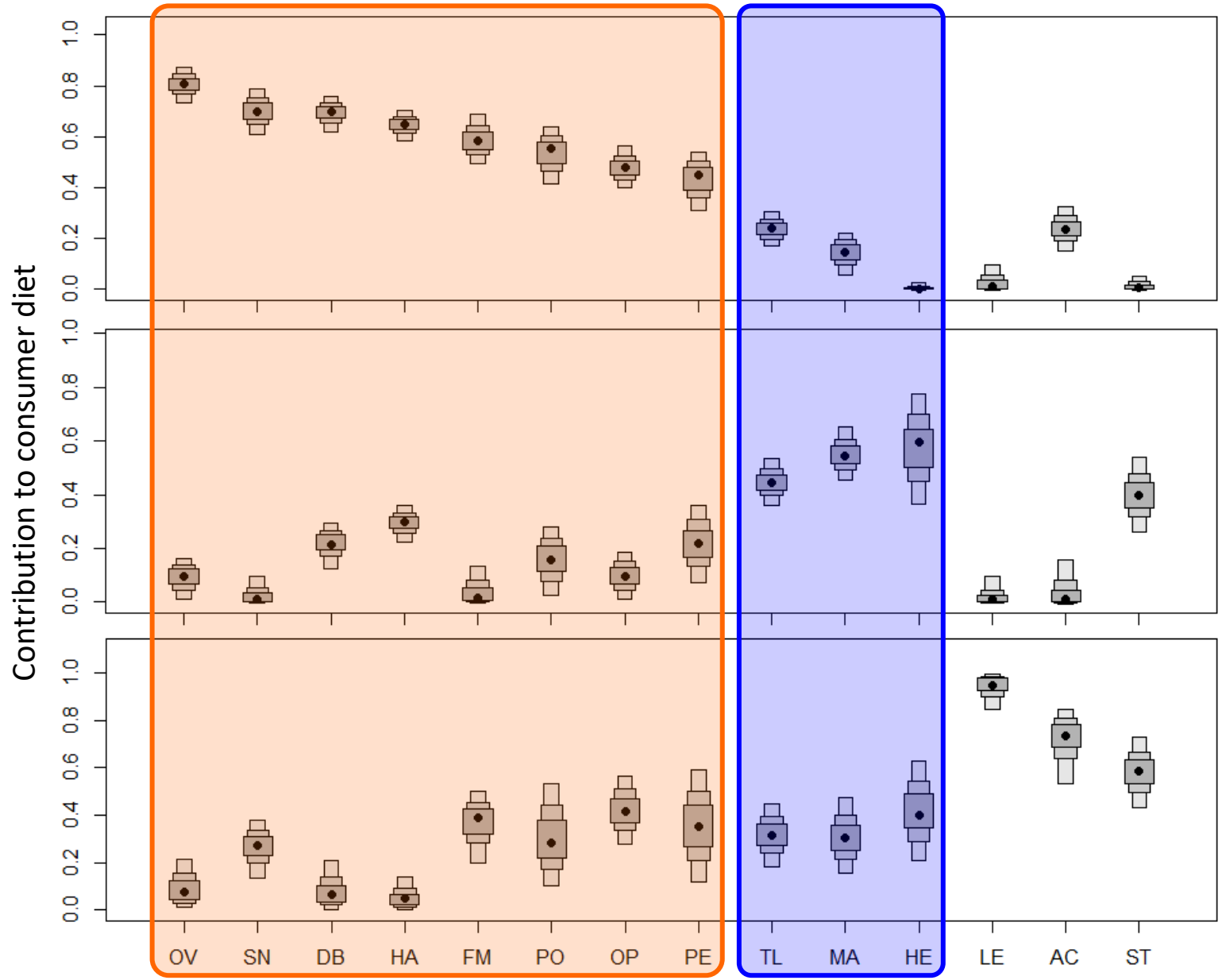

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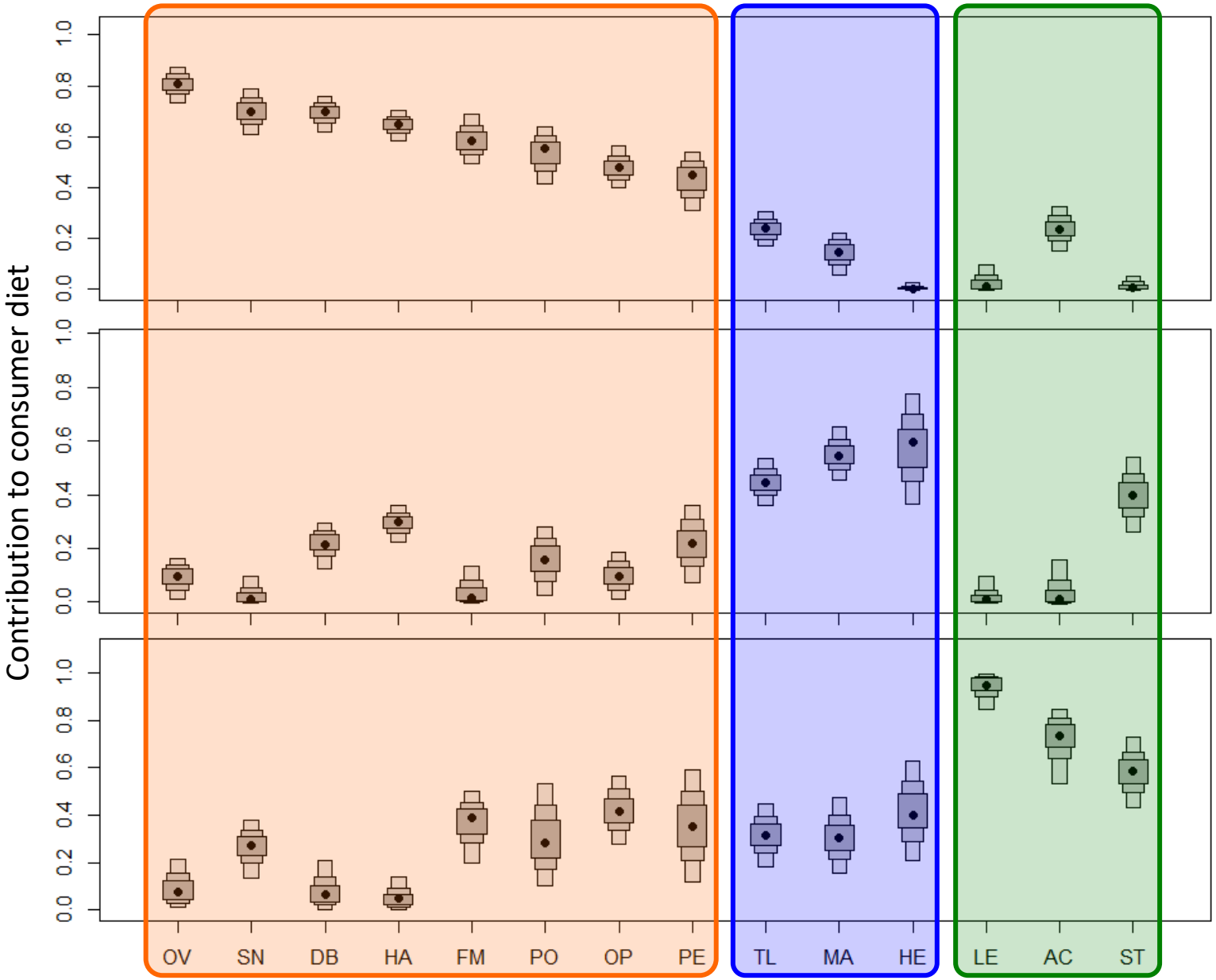

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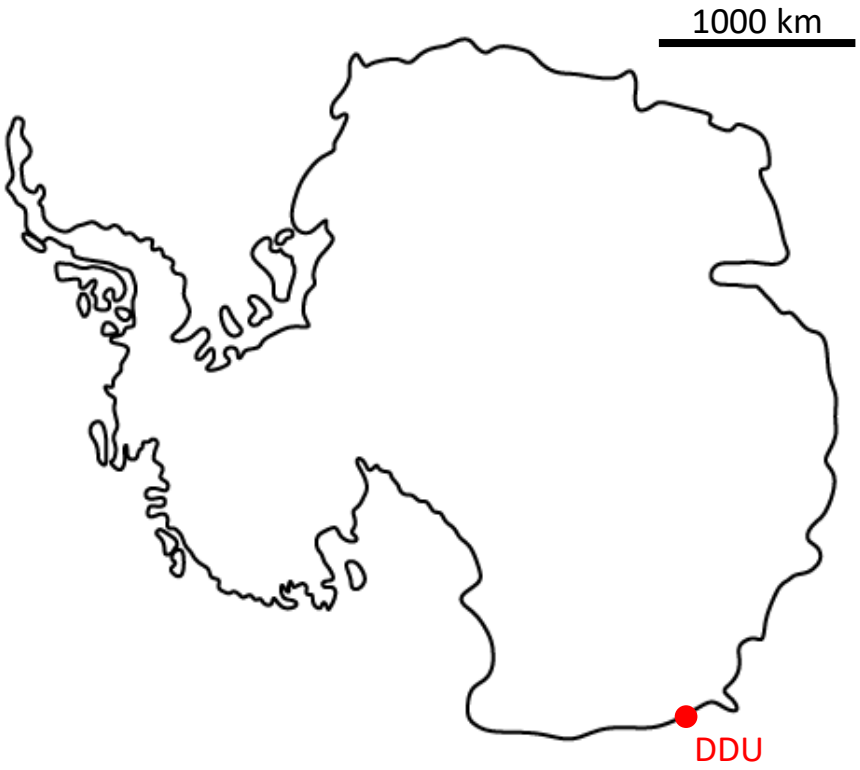
Discrepancies in resource use

Species	DDU
Laternula elliptica	
Adamussium colbecki	
Sterechinus neumayeri	
Odontaster validus	
Staurocucumis sp.	
Harmothoe sp.	

Main food items

Sympagic algae

Benthic algae / Biofilm

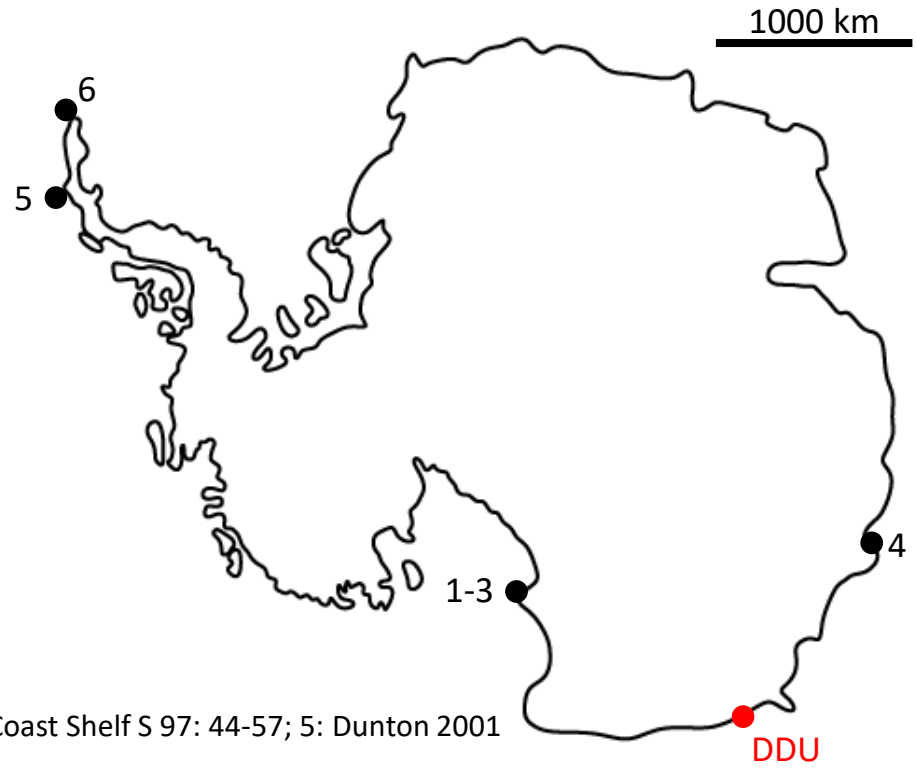


Discrepancies in resource use

Species	DDU	1	2	3	4	5	6
Laternula elliptica							
Adamussium colbecki							
Sterechinus neumayeri							
Odontaster validus							
Staurocucumis sp.							
Harmothoe sp.							

Main food items

- Sympagic algae / Ice POM
- Benthic algae / Biofilm
- Plankton / SPOM
- Sediment POM
- Animal-based diet
- No data



References:
1-3: Norkko et al. 2007 Ecology 88: 2810-2820; 4: Gillies et al. 2012 Estuar Coast Shelf S 97: 44-57; 5: Dunton 2001 Amer Zool 41: 99-112; 6: Corbisier et al. 2004 Polar Biol 27: 75-82

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Sea ice

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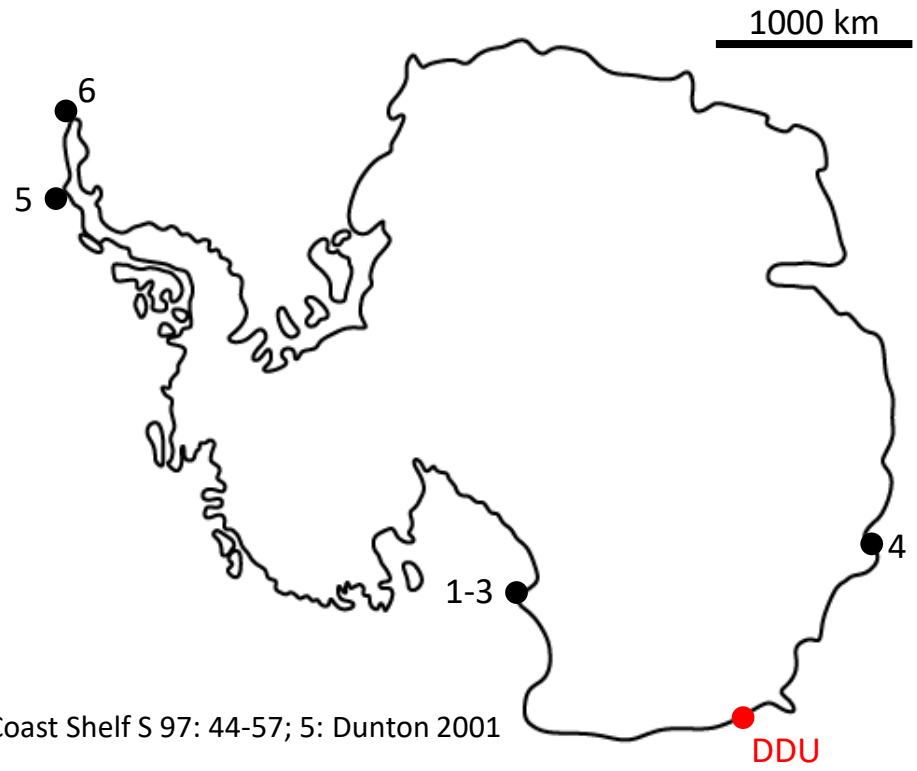

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Main food items

Sympagic algae / Ice POM

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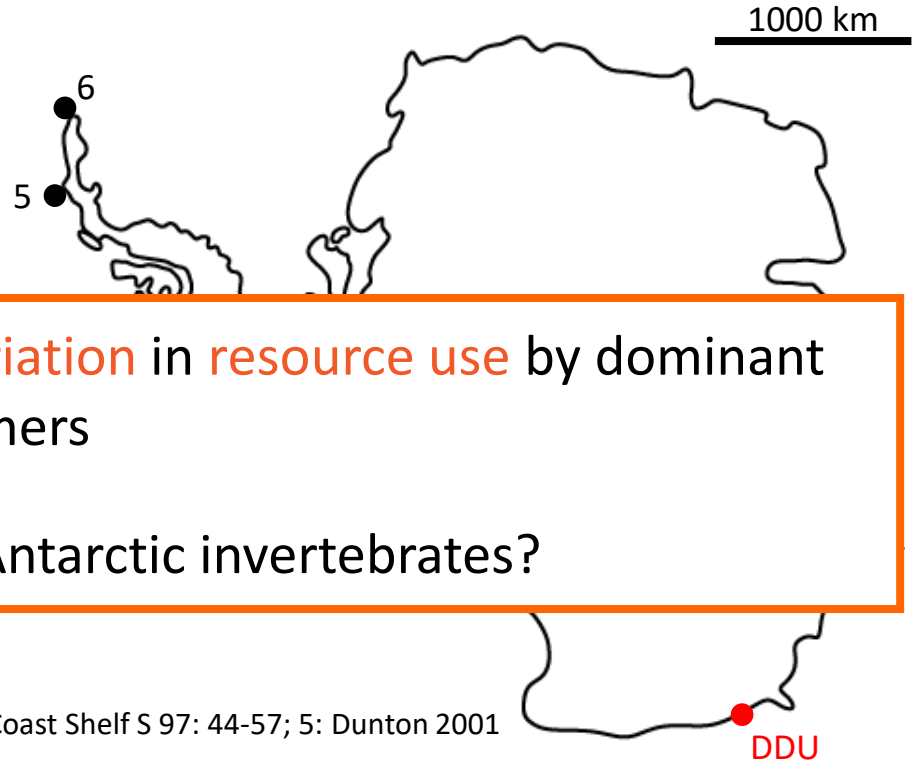
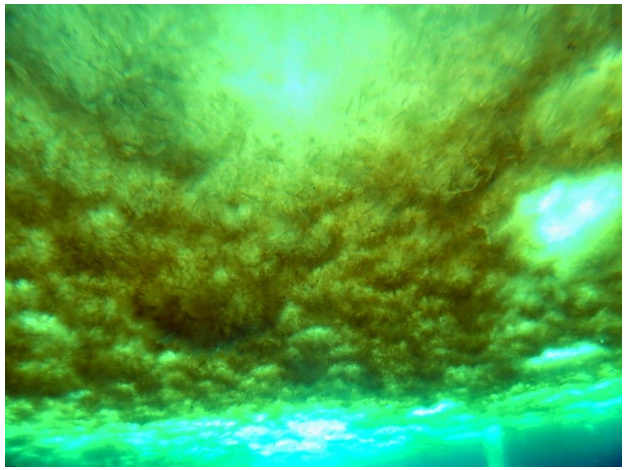


Important spatial and/or temporal variation in resource use by dominant consumers

High trophic plasticity of Antarctic invertebrates?

References:
1-3: Norkko et al. 2007 Ecology 88: 2810-2820; 4: Gillies et al. 2012 Estuar Coast Shelf S 97: 44-57; 5: Dunton 2001 Amer Zool 41: 99-112; 6: Corbisier et al. 2004 Polar Biol 27: 75-82

Sympagic algae consumption: how and why?

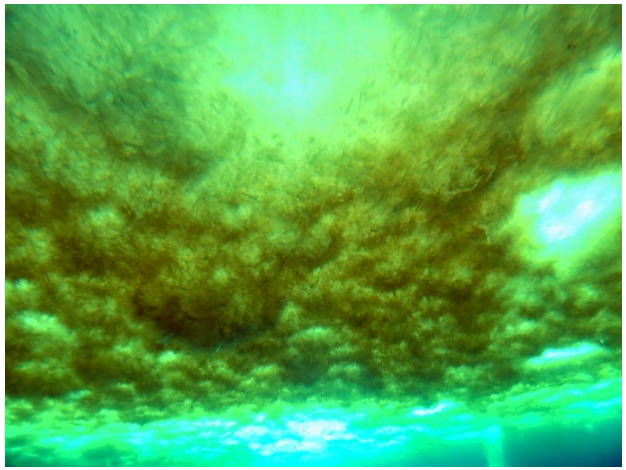


Sea ice is a dynamic system: constant melting/freezing

Sympagic algae aggregates sink quickly

Sinking speed is size-dependent and range from 100 to 500 m/day (i.e. 1-5 hours to reach a depth of 20 m)

Sympagic algae consumption: how and why?



Sea ice is a dynamic system: constant melting/freezing

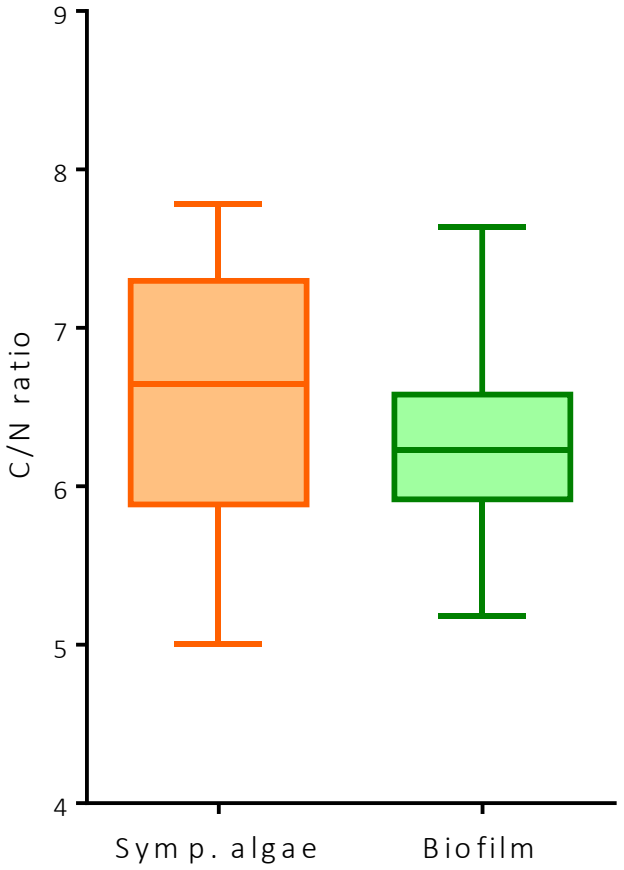
Sympagic algae aggregates sink quickly

Sinking speed is size-dependent and range from 100 to 500 m/day (i.e. 1-5 hours to reach a depth of 20 m)

Why is it preferred by many consumers over more abundant food items such as biofilm?

Better nutritional value? Unlikely… ➔

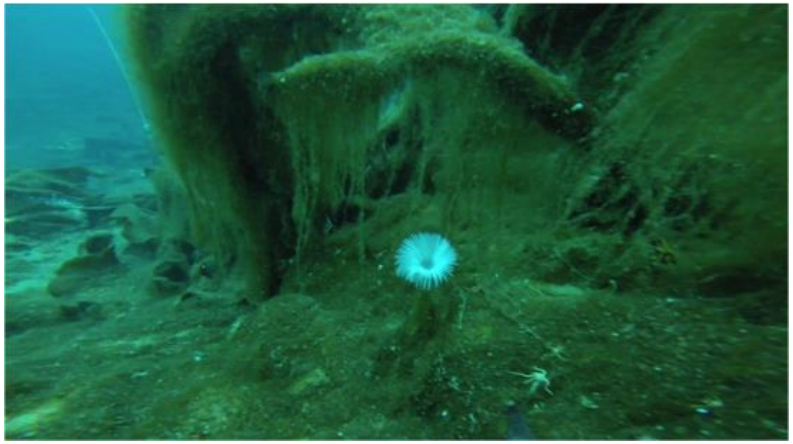
Better palatability? Pure aggregates of microalgae…



Role of benthic biofilm in the food web

Preliminary microscopic examination:
Benthic biofilm = heterogeneous mix of microalgae, amorphous material and detrital items

Here: importance of benthic biofilm in food web comparatively limited despite high abundance



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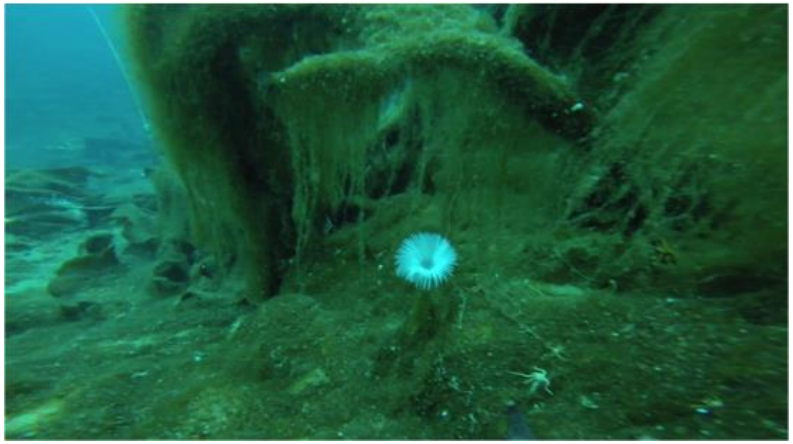

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Ross Sea: Benthic invertebrates consume more detritic matter in sea-ice influenced locations
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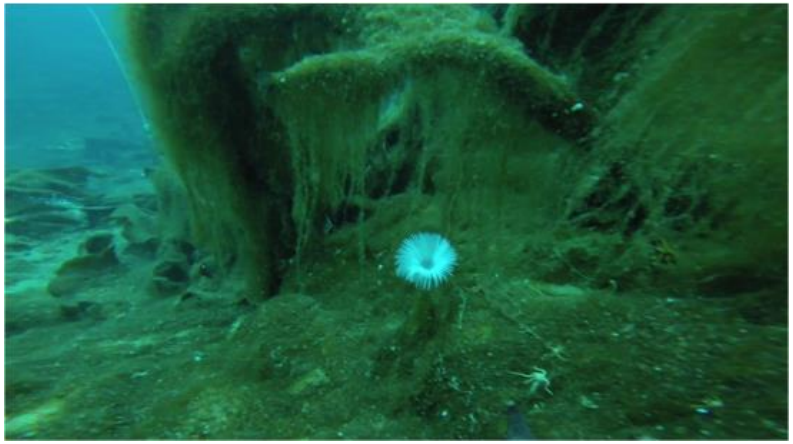

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Ross Sea: Benthic invertebrates consume more detritic matter in sea-ice influenced locations
(Norkko et al. 07)

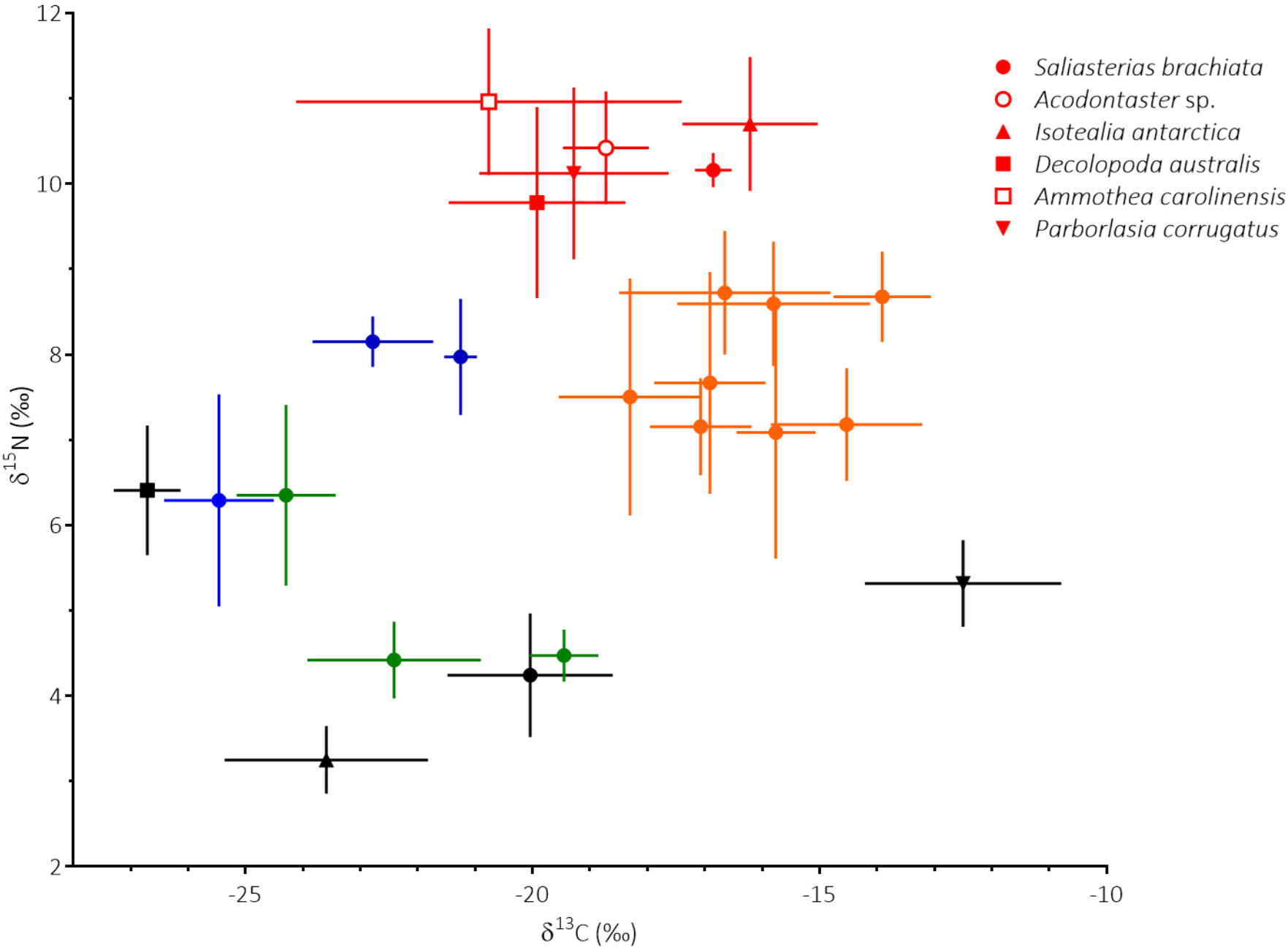
Important variation in benthic ecosystem response to sea ice: sudden changes vs. stable conditions?

However: no data about dynamics of biofilm accumulation!

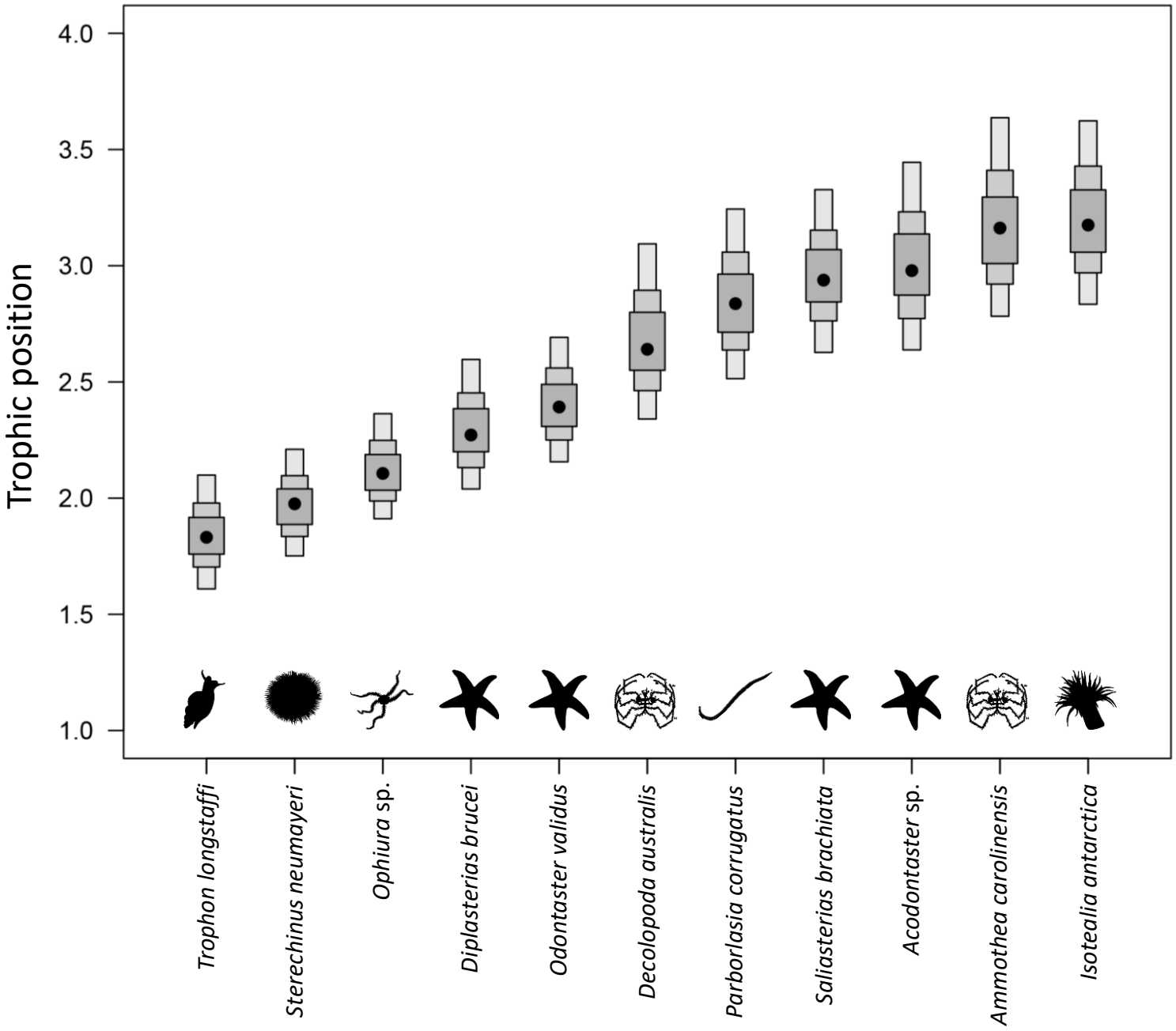
Here: long-lived benthic invertebrates with low metabolic rates ➔ low isotopic turnover? Is isotopic equilibrium reached?

Our model could underestimate actual biofilm importance for invertebrate feeding

Results: full community

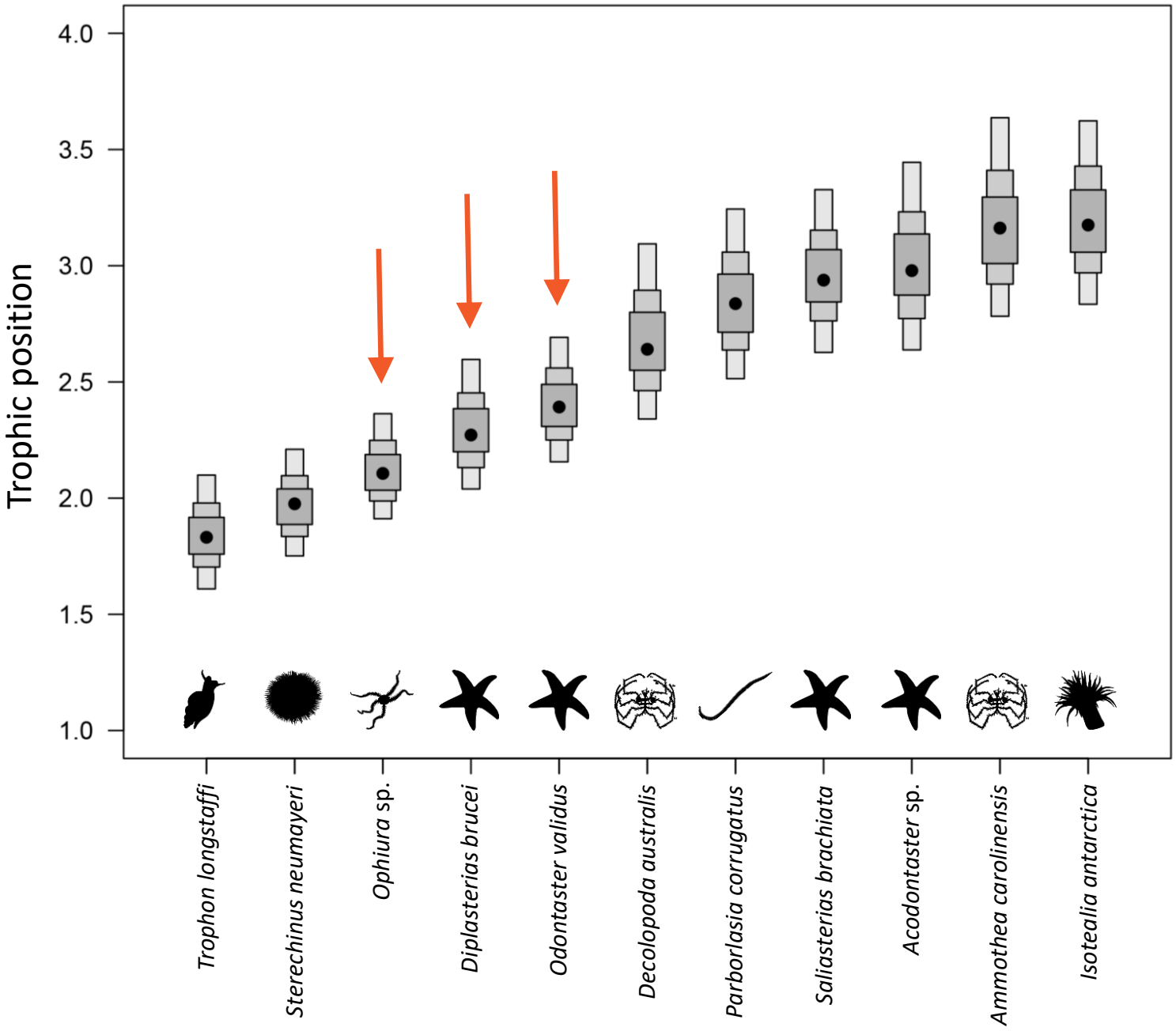


Vertical dimension – Trophic position modelling



Overall: low trophic positions compared to literature

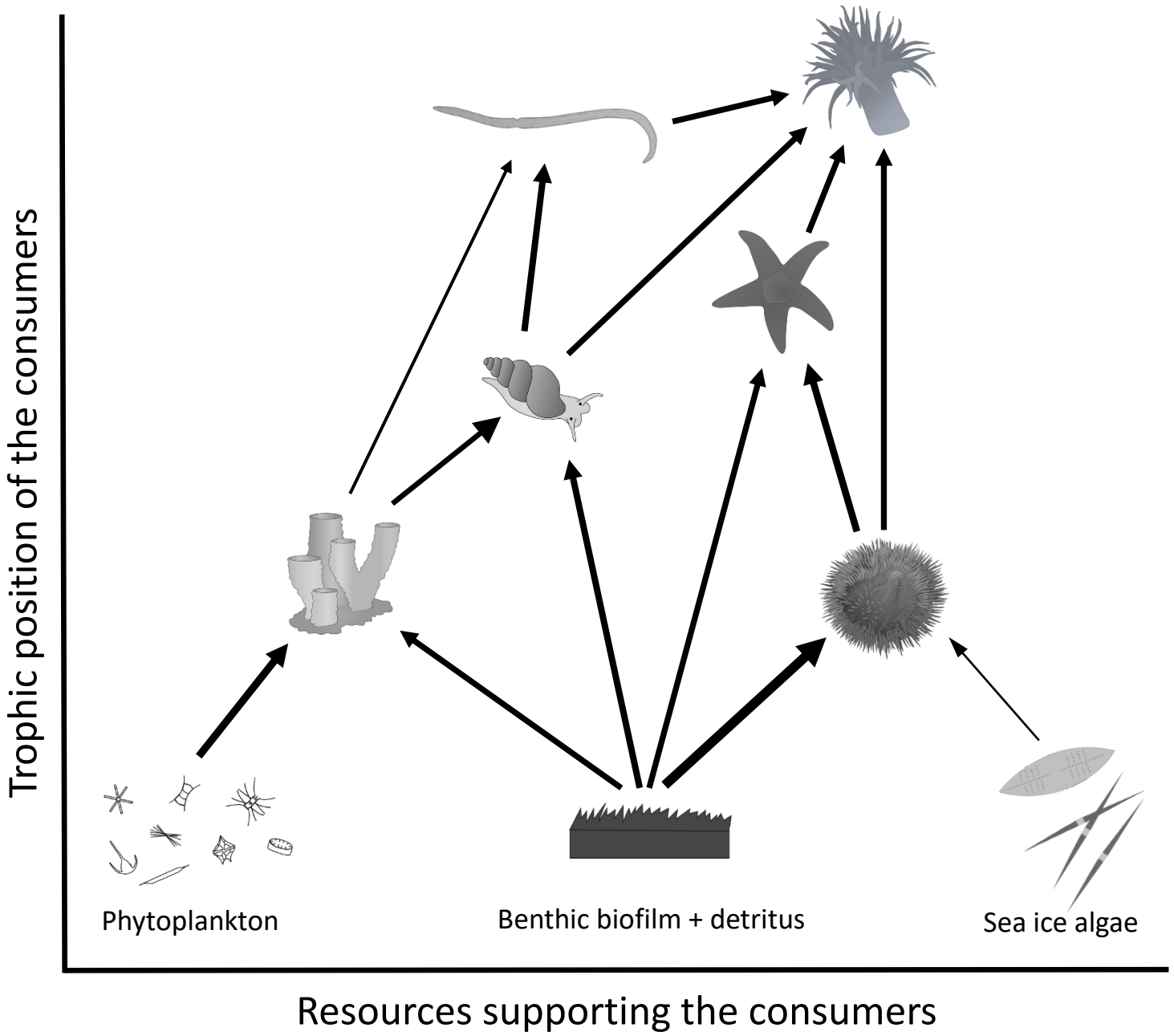
Vertical dimension – Trophic position modelling



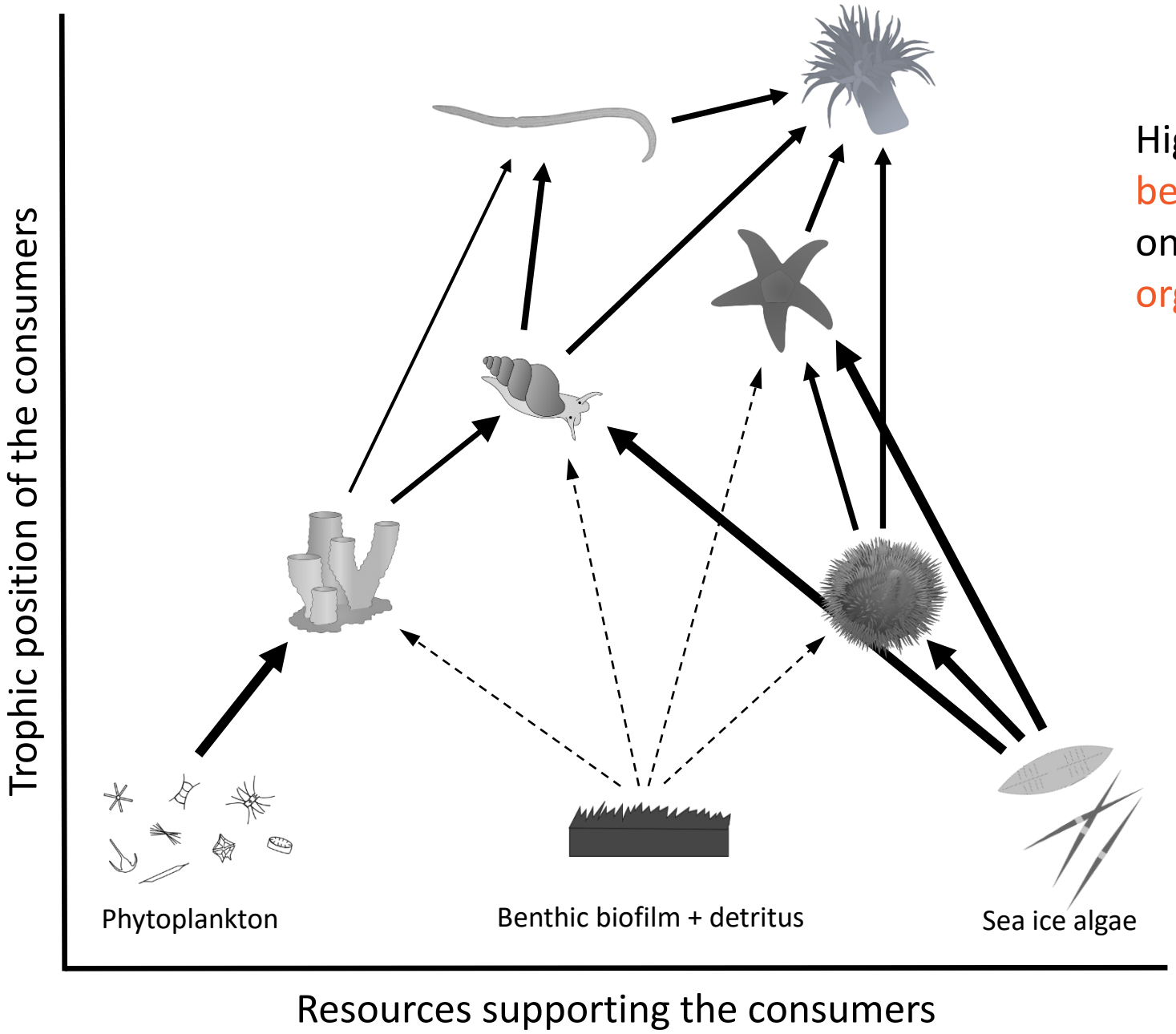
Overall: low trophic positions compared to literature

Dominant omnivore taxa: very low trophic levels, mostly feeding directly on primary producers

The food web we expected



Shift in resources supporting consumers



High dependency of benthic invertebrates on sea ice-derived organic matter

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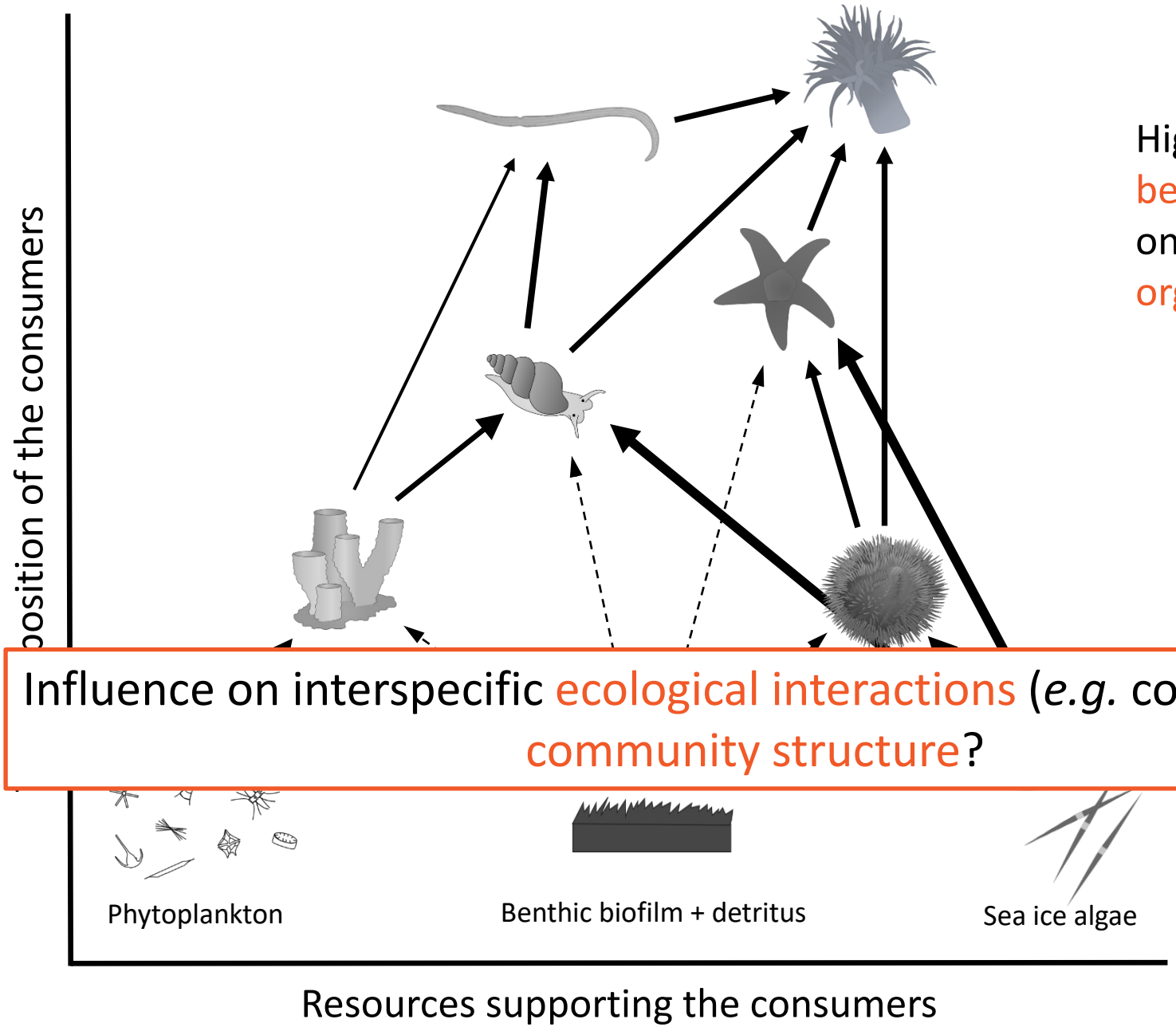
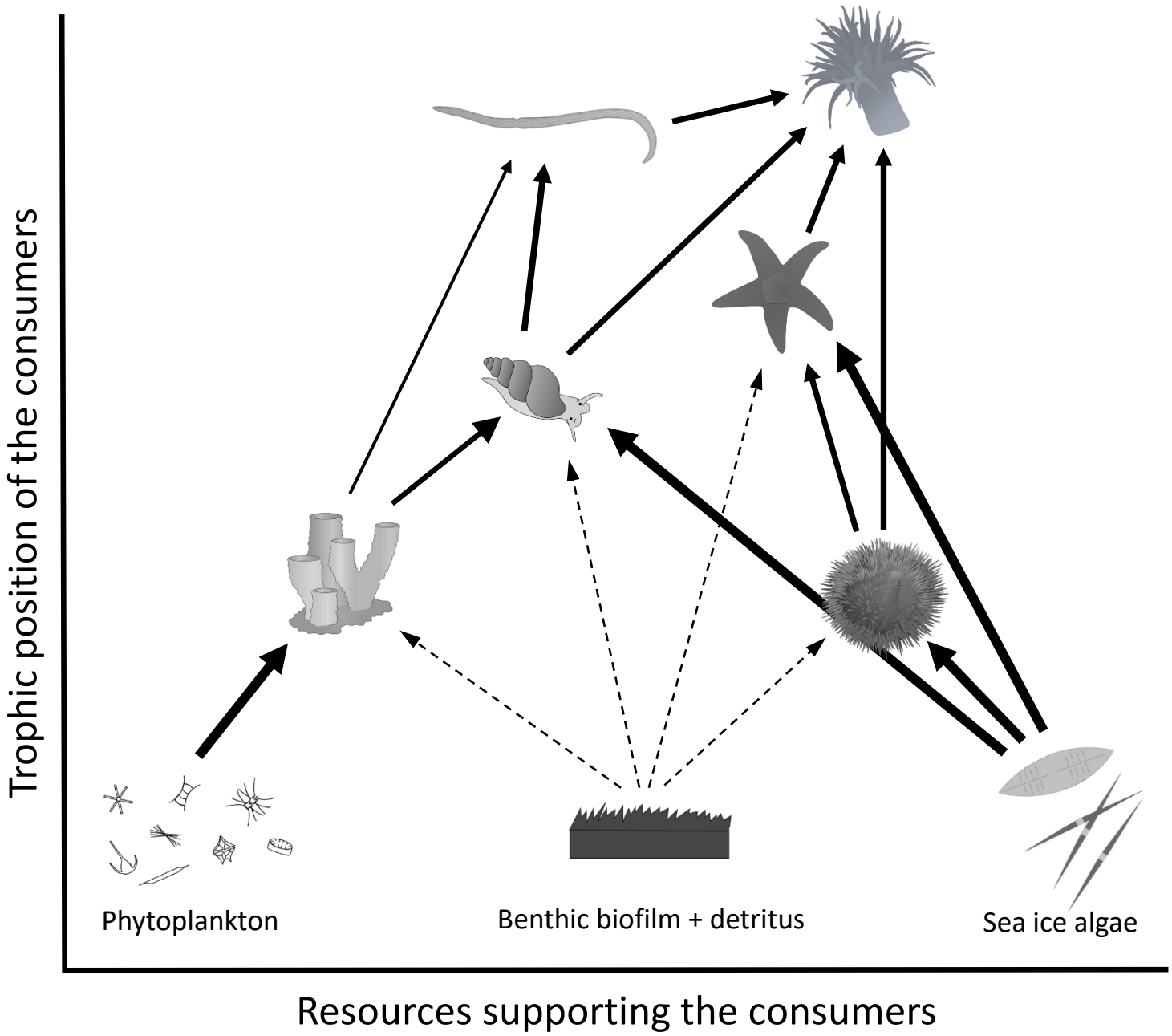


High dependency of benthic invertebrates on sea ice-derived organic matter

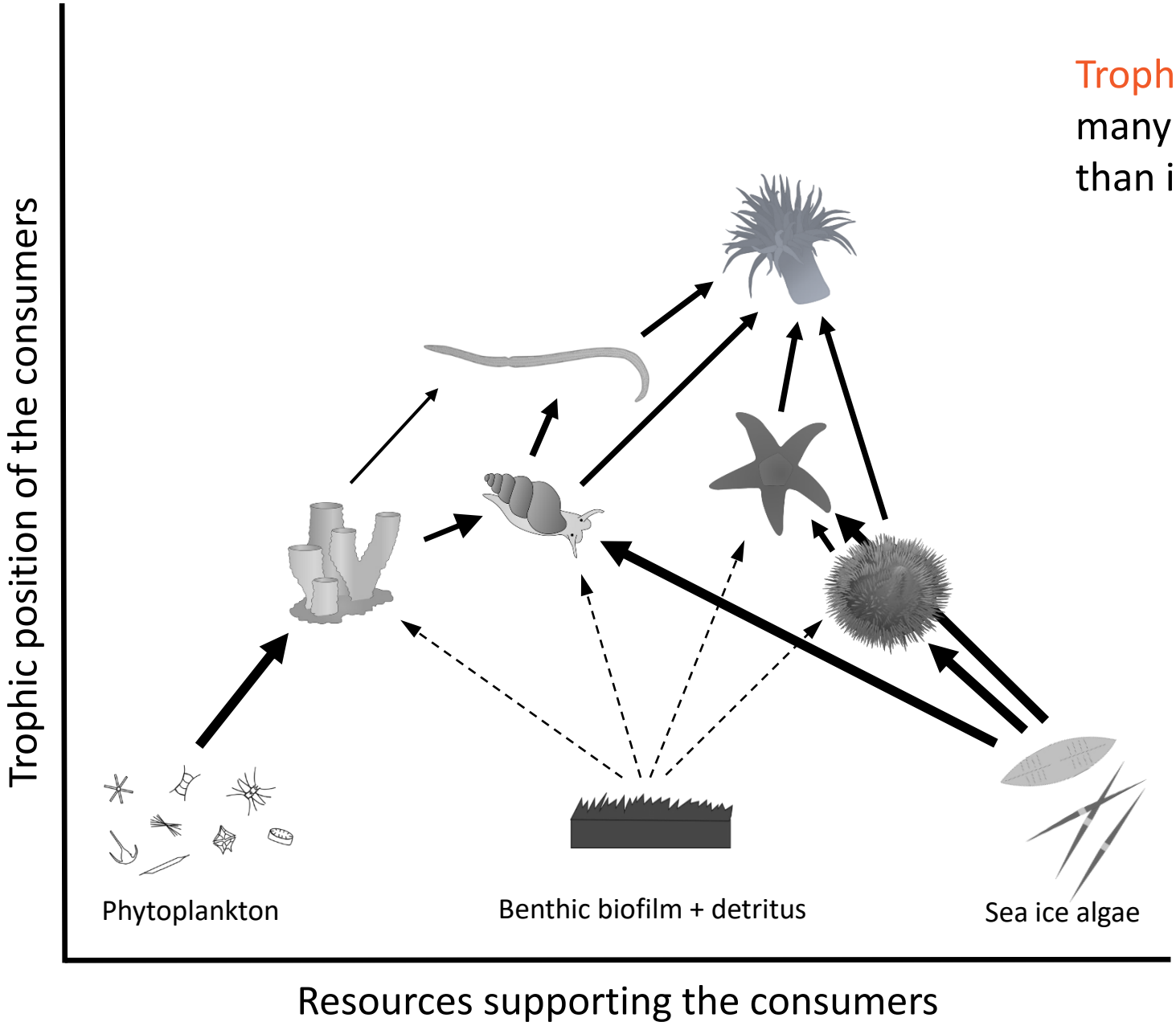
Influence on interspecific ecological interactions (*e.g.* competition) and community structure?

Shift in trophic position of consumers



Shift in trophic position of consumers

Trophic positions of many consumers lower than in other studies



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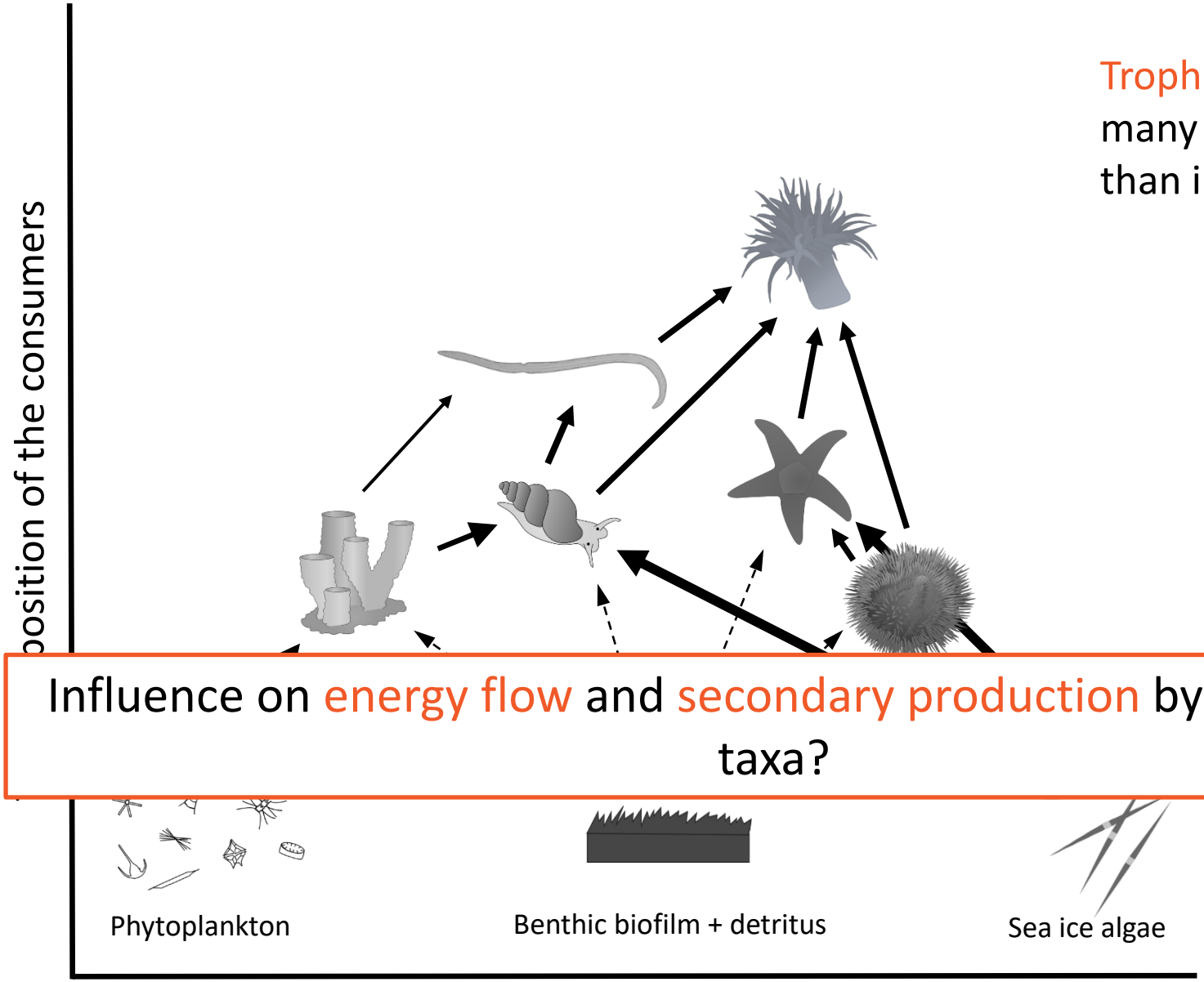
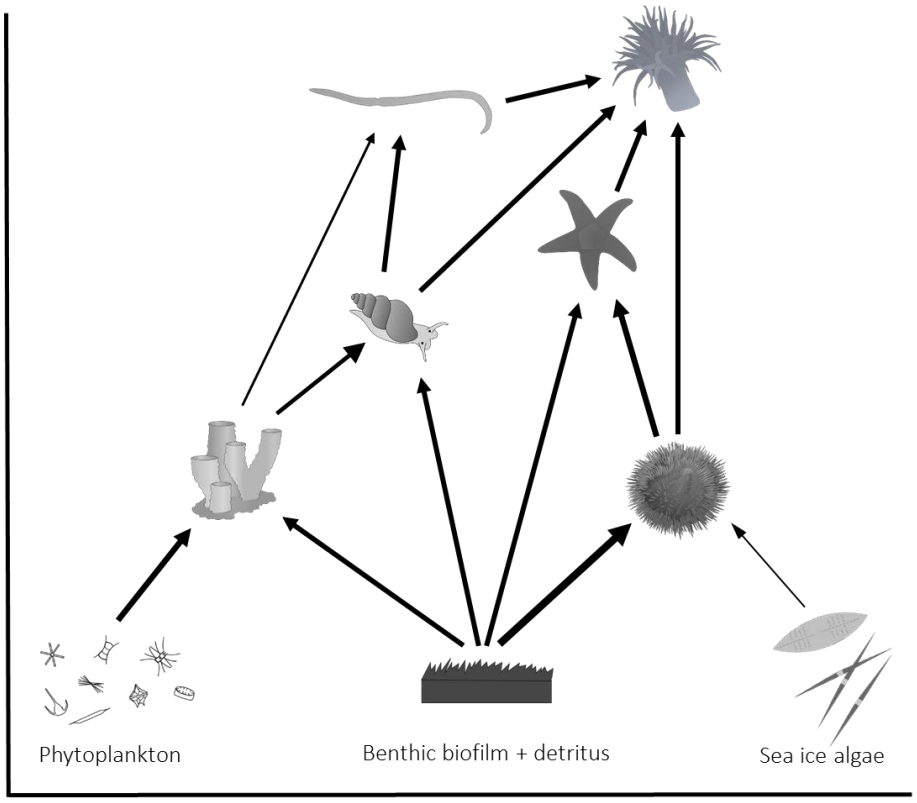
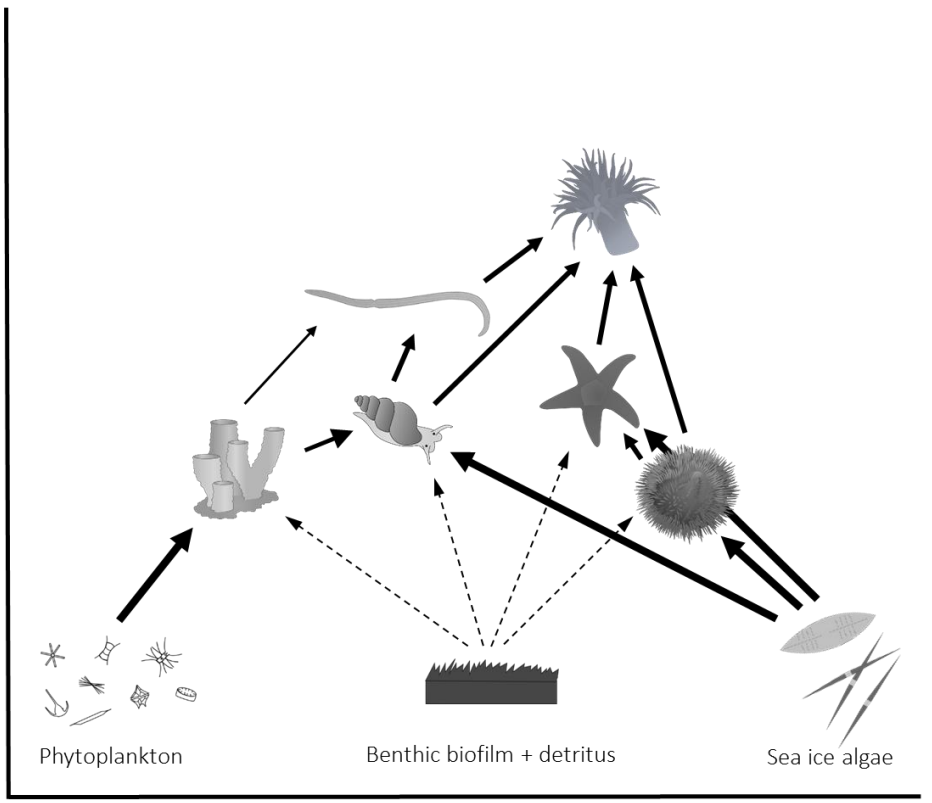


Influence on energy flow and secondary production by key omnivore taxa?

Sea ice & food web structure



Expected food web



Increased sea ice conditions

Increase of sea ice cover strongly influences the benthic food web by modifying both its horizontal and its vertical structure

Take home message

- Important sea ice cover is linked with high reliance of coastal benthic invertebrates on sympagic algae

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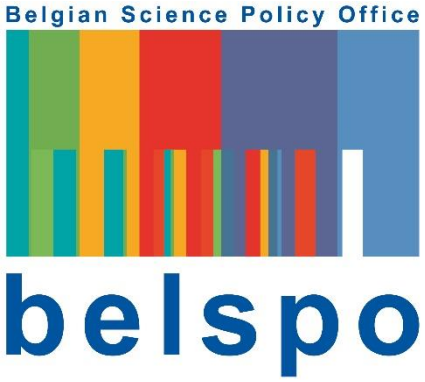
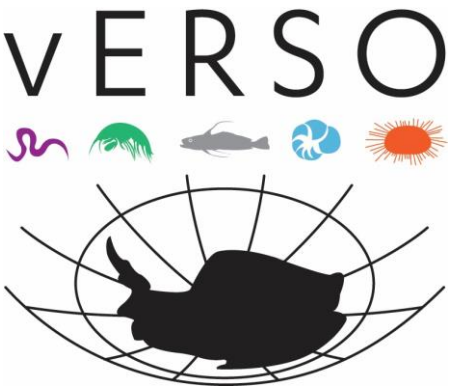
Despite being interpreted as a positive signal by mainstream media, local or large-scale trends of sea ice increase in Antarctica could actually have strong impacts on benthic ecosystems

Funding





Belgian Federal Science Policy Office (BELSPO)

vERSO (Ecosystem Resilience in Southern Ocean) and RECTO (Refugia and Ecosystem Tolerance in the Southern Ocean) projects

French Polar Institute (IPEV)


Thanks for your attention

References & further reading

Calizza, E., Careddu, G., Sporta Caputi, S., Rossi, L. & Costantini, M.L. 2018. Time- and depth-wise trophic niche shifts in Antarctic benthos. *PLoS One*, **13**, e0194796, https://doi.org/10.1371/journal.pone.0194796.

Corbisier, T.N., Petti, M.A.V., Skowronski, R.S.P. & Brito, T.A.S. 2004. Trophic relationships in the nearshore zone of Martel Inlet (King George Island, Antarctica): $\delta^{13}C$ stable-isotope analysis. *Polar Biology*, **27**, 75–82, https://doi.org/10.1007/s00300-003-0567-z.

Dunton, K.H. 2001. $\delta^{15}N$ and $\delta^{13}C$ Measurements of Antarctic Peninsula Fauna: Trophic Relationships and Assimilation of Benthic Seaweeds. *American Zoologist*, **41**, 99–112. https://doi.org/10.1093/icb/41.1.99.

Gillies, C.L., Stark, J.S., Johnstone, G.J. & Smith, S.D.A. 2012. Carbon flow and trophic structure of an Antarctic coastal benthic community as determined by $\delta^{13}C$ and $\delta^{15}N$. *Estuarine, Coastal and Shelf Science*, **97**, 44–57, https://doi.org/10.1016/j.ecss.2011.11.003.

King, J. 2014. A resolution of the Antarctic paradox. *Nature*, **505**, 491–492, https://doi.org/10.1038/505491a.

Massom, R.A. & Stammerjohn, S.E. 2010. Antarctic sea ice change and variability - Physical and ecological implications. *Polar Science*, **4**, 149–186, https://doi.org/10.1016/j.polar.2010.05.001.

Michel, L.N., Danis, B., Dubois, P., Eleaume, M., Fournier, J., Gallut, C., Jane, P. & Lepoint, G. 2019. Increased sea ice cover alters food web structure in East Antarctica. *Scientific Reports*, **9**, 8062, https://doi.org/10.1038/s41598-019-44605-5.

Norkko, A., Thrush, S.F., Cummings, V.J., Gibbs, M.M., Andrew, N.L., Norkko, J. & Schwarz, A.M. 2007. Trophic structure of coastal Antarctic food webs associated with changes in sea ice and food supply. *Ecology*, **88**, 2810–2820, https://doi.org/10.1890/06-1396.1.

Peck, L.S. 2018. Antarctic Marine Biodiversity : Adaptations , Environments and Responses To Change. *Oceanography and Marine Biology: An Annual Review*, **56**, 105–236, https://doi.org/10.1201/9780429454455.

References & further reading

Raymond, B., Marshall, M., Nevitt, G., Gillies, C.L., Hoff, J. van den, Stark, J.S., Losekoot, M., Woehler, E.J. & Constable, A.J. 2011. A Southern Ocean dietary database. *Ecology*, **92**, 1188–1188, https://doi.org/10.1890/10-1907.1.

Riebesell, U., Schloss, I. & Smetacek, V. 1991. Aggregation of algae released from melting sea ice: implications for seeding and sedimentation. *Polar Biology*, **11**, https://doi.org/10.1007/BF00238457.

Rossi, L., Sporta Caputi, S., Calizza, E., Careddu, G., Oliverio, M., Schiaparelli, S. & Costantini, M.L. 2019. Antarctic food web architecture under varying dynamics of sea ice cover. *Scientific Reports*, **9**, 12454, https://doi.org/10.1038/s41598-019-48245-7.

Sporta Caputi, S., Careddu, G., Calizza, E., Fiorentino, F., Maccapan, D., Rossi, L. & Costantini, M.L. 2020. Seasonal food web dynamics in the Antarctic benthos of Tethys Bay (Ross Sea): Implications for biodiversity persistence under different seasonal sea-ice coverage. *Frontiers in Marine Science*, **7**, 594454, https://doi.org/10.3389/fmars.2020.594454.

Summerhayes, V.S. & Elton, C.S. 1923. Contributions to the ecology of Spitsbergen and Bear Island. *Journal of Animal Ecology*, **11**, 216–233, https://doi.org/10.2307/2255863.