On thin ice: the (variable) role of **ice algae** in Arctic food webs in a changing icescape

Doreen Kohlbach –Alfred Wegener Institute

Helmholtz Young Investigator Group
Double-Trouble

Photo: Peter Leopold

GRC Polar Marine Science 2025, Ocean ecosystem dynamics in the presence of sea ice, 13 March 2025

i) Ice algae as a food source in **Arctic food webs**

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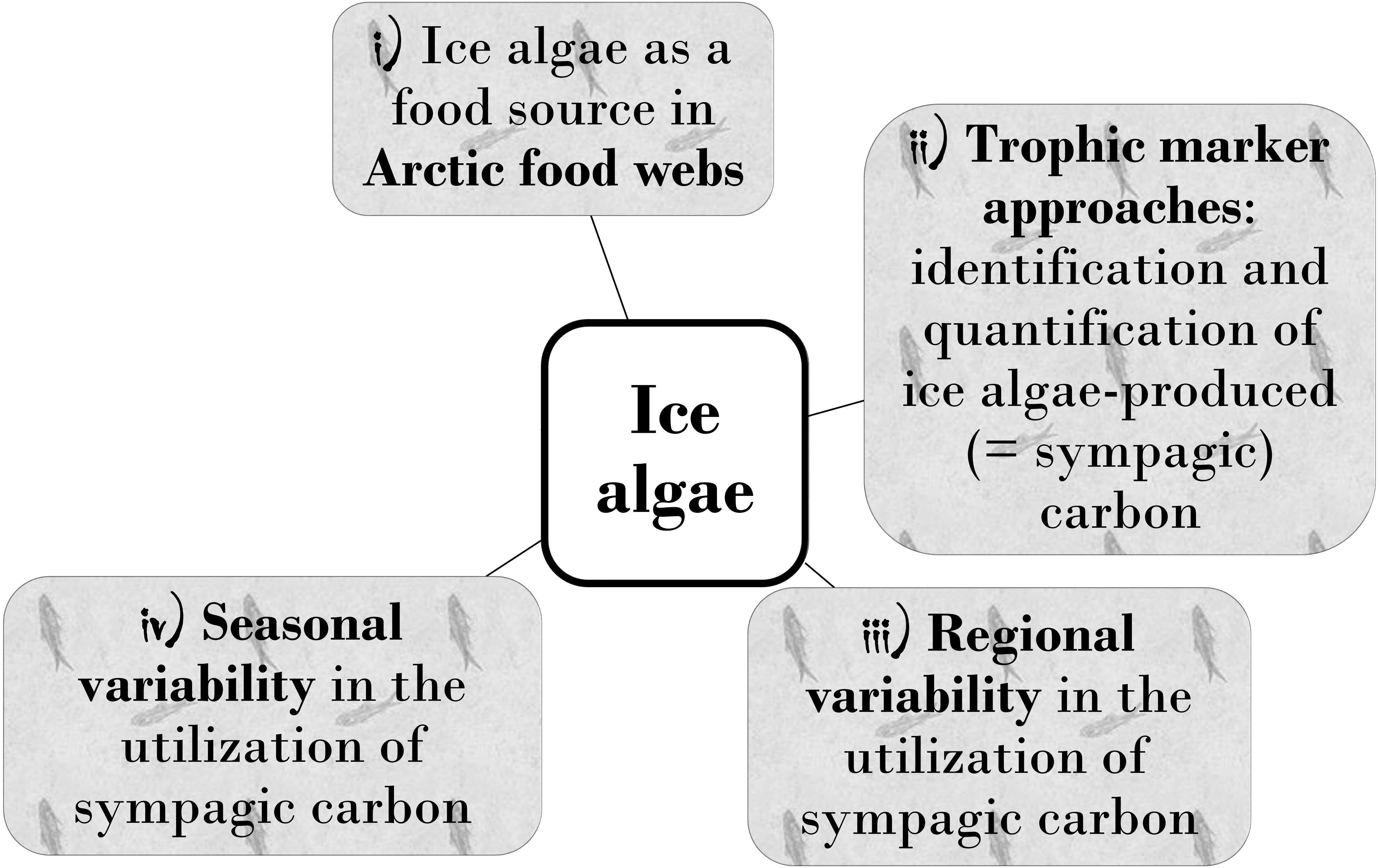
iii) **Regional variability** in the utilization of sympagic carbon



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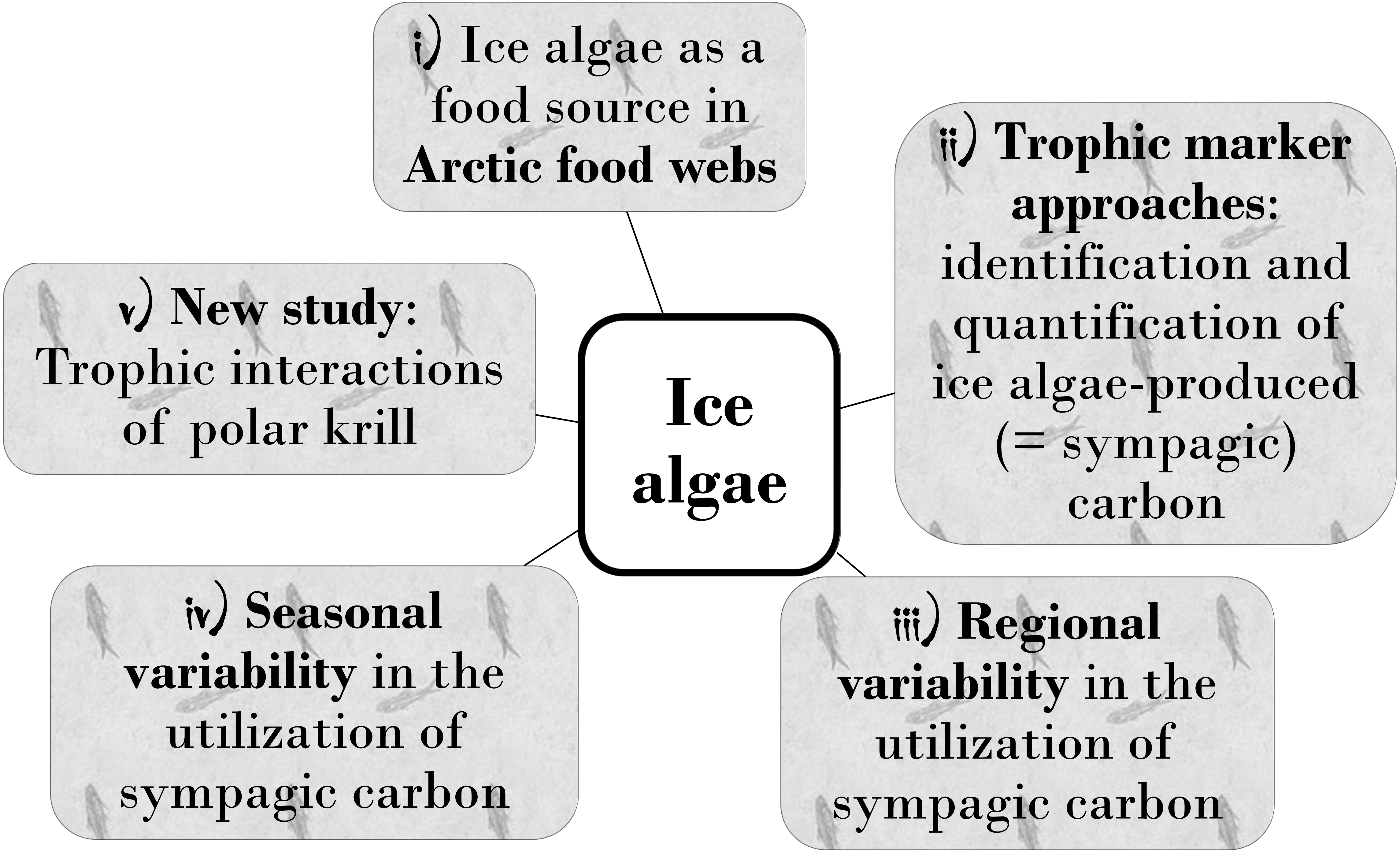
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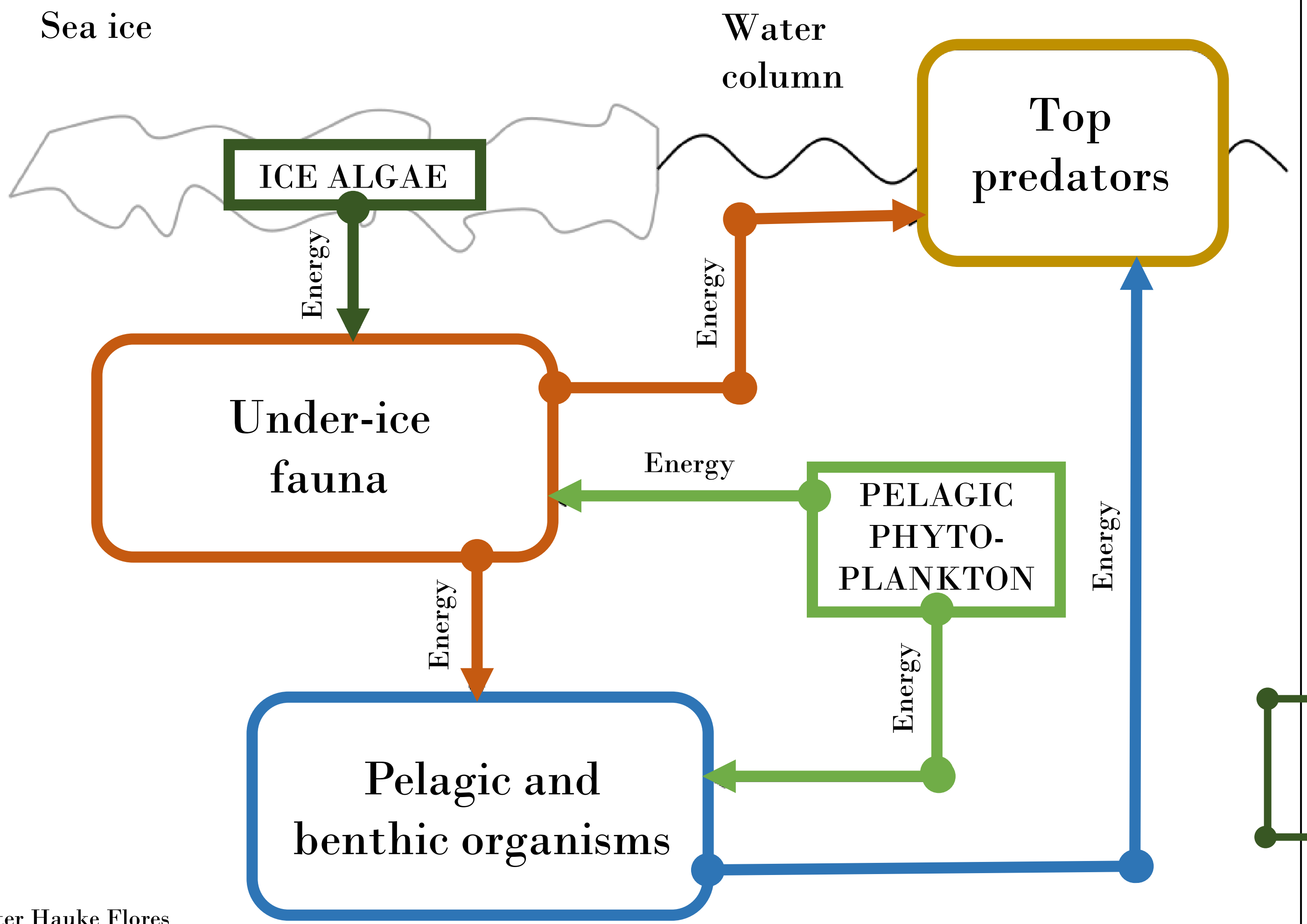
iv) **Seasonal variability** in the utilization of sympagic carbon
v) **New study**: Trophic interactions of polar krill
Ice algae

i) Arctic food webs

Ice algae grow **within the ice** (dominated by pennate diatoms) and **underneath the ice** (sub-ice diatoms *Melosira arctica*)



After Hauke Flores

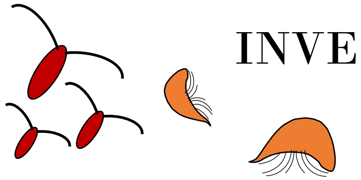
Ice-associated (<u>sympagic</u>) primary production

- **Seasonally ice-covered** regions: up to 22% in the Barents Sea (Hegseth, 1998)
- **Year-round ice-covered** regions: >50% in the Central Arctic Ocean (Gosselin et al., 1997; Fernández-Méndez et al., 2015)

Nutritional value (content of polyunsaturated fatty acids) **seasonally variable:** high during spring production, lower during post-bloom periods (Leu et al., 2010; Kohlbach et al. 2022)

Ice algae **important as a food source** in all marine environments (sympagic, pelagic, benthic) and for all trophic levels…

Koch et al. (2023): Sympagic carbon present in **96% of >2000 samples spanning >150 species**



INVERTEBRATES

- Under-ice fauna, Central Arctic Ocean: **up to >90%** (Kohlbach et al., 2016)
- Under-ice fauna and pelagic zooplankton, Barents Sea: **only supplementary** (Kohlbach et al., 2021a, 2022, 2024)
- Benthic fauna, Canadian Arctic: **>77%** (Kohlbach et al., 2019 and Yunda-Guarin et al., 2020)
- Benthic fauna, northeast Greenland shelf: **~90%** (Cautain et al., 2024)

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- Polar cod, Barents Sea: **no sympagic metabolites detected** (Kohlbach et al., 2022)
- Arctic cod, Barrow, Alaska: **up to > 70%** (Budge et al., 2008)
- Greenland halibut and capelin, Canadian Arctic: **~50%** and **~20%**, resp. (Brown et al., 2017)

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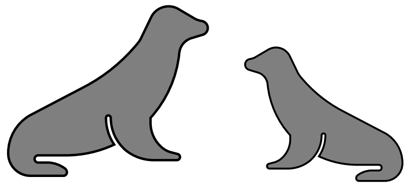

HIGHER TROPHICS

- Harp and ringed seals, European Arctic: **~70%**, (Kunisch et al., 2021)
- Harp and ringed seals, Canadian Arctic: **~50%** and **~80%**, resp. (Desforges et al., 2022)
- Polar bear, Canadian Arctic: **>72%** (Brown et al., 2018)
- Pacific walrus, Chukchi Sea & Northern Bering Sea: **~30% to 50%** (Koch et al., 2021)

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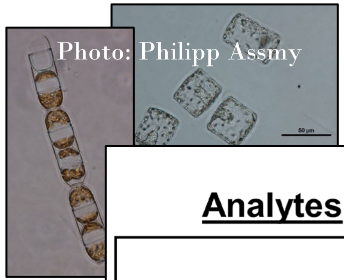
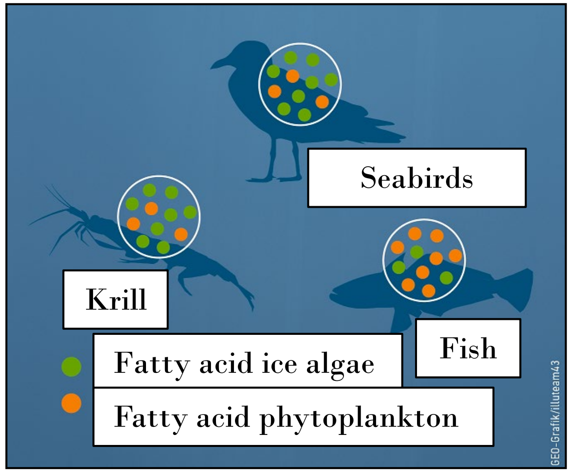
…but with **noteworthy differences!**

ii) Trophic marker approaches



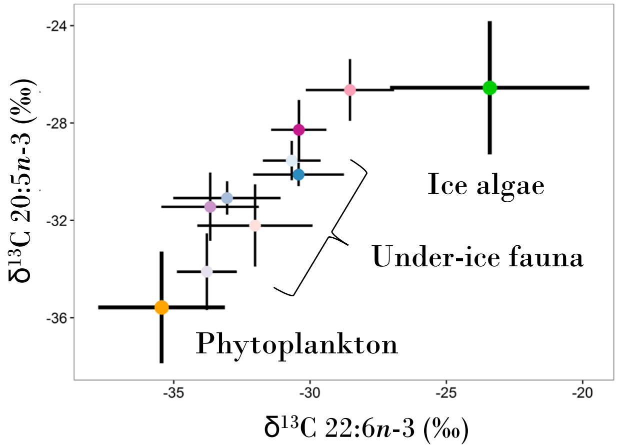
Analytes	Method	Carbon and food sources
Marker fatty acids	***Gas chromatography (GC)*** → Relative proportions	Dinoflagellate-derived / Diatom-derived
Stable isotopes in fatty acids and amino acids	***GC- Isotope Ratio Mass Spectrometry*** → $\delta^{13}C$	*Quantification* Pelagic / Sympagic
Highly branched isoprenoids	***GC-Mass Spectrometry*** → µg g^{-1} dry weight	



Diatom-produced fatty acids
16:1*n*-7, 20:5*n*-3
→ *abundant in sea ice and water column*

Dino(flagellate)-produced fatty acids
18:4*n*-3, 22:6*n*-3
→ *abundant in water column*

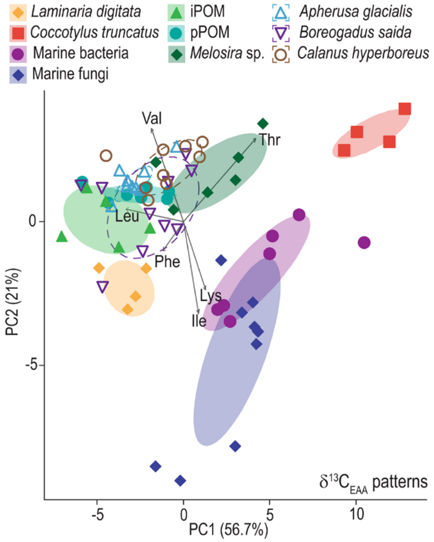
Carbon stable isotopes ($\delta^{13}C^*$) fatty acids



$\delta^{13}C$: $^{13}C/^{12}C$

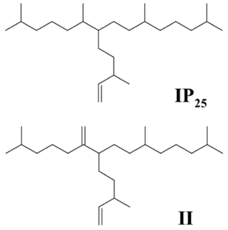
Kohlbach et al. (2016)

$\delta^{13}C$ essential amino acids



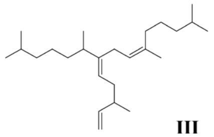
Vane et al. (2023, 2025)

Highly branched isoprenoids (HBIs) produced by



sympagic diatoms

pelagic diatoms



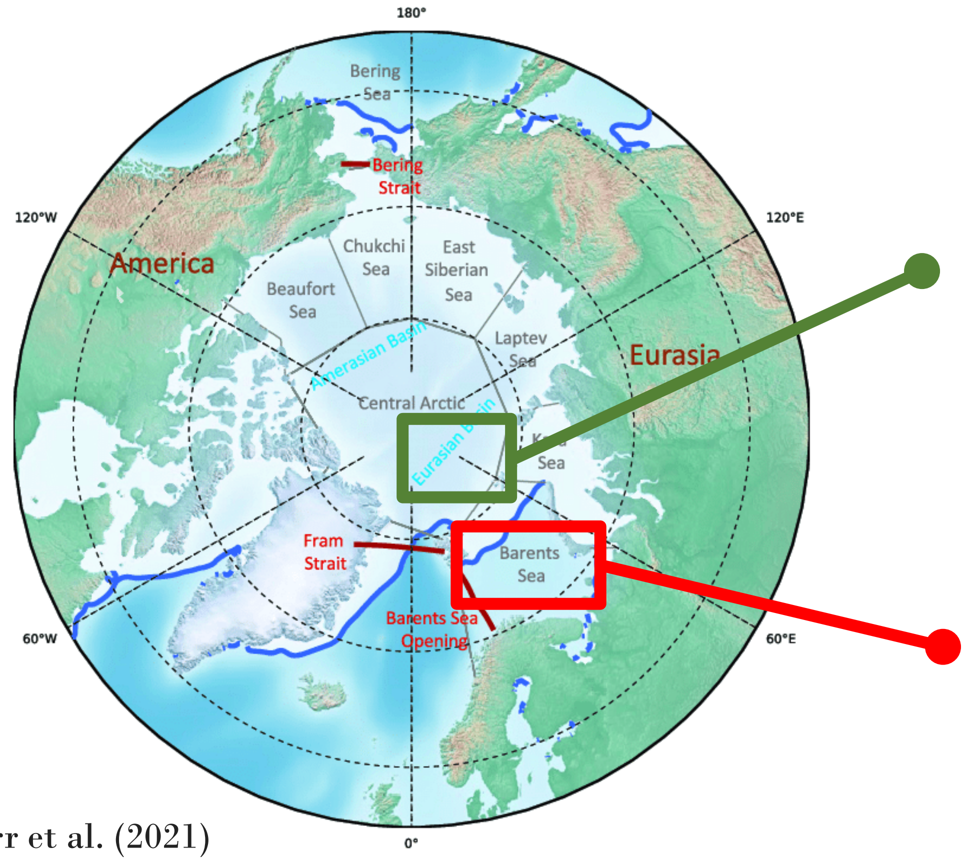
Brown et al. (2017, 2018)

! **Spatio-temporal variability** in trophic markers
(e.g., Leu et al., 2020)
→ multi-trophic marker applications

iii) Regional variability in the utilization of sympagic carbon

Year-round *vs.* seasonally ice-covered ecosystems

Food webs in the



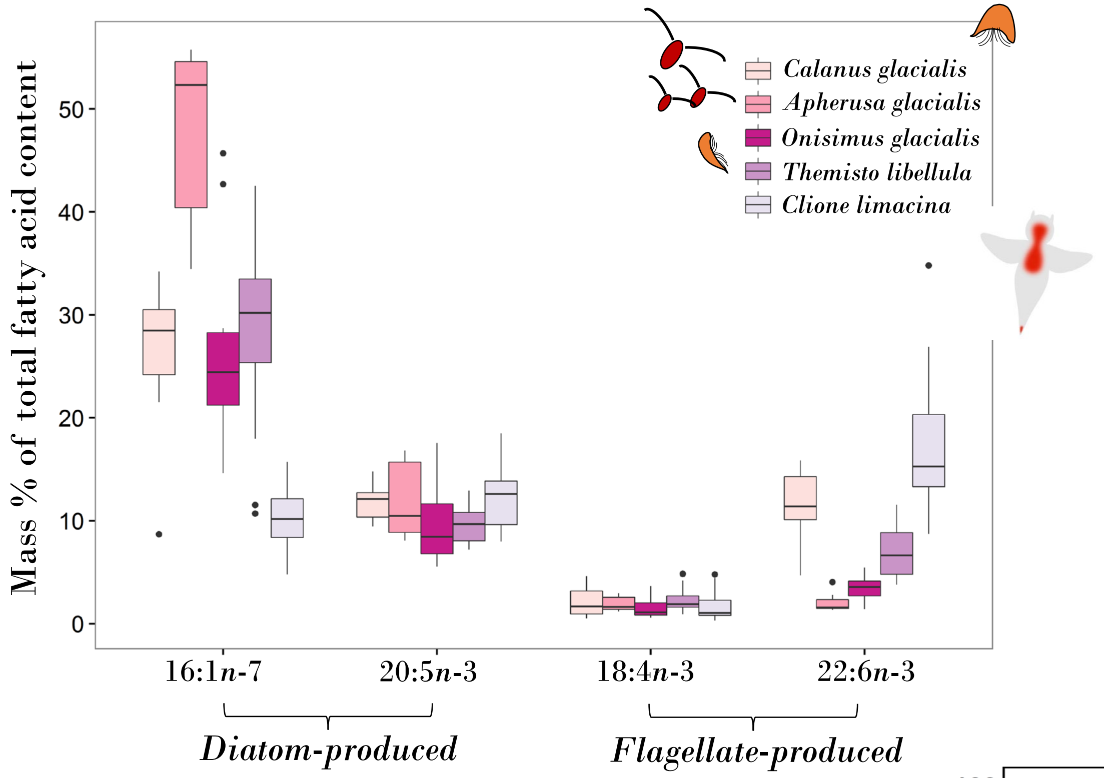
Map: Dörr et al. (2021)

Central Arctic Ocean:
perennial sea-ice cover

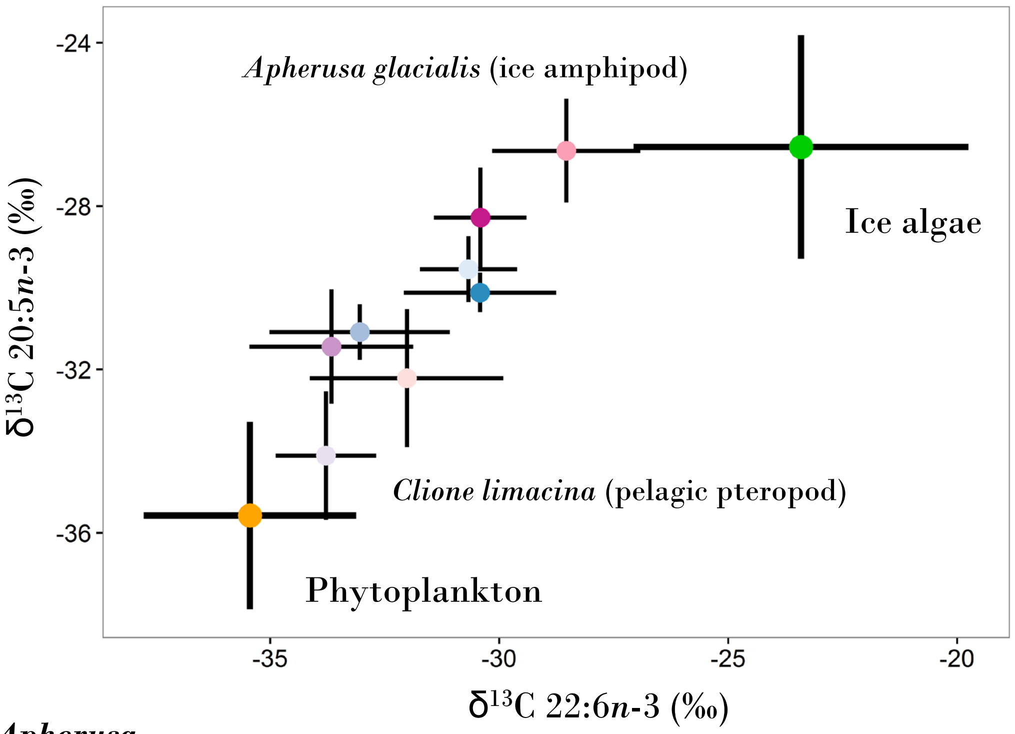
Barents Sea:
seasonal sea-ice cover

Central Arctic Ocean: perennial sea-ice cover

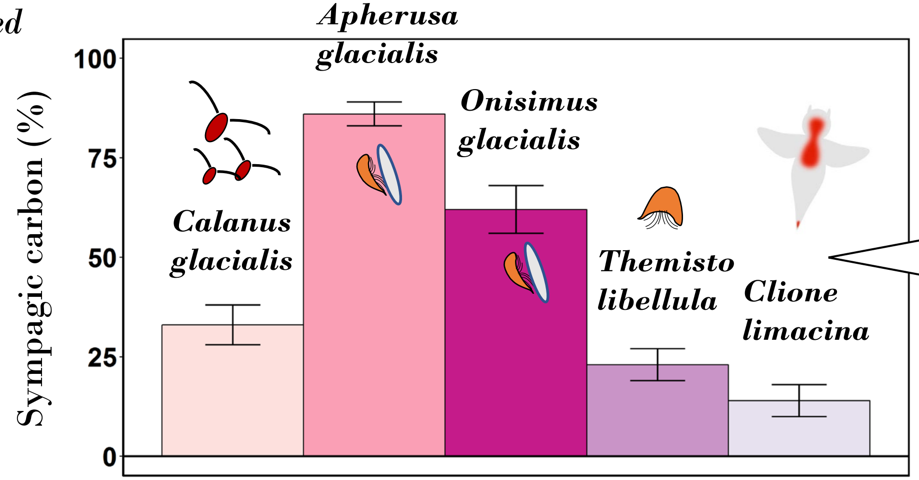
Relative proportions of marker fatty acids



δ13C of marker fatty acids



Stable isotope mixing models: Quantification of sympagic *vs.* pelagic carbon sources

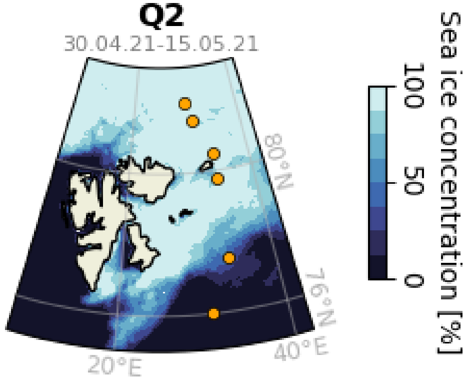


Central Arctic Ocean under-ice fauna **thrives significantly on sympagic carbon**

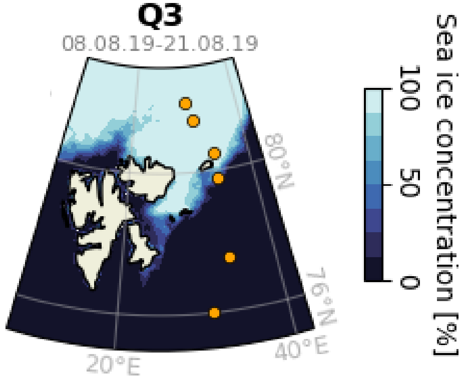
Kohlbach et al. (2016)

Barents Sea: seasonal sea-ice cover

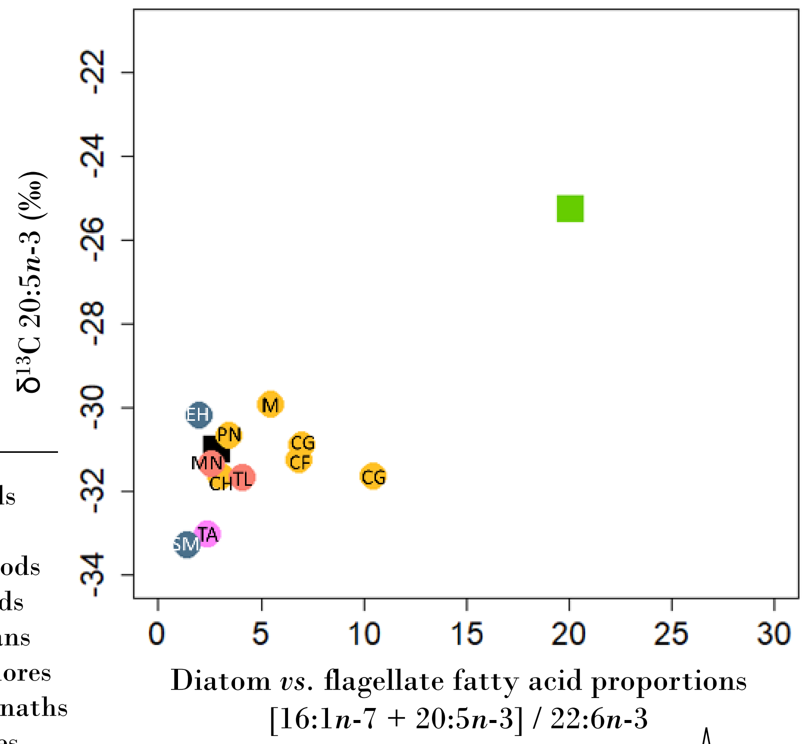
Spring



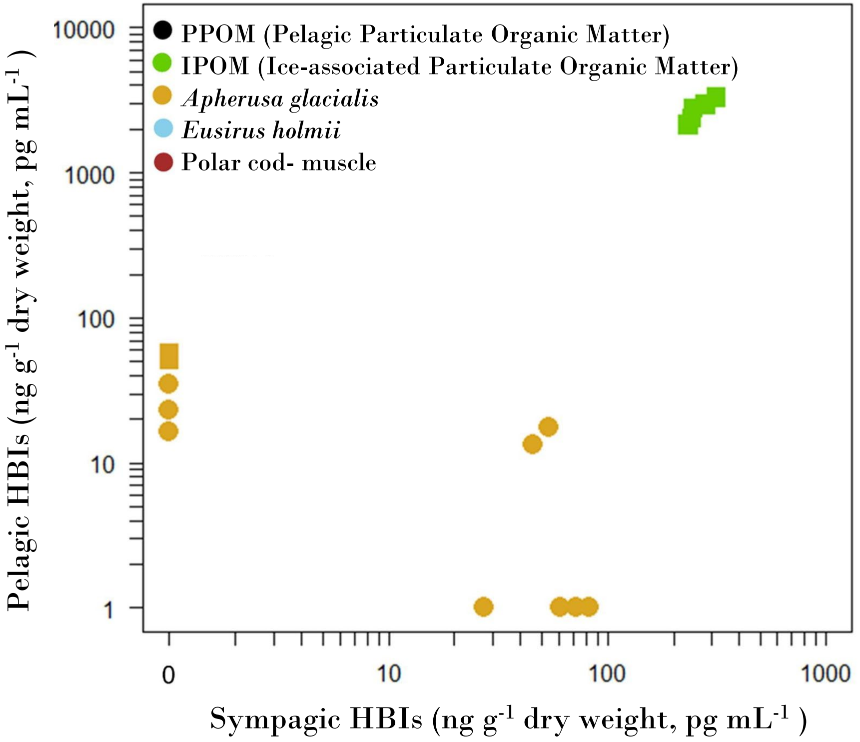
Summer



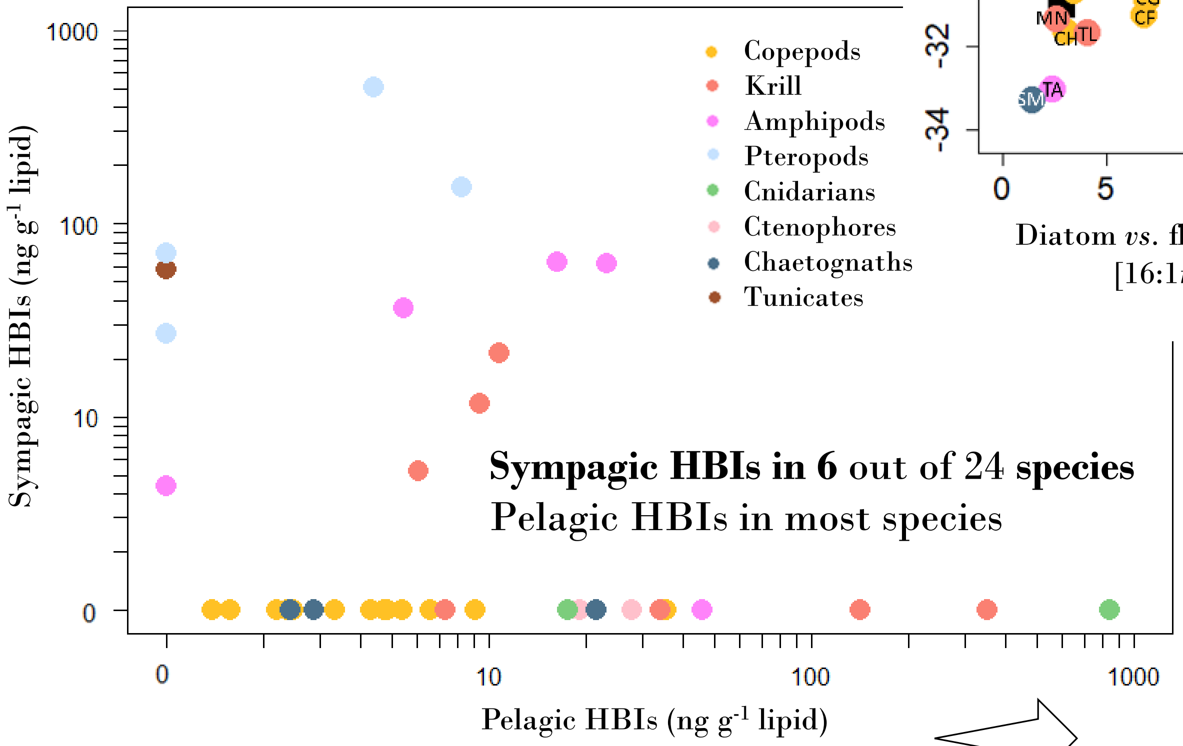
Kohlbach et al. (2021a, 2023)



Under-ice fauna



Pelagic zooplankton

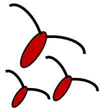
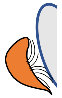
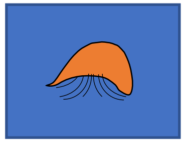


Sympagic HBIs in 6 out of 24 **species**
Pelagic HBIs in most species

Barents Sea under-ice fauna and pelagic zooplankton **thrive significantly on pelagic carbon**

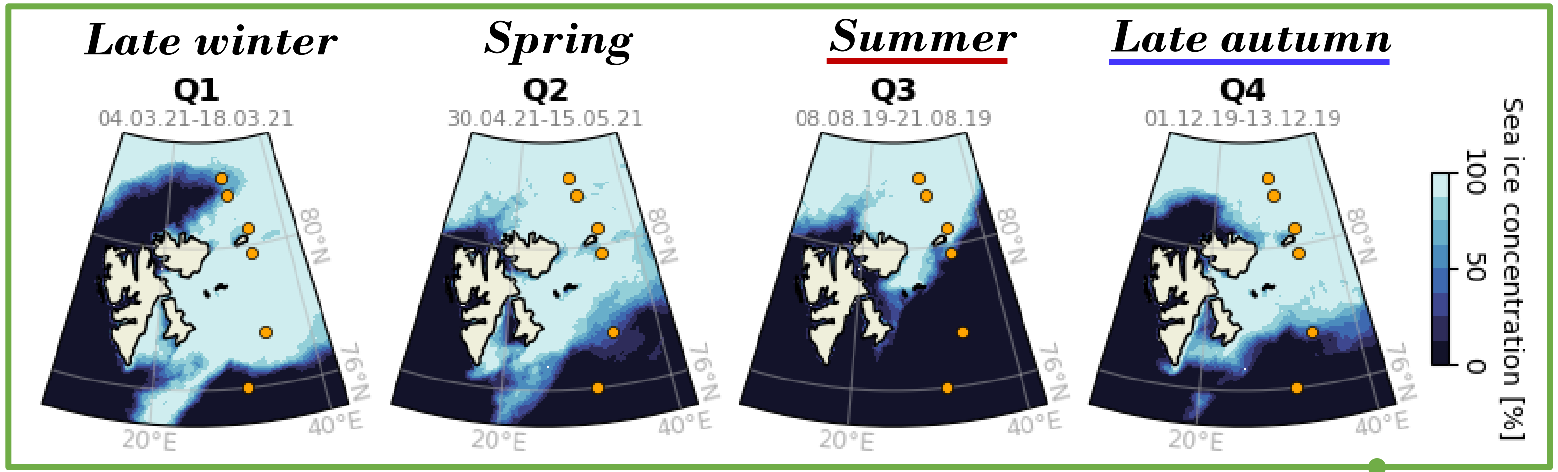
Kohlbach et al. (2022)

Sympagic carbon (%)

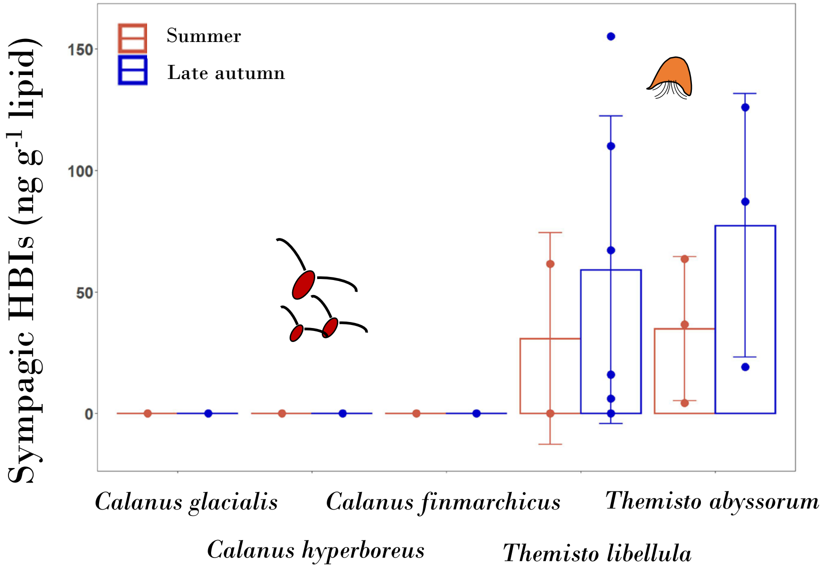
Species	Season	Central Arctic Ocean	Season	Barents Sea
 *Calanus* spp.	summer	Up to ~50%[1]	All	No sympagic HBIs detected[2]
 *Apherusa glacialis*		Up to 90%[1]	Spring	Variable concentrations of sympagic HBIs[3]
 *Themisto libellula*		Up to ~50%[1]	All	Sympagic HBIs only in summer and autumn[2]
 *Clione limacina*		Up to 30%[1]	All	Sympagic HBIs only in summer[2]
 Polar cod *Boreogadus saida*		Up to 65%[4]	spring	No sympagic HBIs detected[3]

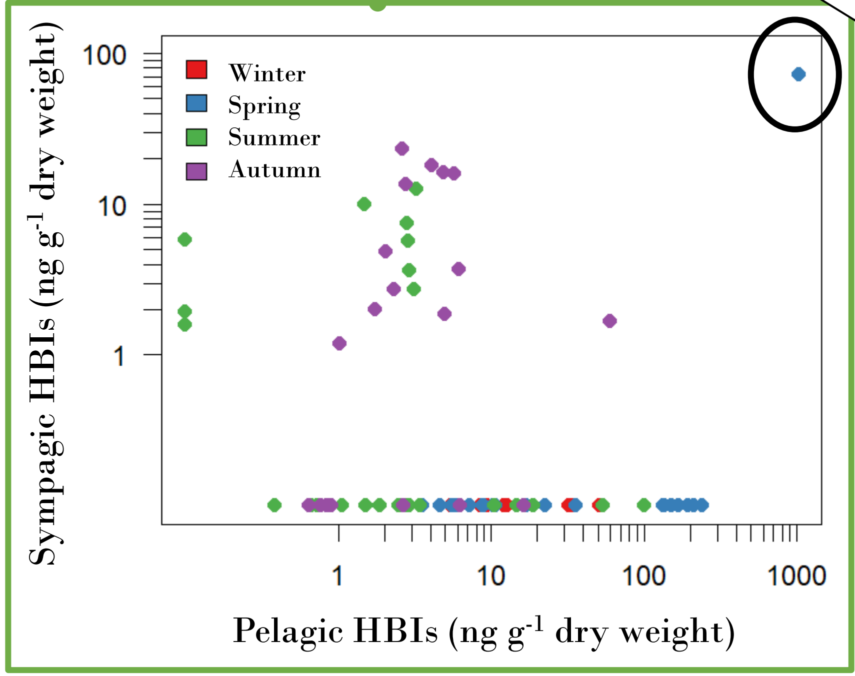
[1]Kohlbach et al. (2016): based on fatty acid stable isotopes; [2]Kohlbach et al. (2024): based on highly branched isoprenoids; [3]Kohlbach et al. (2022): based on highly branched isoprenoids; [4]Kohlbach et al. (2017): based on fatty acid stable isotopes

iv) Seasonal variability in the utilization of sympagic carbon



Krill *Meganyctiphanes norvegia* unique in its HBI composition: **only species containing HBIs in spring**





Seasonal importance of sympagic carbon: supplements diets of krill, amphipods and pteropods **mainly in summer and autumn**

Kohlbach et al. (2024)

Barents Sea zooplankton: Increased carnivory during polar night, **sympagic carbon likely not crucial** dietary component

Kohlbach et al. (2021b)

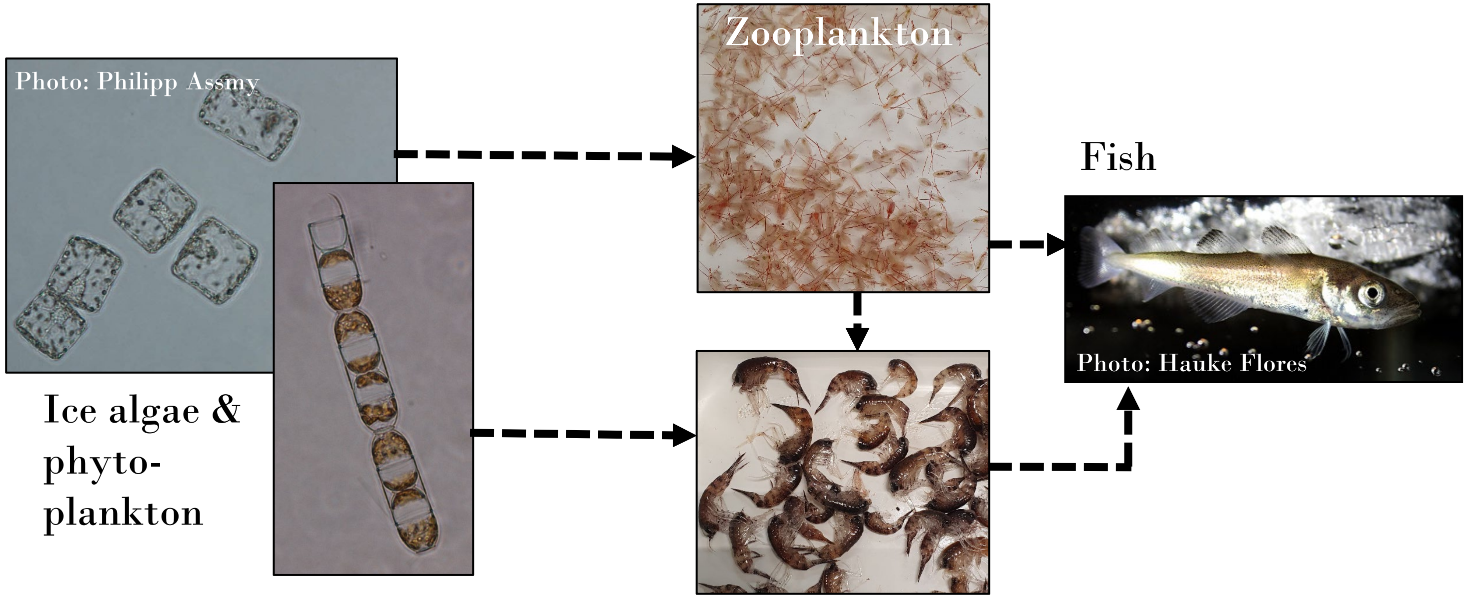
Helmholtz Young Investigator Group 2024-2029

University of Bremen

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

DOUBLE-TROUBLE

Resilience and vulnerability of the Central Arctic Ocean food web to cumulative stress by warming and anthropogenic pollution



i) *Status quo* Central Arctic Ocean **food-web structure and functioning**

ii) *Status quo* **anthropogenic pollution** in Central Arctic Ocean food web (legacy pollutants and contaminants of emerging Arctic concern)

iii) Modelling trophic transfer of carbon and pollutants **under current and future environmental conditions**

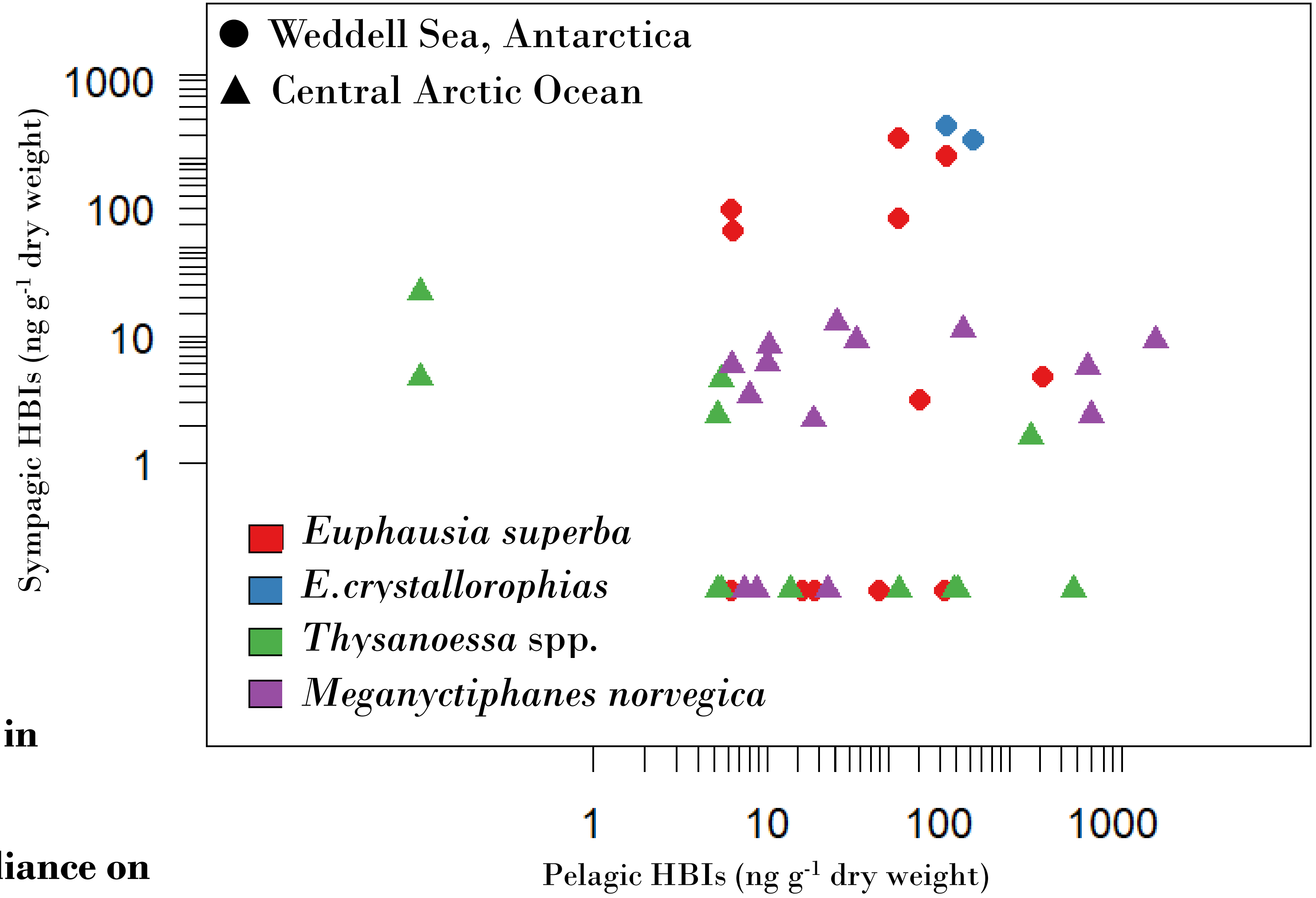
v) New study: Trophic interactions and reliance of polar krill species on sympagic carbon

- Fatty acid profiles
- δ^{13}C of fatty acids
- δ^{13}C of amino acids
- Sterols
- **HBIs**

Antarctic krill species: *Euphausia superba*, *E. crystallorophias*

Arctic krill species: *Thysanoessa* spp., *Meganyctiphanes norvegica*

First results



❖ Generally **higher sympagic HBI concentrations in Antarctic *vs.* Arctic** krill species

❖ Arctic ***M. norvegica*** with seemingly **higher reliance on sympagic carbon than *Thysanoessa* spp.**, congruent with results from Barents Sea

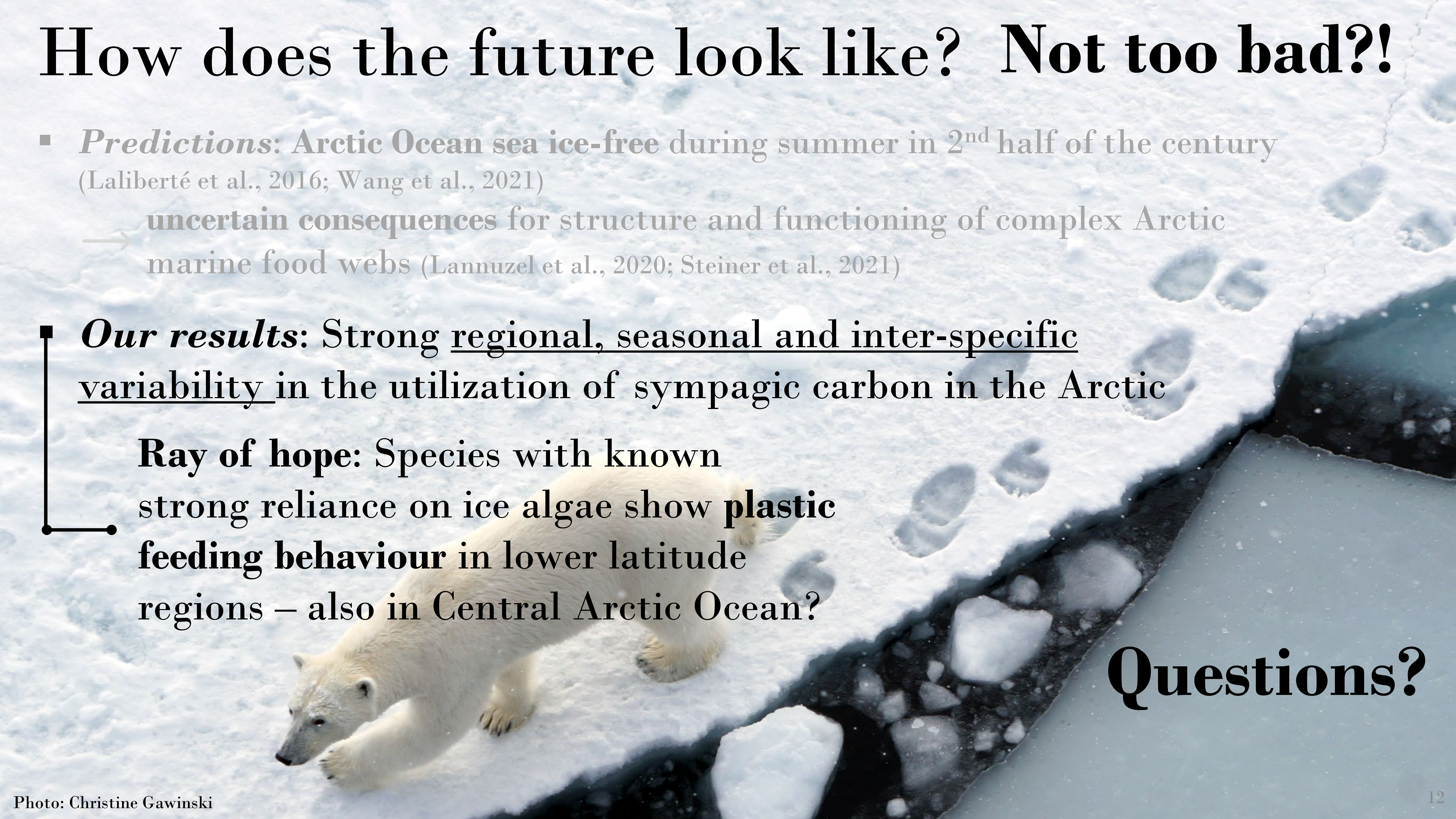
Credit to Anja Müller & Juliane Müller, AWI Marine Geology

How does the future look like?

- ***Predictions*: Arctic Ocean sea ice-free** during summer in 2nd half of the century (Laliberté et al., 2016; Wang et al., 2021)

  → **uncertain consequences** for structure and functioning of complex Arctic marine food webs (Lannuzel et al., 2020; Steiner et al., 2021)

Photo: Christine Gawinski



How does the future look like? **Not too bad?!**

- *Predictions*: **Arctic Ocean sea ice-free** during summer in 2nd half of the century (Laliberté et al., 2016; Wang et al., 2021)

  → **uncertain consequences** for structure and functioning of complex Arctic marine food webs (Lannuzel et al., 2020; Steiner et al., 2021)

- ***Our results***: Strong regional, seasonal and inter-specific variability in the utilization of sympagic carbon in the Arctic

  Ray of hope: Species with known strong reliance on ice algae show **plastic feeding behaviour** in lower latitude regions – also in Central Arctic Ocean?

Questions?

Photo: Christine Gawinski

Acknowledgements

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Steven H. Ferguson, Bruno Rosenberg, David Yurkowski, Cody Carlyle, Christine Michel

Jean-Pierre Desforges

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