New dawn fades: returning to dark data amid a zooplankton technology revolution

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With thanks to:

Katrin Schmidt, Evgeny Pakhomov, Volker Siegel, Simeon Hill, Emma Cavan, Guang Yang, Stefano Corona, Christian Reiss, Saskia Rühl, Geraint Tarling, Matthew Holland, Abigail McQuatters-Gollop, Mike Best, and UK Pelagic Habitats Expert Group, Andrea McEvoy, Claire Widdicombe, Elaine Fileman, Glen Tarran, Malcolm Woodward, Deborah Steinberg, Amanda Beesley, Gregory Beaugrand, Martin Edwards, Frances Perry, Glynn Gorick, Anna Belcher, Kevin Flynn, Carolyn Harris, Bettina Meyer, Ryan Heneghan, Martin Lilley, Andrew Hirst, Gary Sprules, Axel Rossberg, Ursula Gaedke

AWR | ANTARCTIC WILDLIFE RESEARCH FUND

WWF SUPPORTING INFORMED CONSERVATION OF ANTARCTIC WILDLIFE

Western Channel Observatory

FOCUS

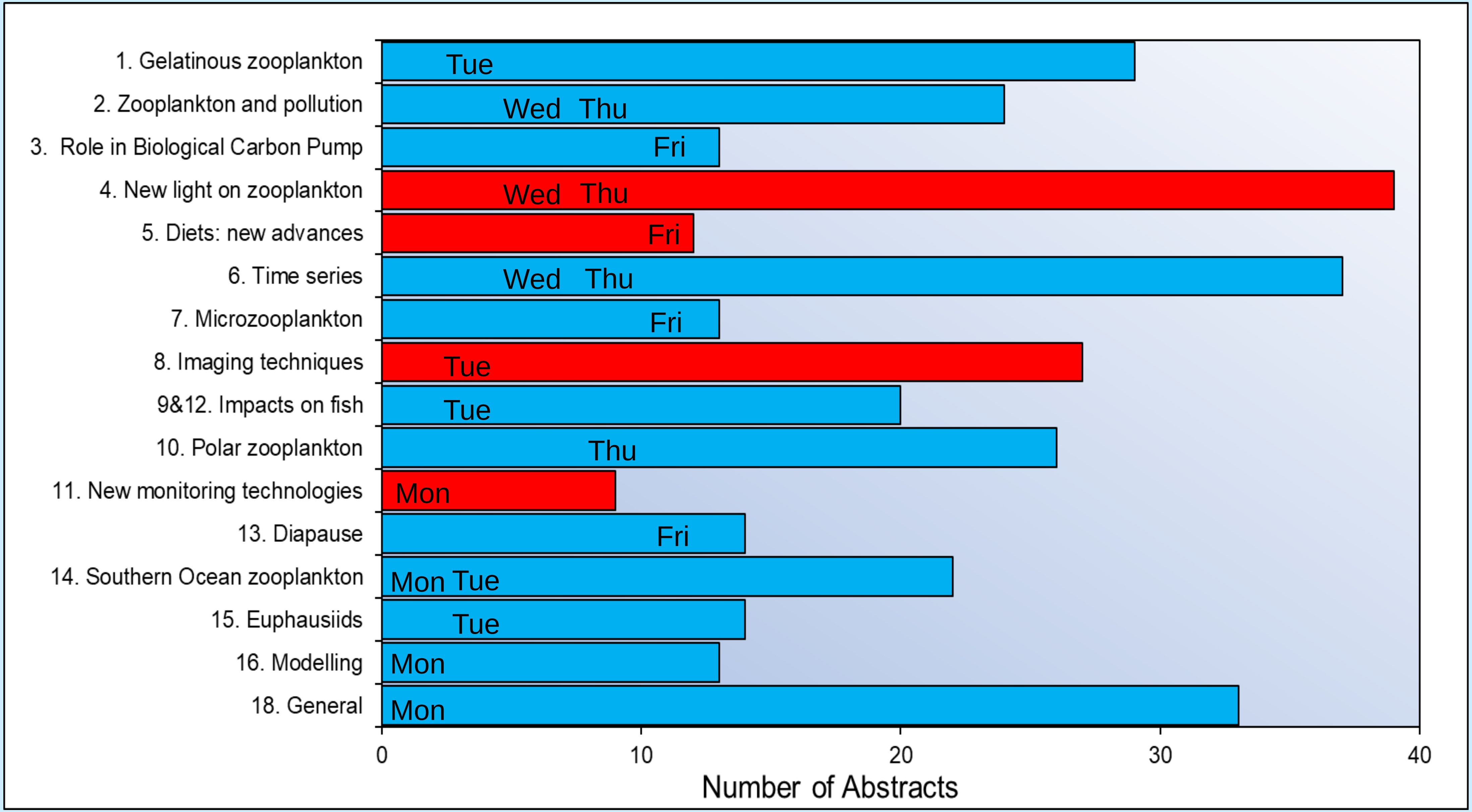
CLASS CLIMATE LINKED ATLANTIC SECTOR SCIENCE

NCEA Natural Capital and Ecosystem Assessment

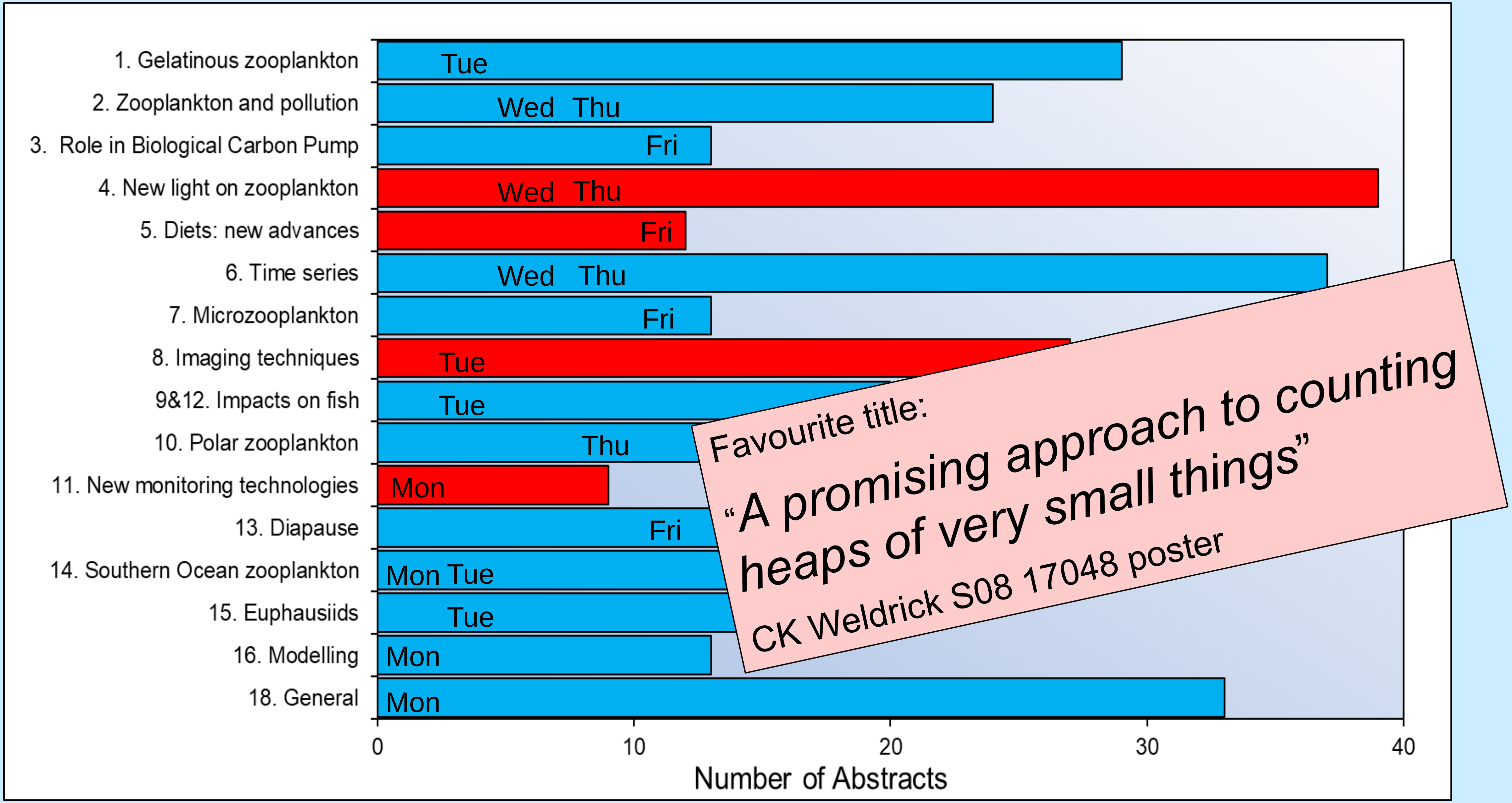
KRILL BASE

Image: Glynn Gorick

Zooplankton technology revolution



Zooplankton technology revolution



New dawn fades: returning to dark data amid a zooplankton technology revolution

- Traditional and developing methods: uses and limitations

Lombard et al. (2019) *FMS*
Giering et al. (2022) *FMS*
Ratnarajah et al. (2023) *Nat Comms*
Hill et al (2024) *FMS*

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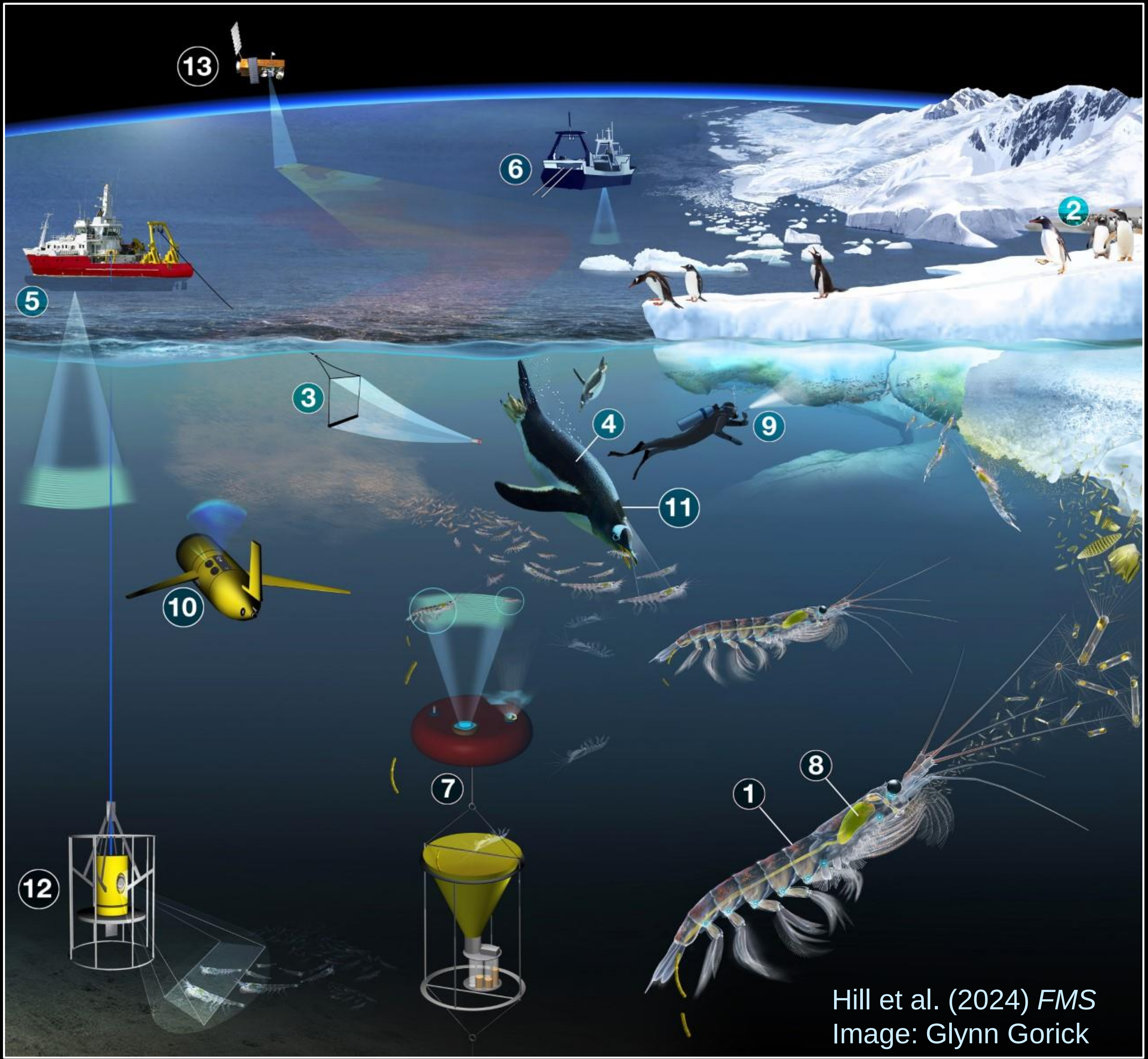

13
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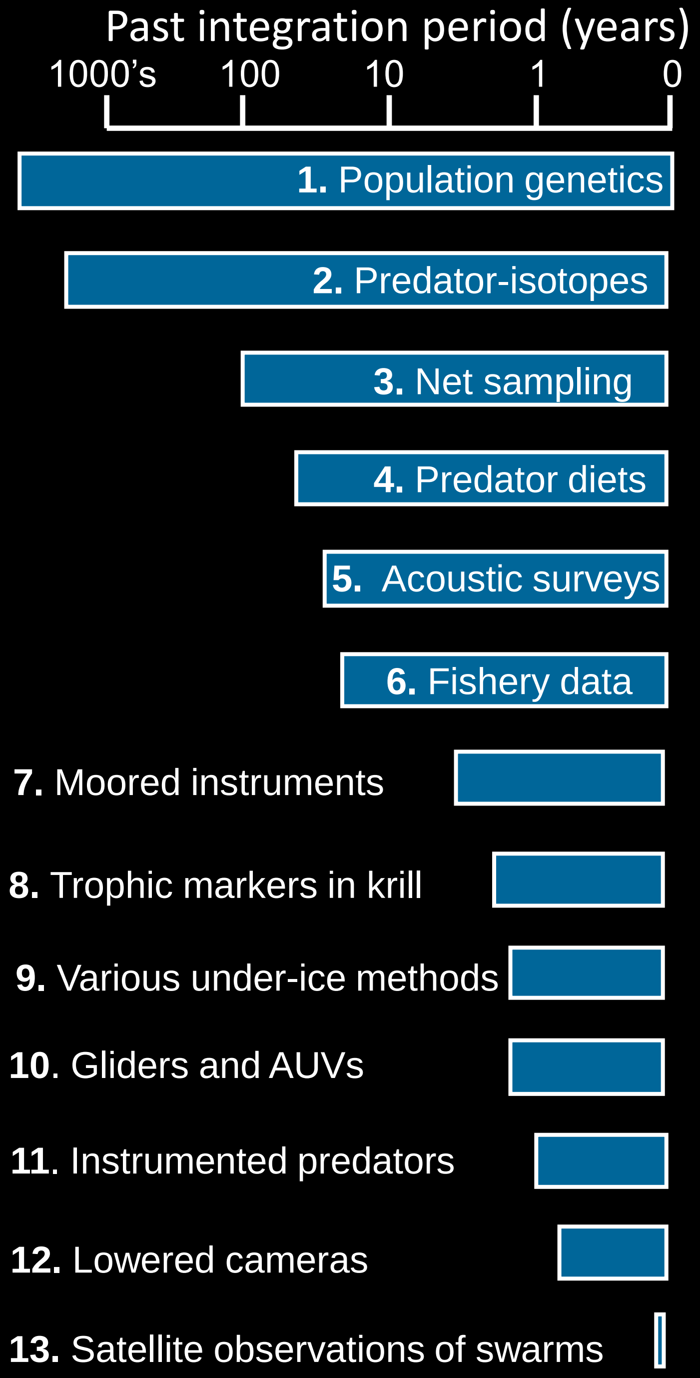
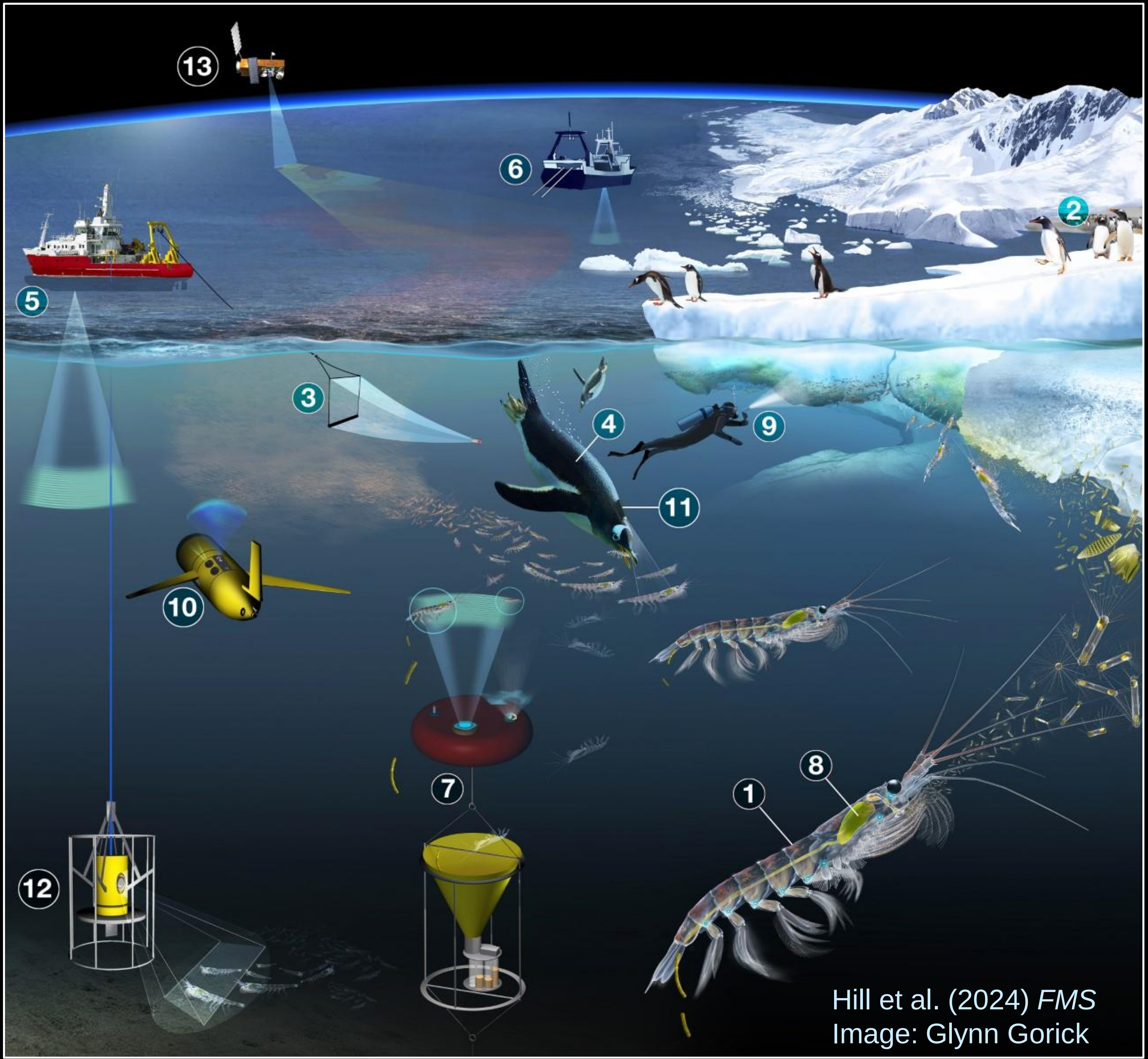
Hill et al. (2024) FMS
Image: Glynn Gorick



Past integration period (years)
1000's
100
10
1
0
1. Population genetics
2. Predator-isotopes
3. Net sampling
4. Predator diets
5. Acoustic surveys
6. Fishery data
7. Moored instruments
8. Trophic markers in krill
9. Various under-ice methods
10. Gliders and AUVs
11. Instrumented predators
12. Lowered cameras
13. Satellite observations of swarms



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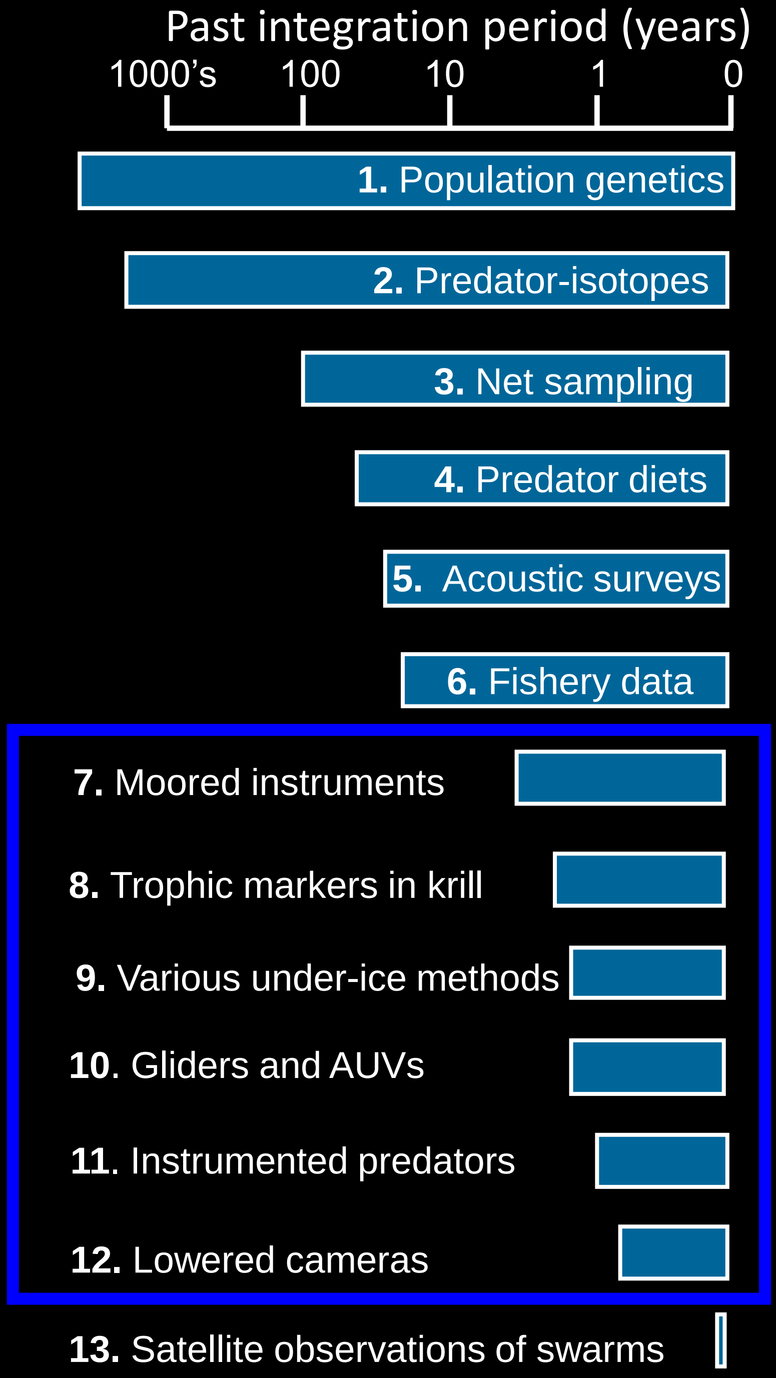

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Method	Large scale ⟷ Small scale					
	Long-term stock trajectory	Large-scale Distribution	Recruitment trends	Changing availability to Predators	Food web structure & function	Behaviour, Swarming, migration
Net-sampling	45	59	62	40	40	47
Research vessel acoustics	50	65	22	53	29	61
Predator diets/foraging indices	26	32	42	55	53	24
Fisheries data: pop structure	24	18	48	23	18	16
Moorings, in situ instruments	24	19	22	30	27	47
Instrumented predators	7	34	15	59	46	47
Under ice observations	7	16	27	31	46	58
Gliders, AUVs	20	54	13	38	26	56
Lowered cameras	0	4	9	21	27	59

Less useful ⟷ Very useful

< 20	20-29	30-39	40-49	50-59	60-66

SCAR Krill Expert Group (SKEG) Annual Workshop 2021: linking science to krill fishery management

https://scar.org/science/life/skeg

Hill et al. (2024) *FMS*

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Established methods: larger scale coverage

New technology: smaller scale dynamics

Hill et al. (2024) *FMS*

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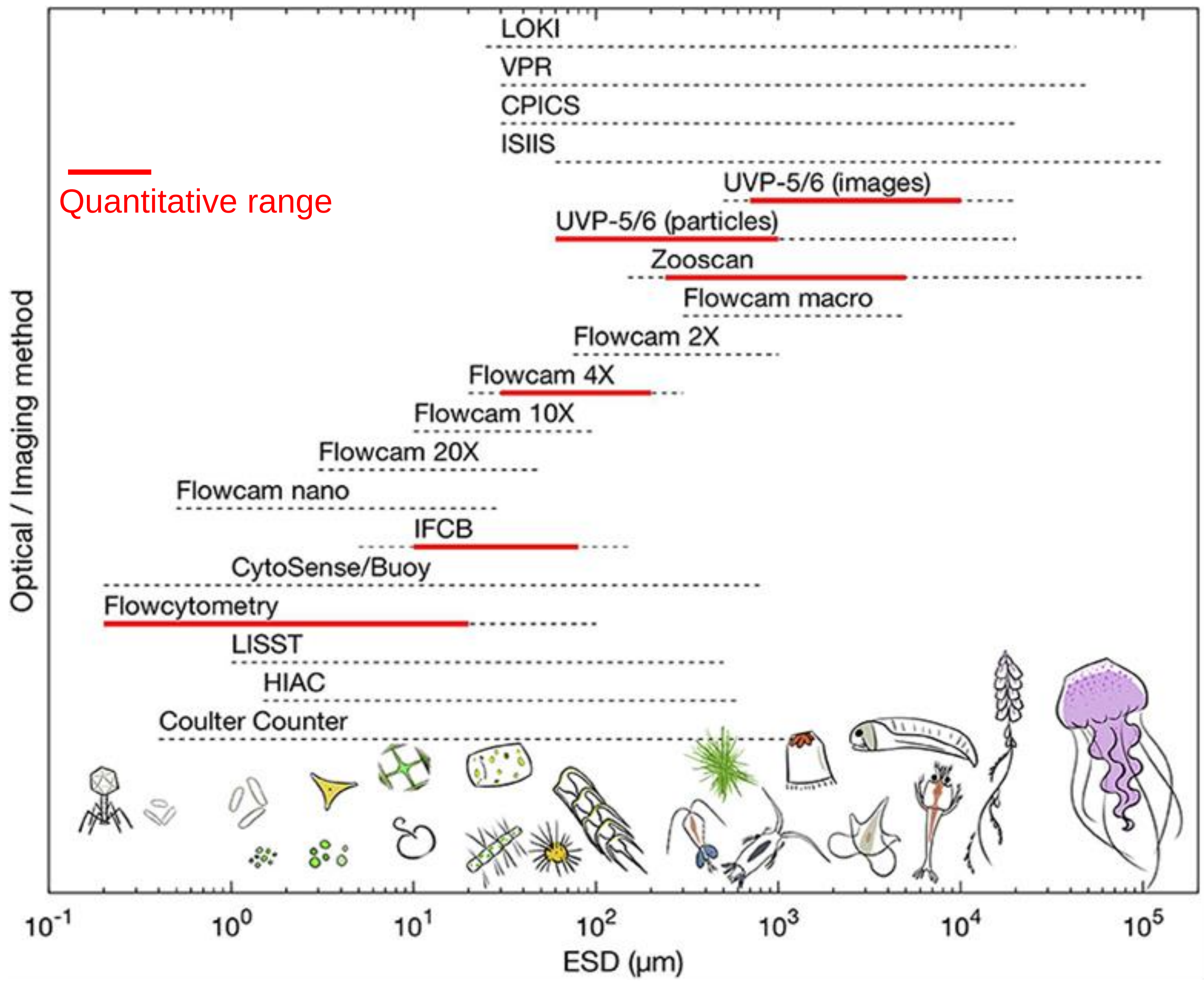
Imaging technology is great for size-based approaches



Lombard et al. (2019) *FMS*

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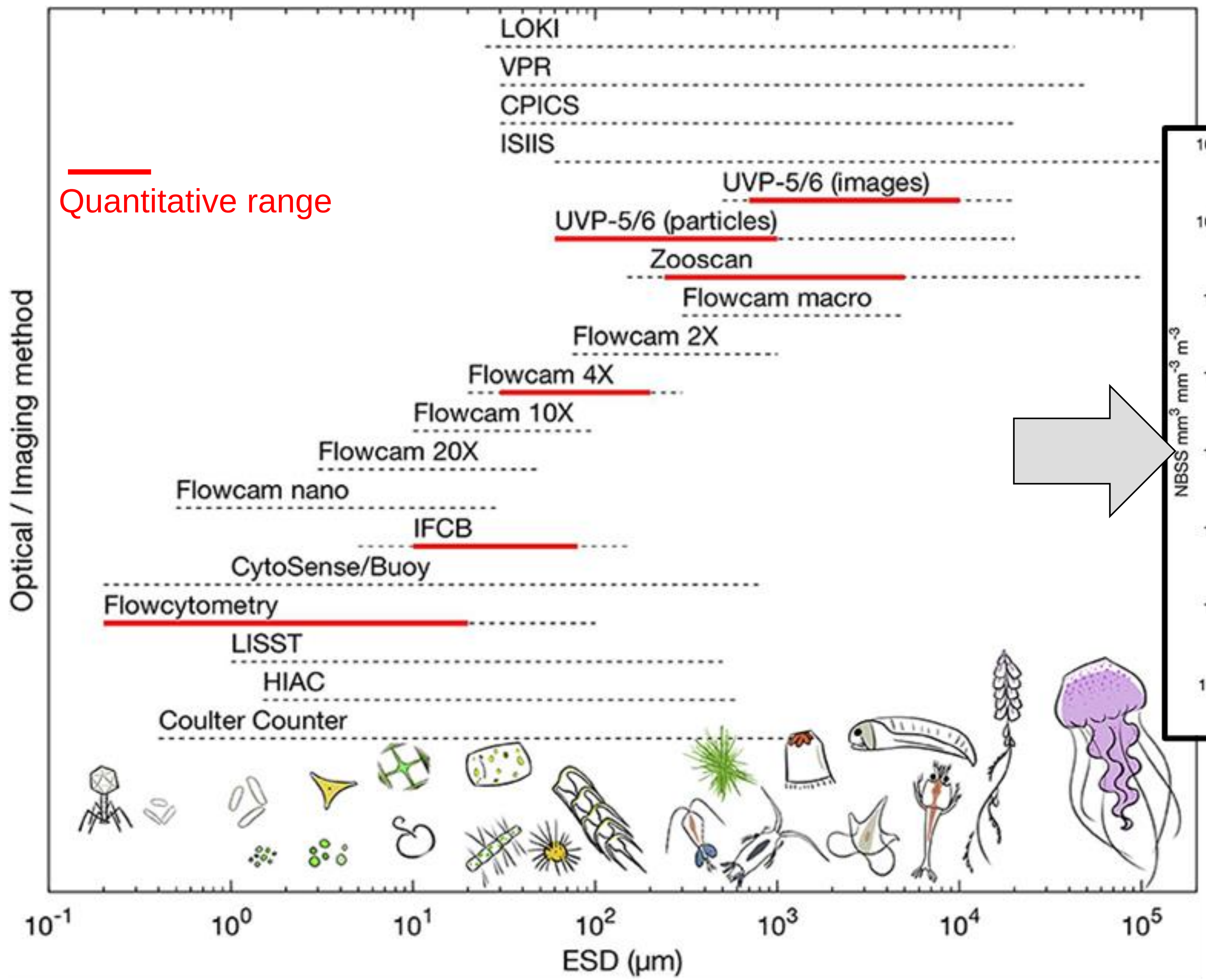
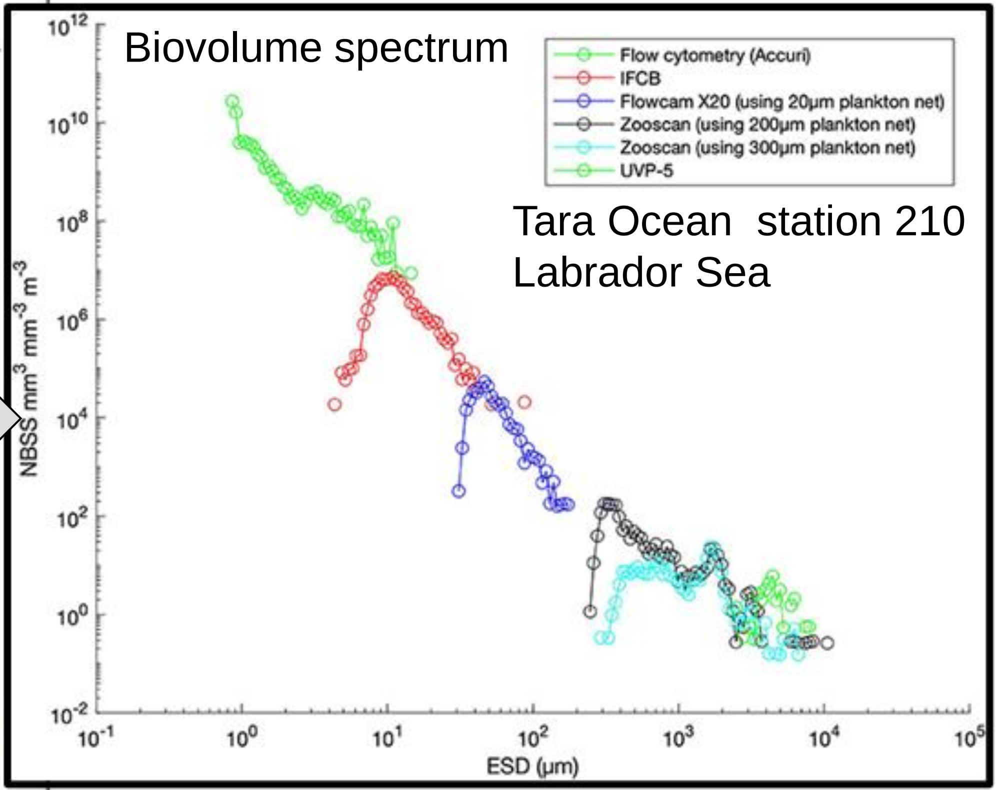
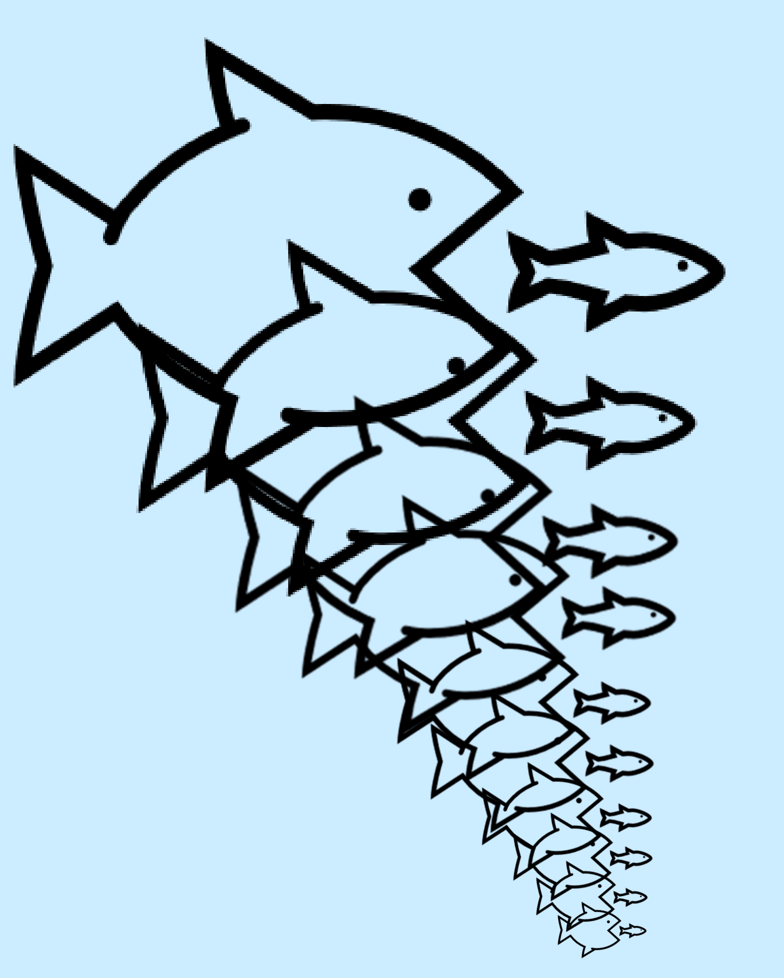




Lombard et al. (2019) *FMS*

Body size as a "master trait"

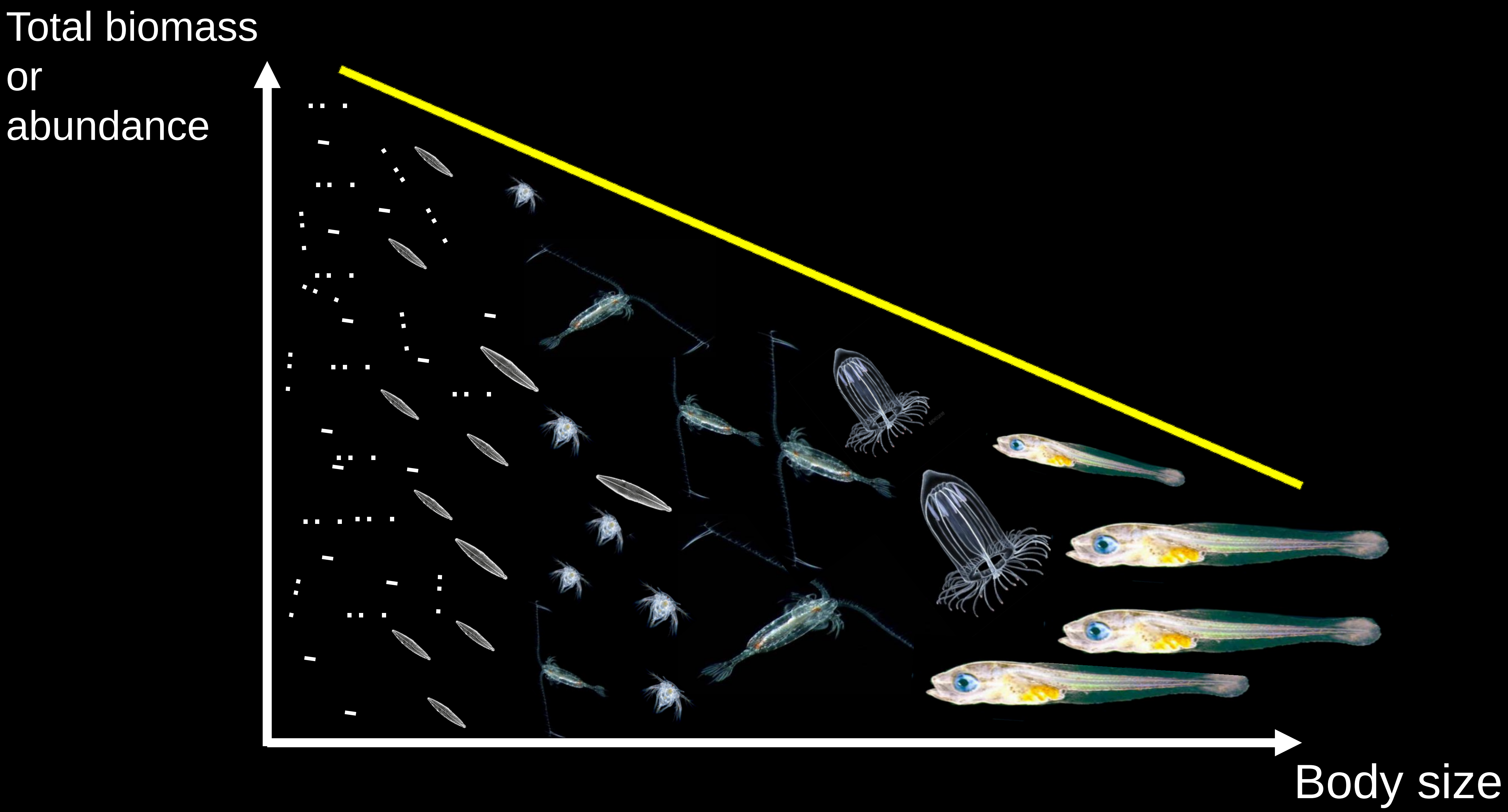
Body size helps to dictate rates of:



- Metabolism, feeding, growth
- Predator-prey mass ratio
- Movement, migration, aggregation ability
- Mortality, population increase

- Sinking, export efficiency
- etc etc

What do biomass spectra tell us about energy flow?



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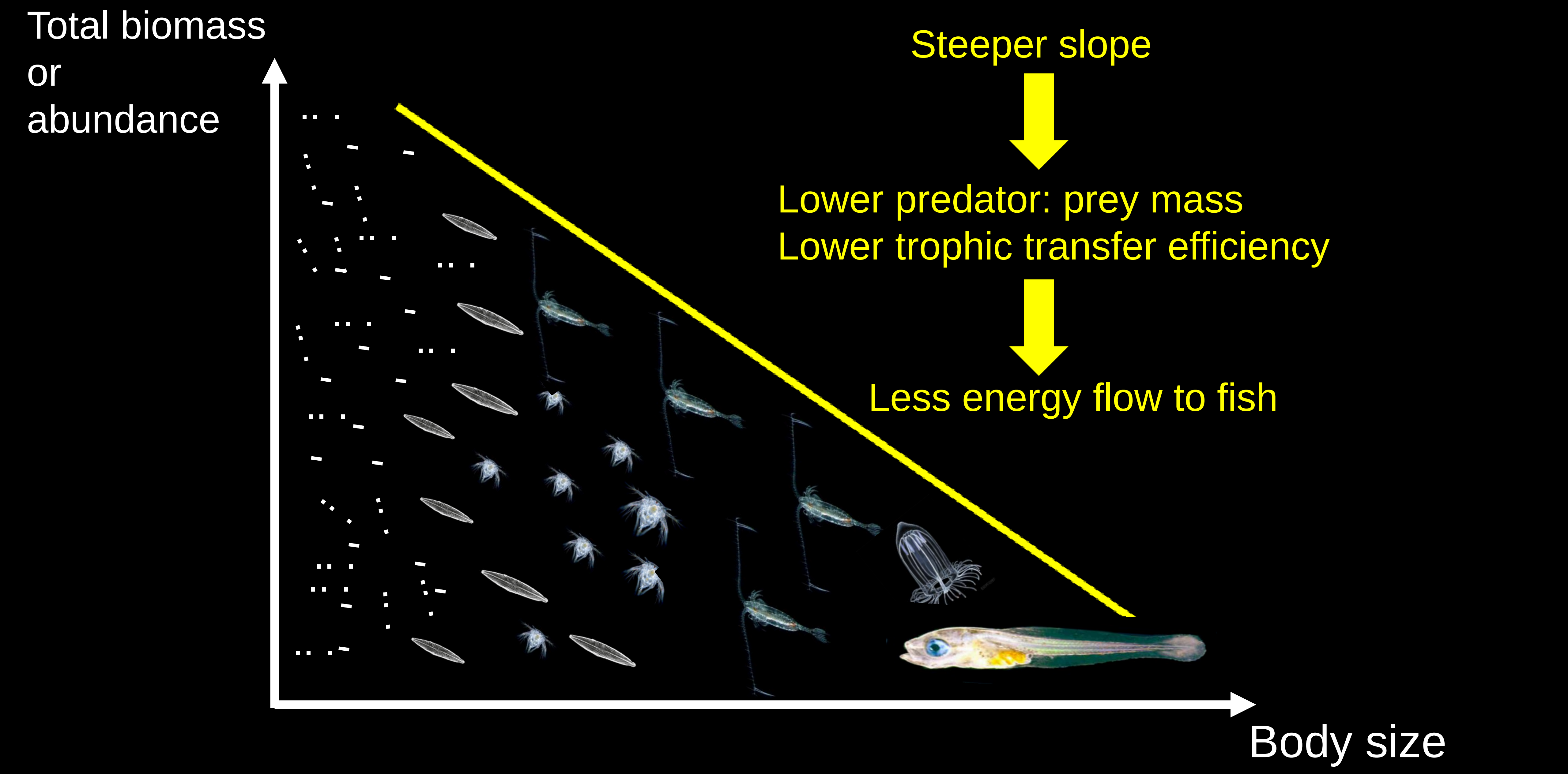


Slope of Normalised Biomass Size Spectra (NBSS)

Slope of NBSS

Trophic Transfer Efficiency

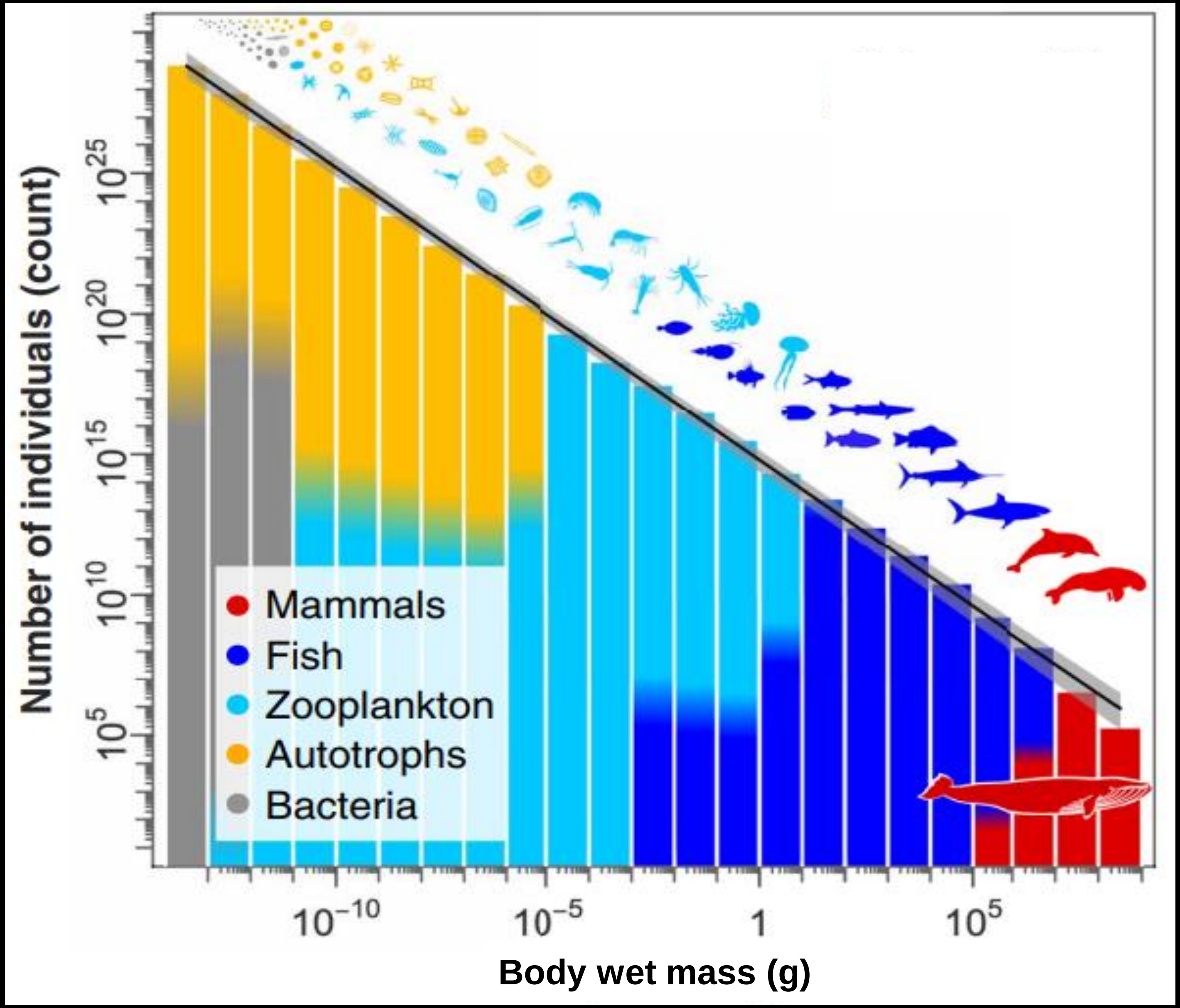
~Body mass scaling coefficient of metabolism

$$S = \frac{\mathrm{Log}_{10}\,(TTE)}{\mathrm{Log}_{10}\,(PPMR)} - 0.75$$

Predator-Prey Mass Ratio

From: Mehner et al. (2018) *Ecology*
Eddy et al. (2021) *TREE*

Remarkable regularity of pelagic size spectra



Global total numbers of organisms (in top 200 m) in equal logarithmic mass bins

Hatton et al. (2021) *Sci Adv*

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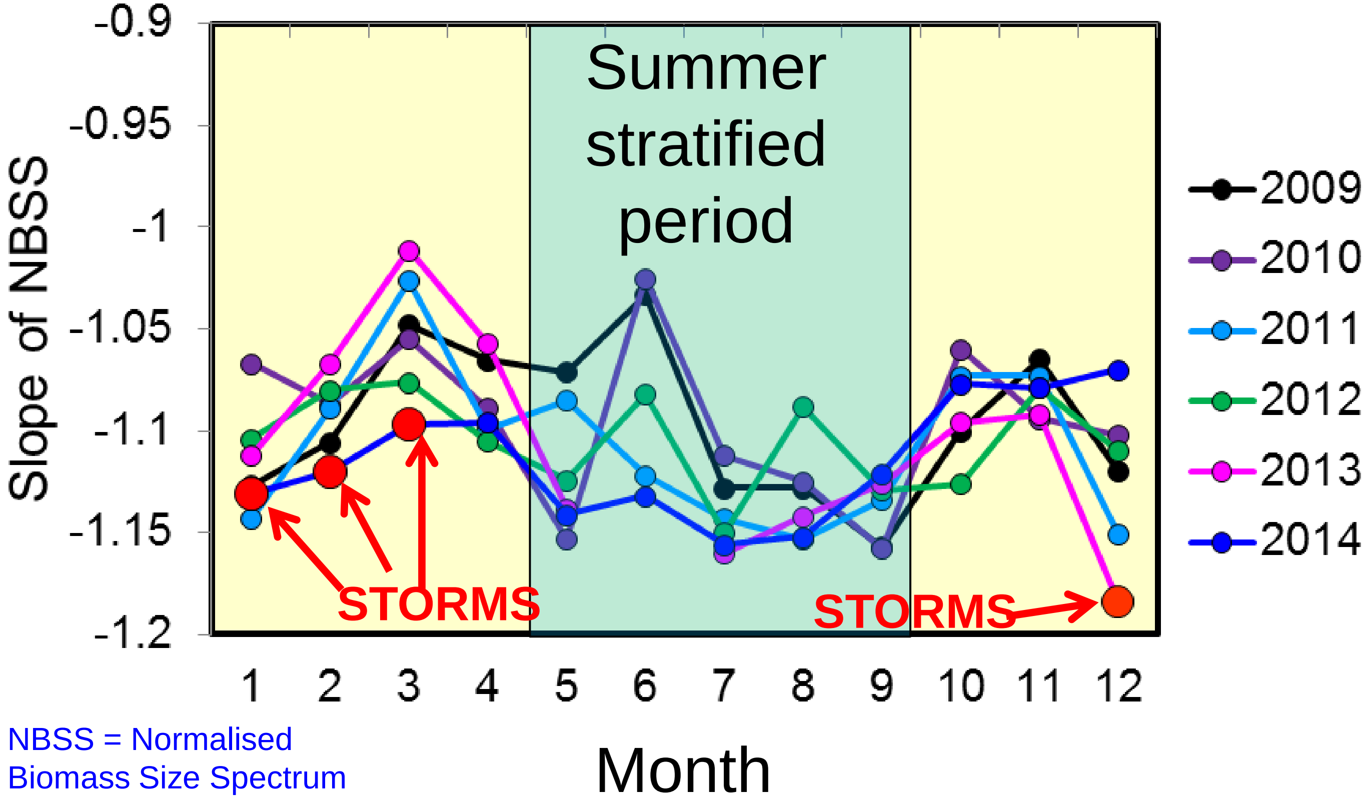
Applications of size spectra: 1. response to climatic extremes

Extreme weather is projected to increase in future

Applications of size spectra: 1. response to climatic extremes

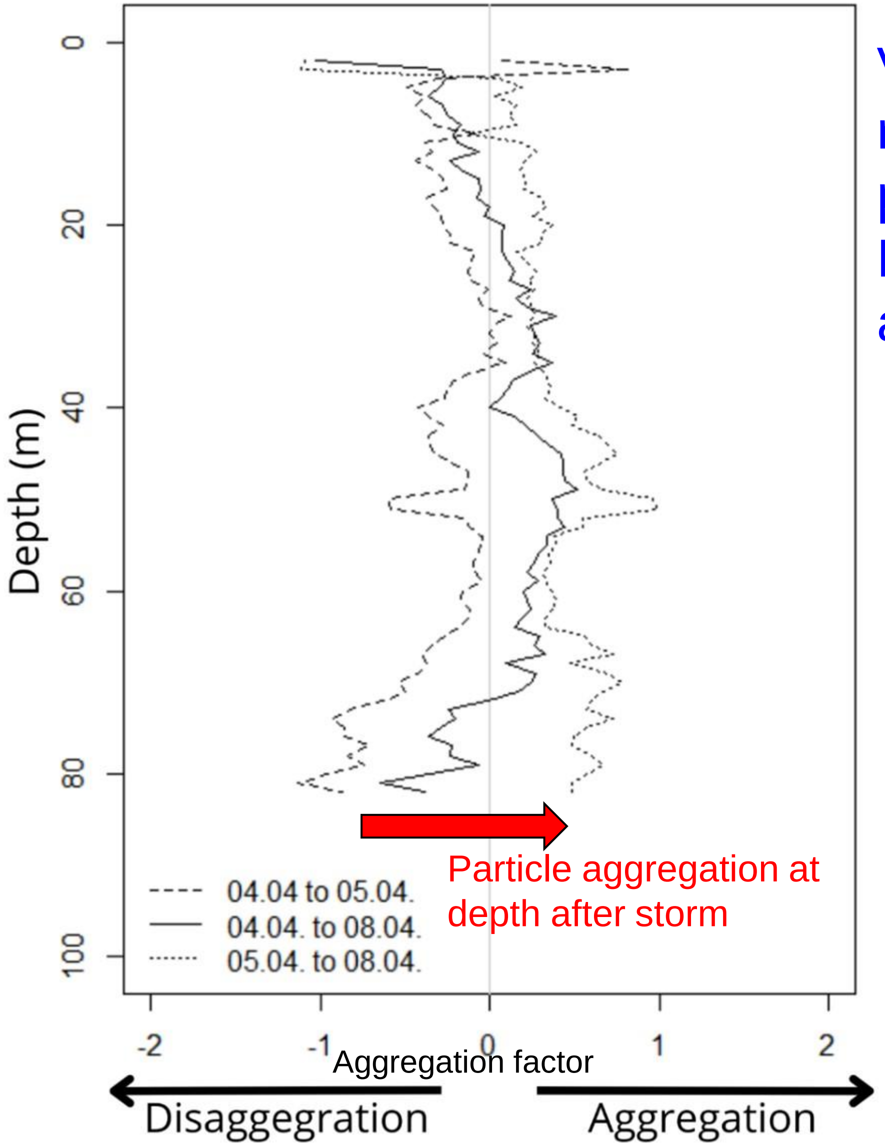
This example is based on weekly monitoring of our Plymouth L4 time series and traditional microscopic identification



NBSS = Normalised Biomass Size Spectrum

Maud et al. (2018) *Limnol Oceanogr*
Atkinson et al. (2021) *Limnol. Oceanogr*.

Applications of size spectra: 1. response to climatic extremes



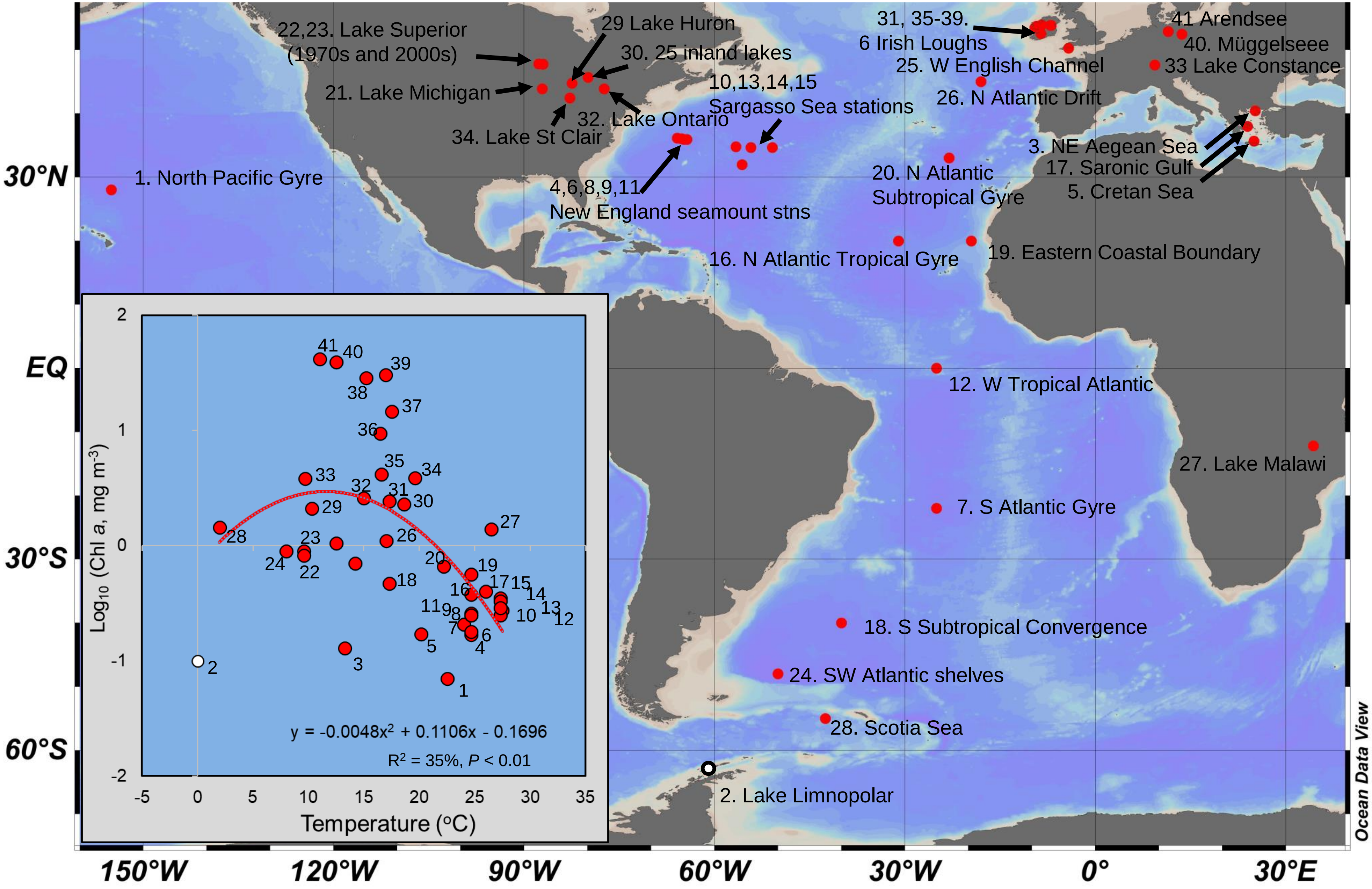
Video plankton recorder tow-yo profiles in Bornholm Basin, Baltic Sea just after a storm

Rühl et al. (in review) Queries? please contact Saskia : sru@pml.ac.uk

Applications of size spectra: 2. What drives pelagic food web efficiency?

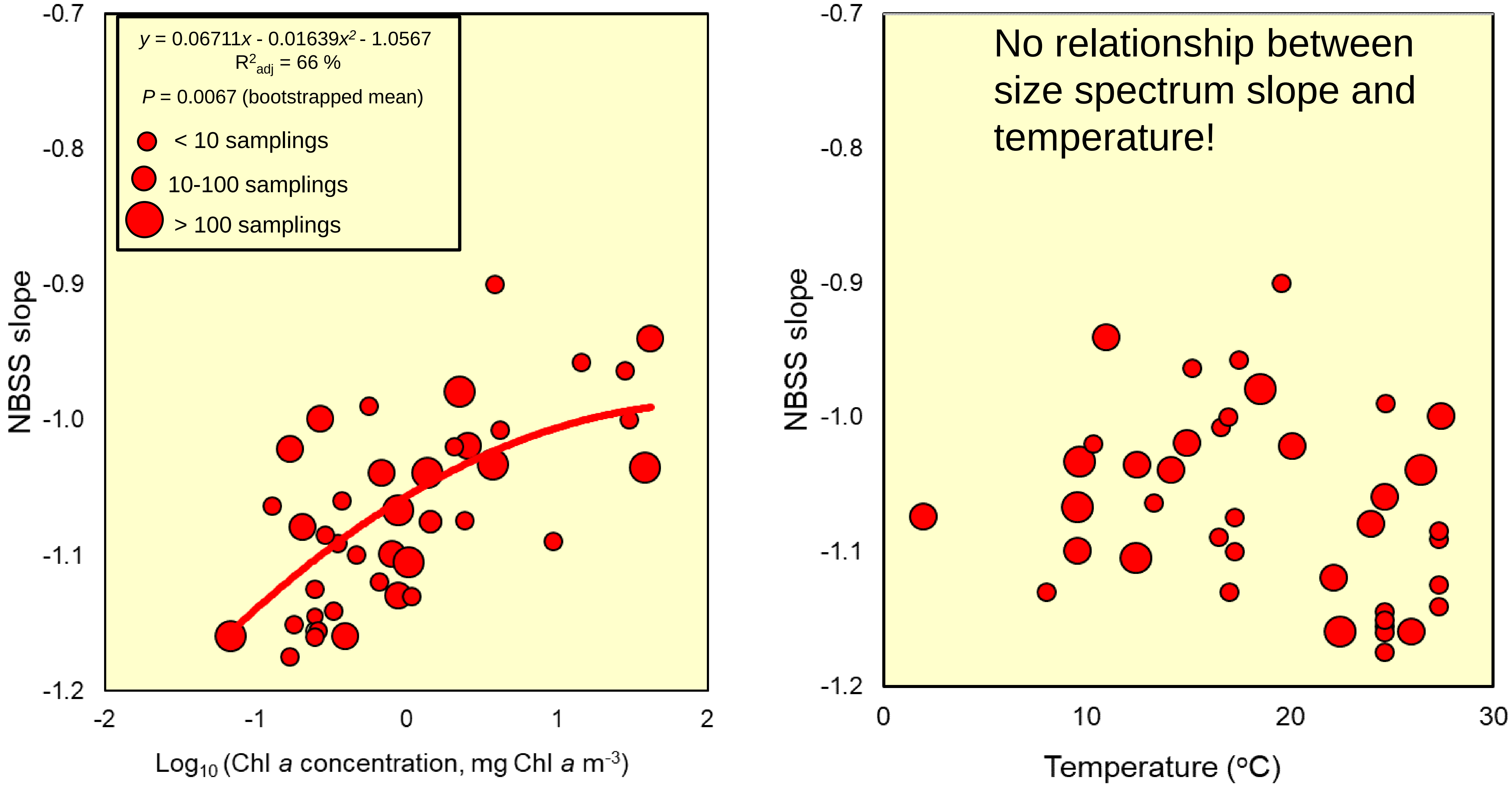
Global meta-analysis of high-quality size spectra

Helps understand how temperature and nutrient status jointly control size spectra



Atkinson et al. (2024) *Nature Comms*

At the largest scale, nutrient supply drives size spectrum slopes



Atkinson et al. (2024) *Nature Comms*

Less efficient energy transfer as chl *a* declines

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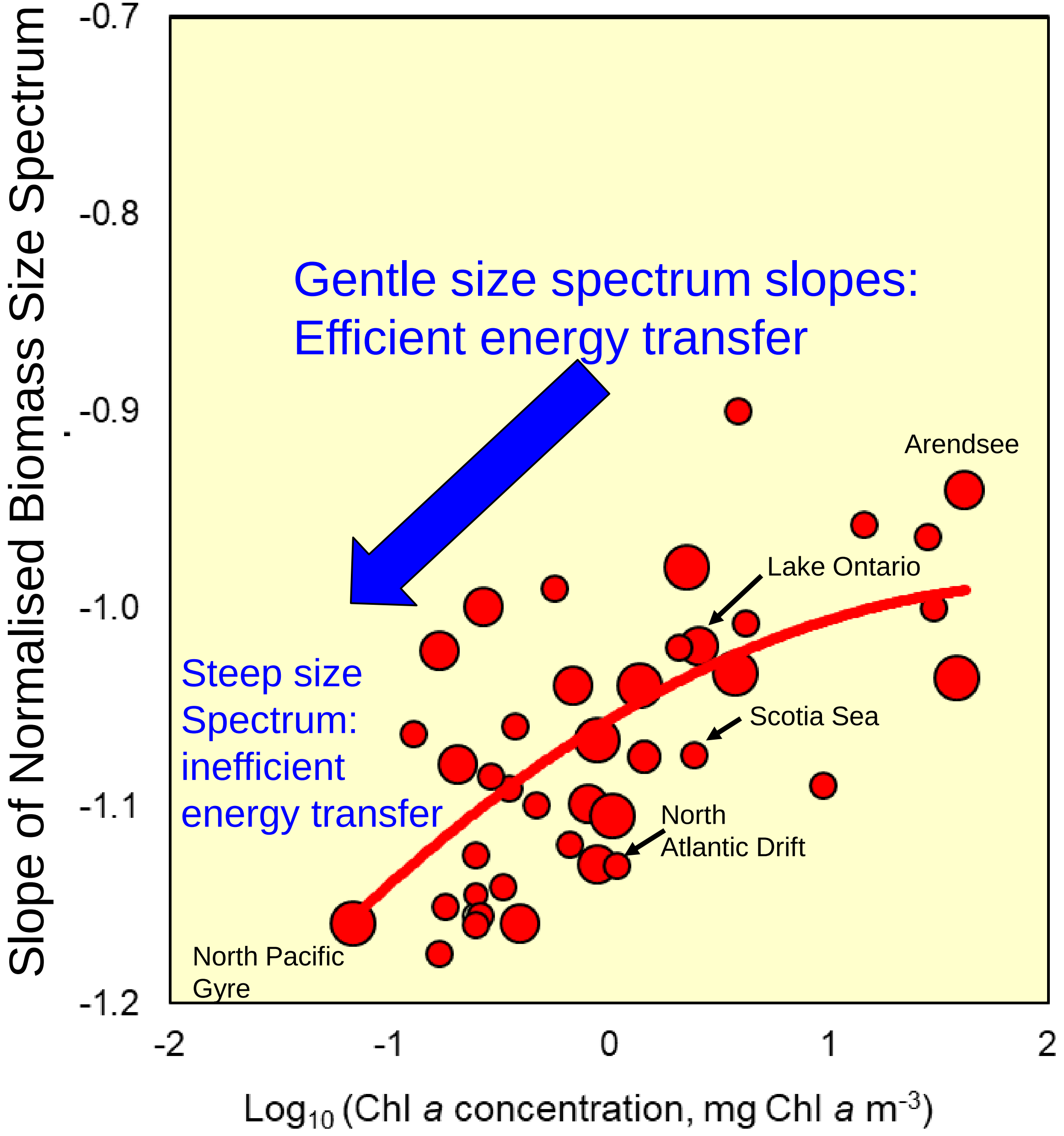


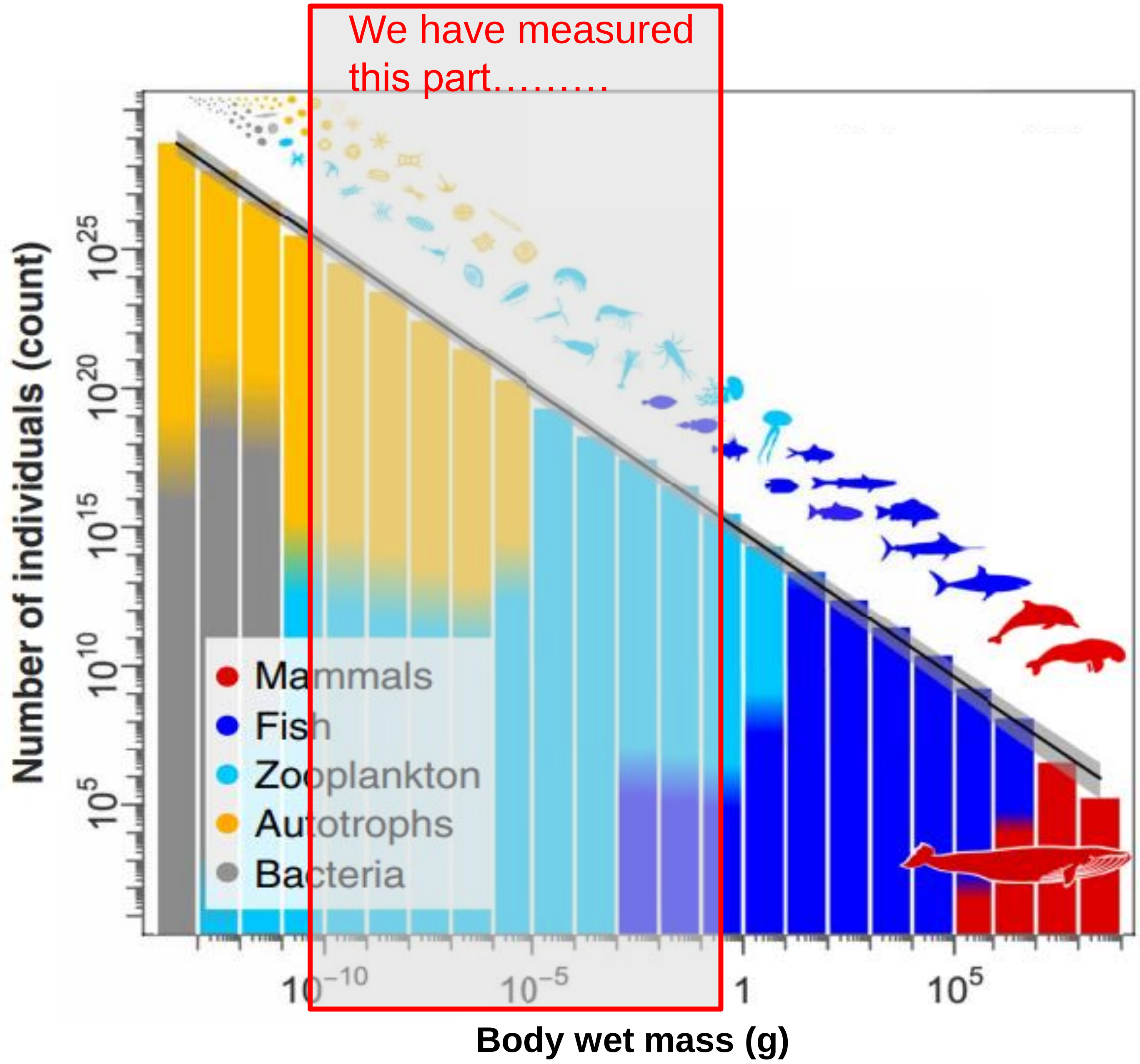
Double effect from a reduction in phytoplankton:

1. Less food available at base of food web
2. Efficiency of transfer through food web declines

(i.e. TROPHIC AMPLIFICATION of biomass declines

Atkinson et al. (2024) *Nature Comms*

Regularity of size spectra allows estimation of supportable fish biomass



Hatton et al. (2021) *Sci Adv*

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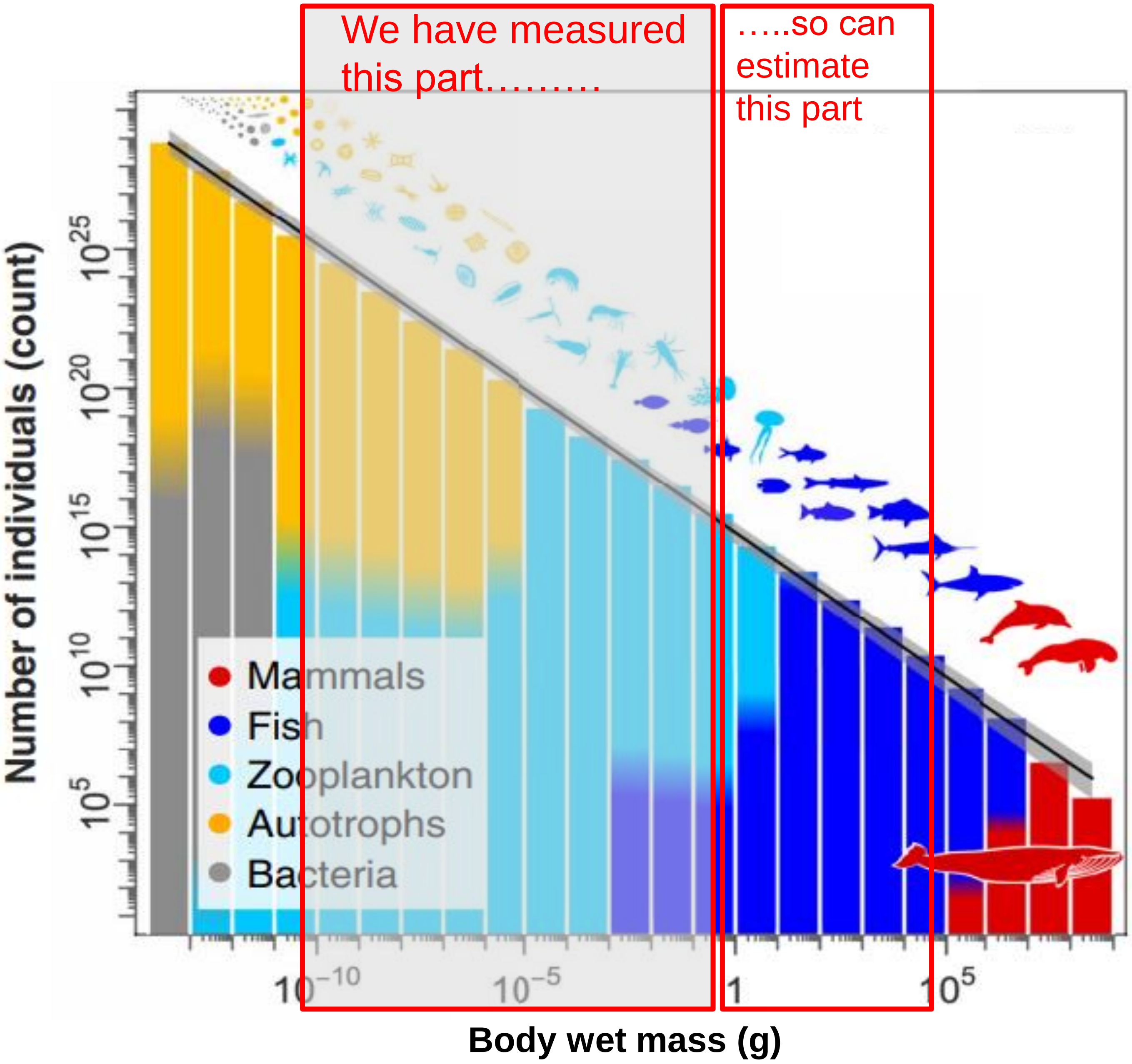
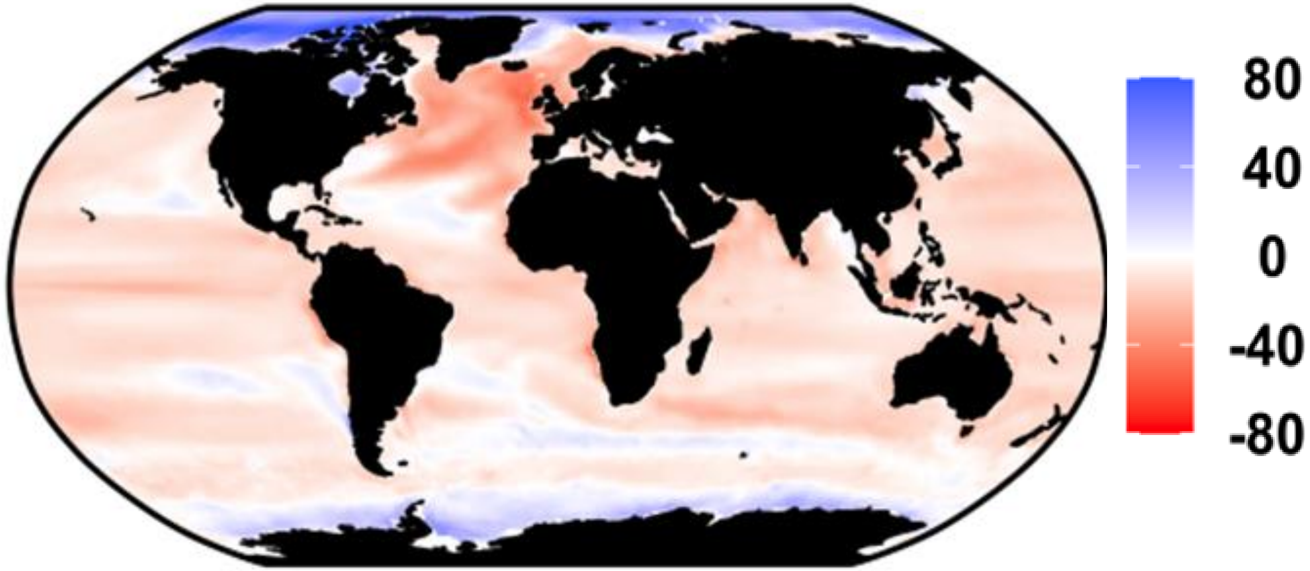


Hatton et al. (2021) *Sci Adv*

Implications for a warmer world

Phytoplankton

% Change (1990-1999 to 2090-2099)



Average results from an ensemble of 5 CMIP6 Earth System Models
Mid- latitudes: warming, increased stratification and
declining nutrient supply thought to reduce phytoplankton

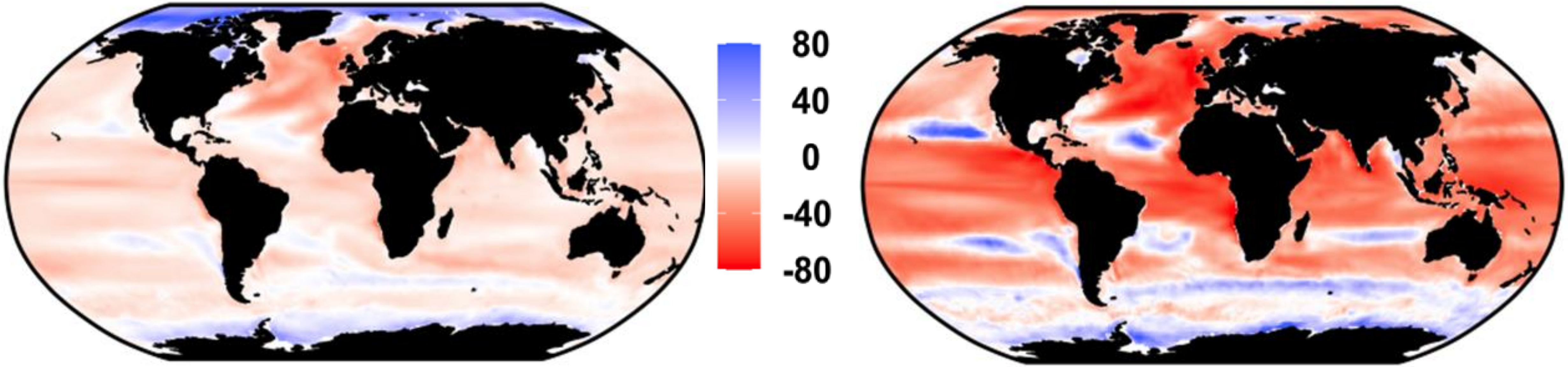
Atkinson et al. (2024) *Nat Comms*

Implications for a warmer world

Phytoplankton

Supportable fish biomass

% Change (1990-1999 to 2090-2099)



A modest decline in phytoplankton amplifies into a major decline in biomass of fish that this can support

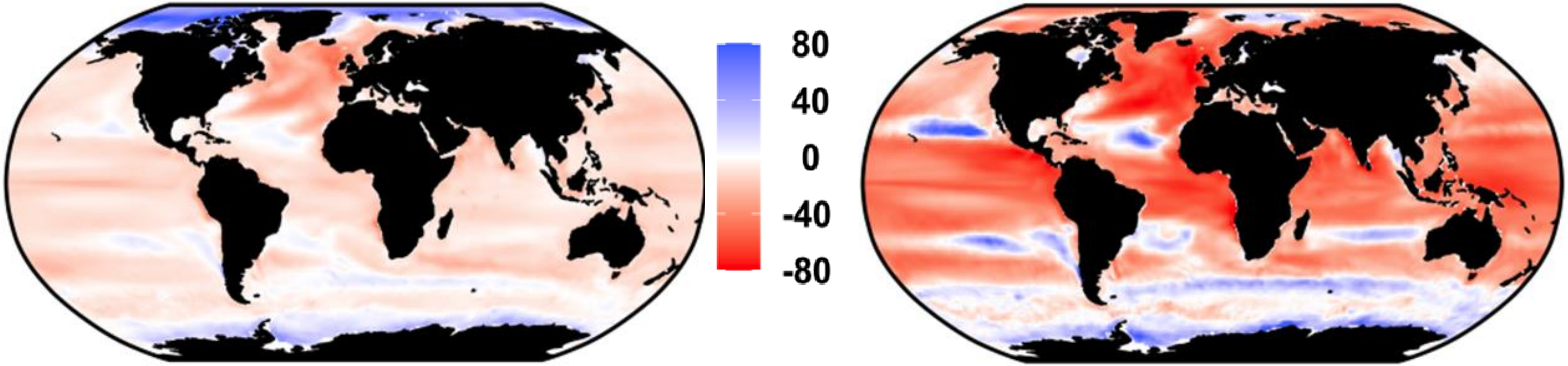
Atkinson et al. (2024) *Nat Comms*

Implications for a warmer world

Phytoplankton

Supportable fish biomass

% Change (1990-1999 to 2090-2099)



What would this small (7%) decline in phytoplankton biomass mean for fish?

SIZE SPECTRUM APPROACH – 19% global decline in supportable fish biomass
ENSEMBLES OF FOOD WEB MODELS - 29% decline in fish to a 2.4% increase

Heneghan et al (2019) *PIO*, Tittensor et al. (2021) *NCC*, Atkinson et al. (2024) *N Comms*

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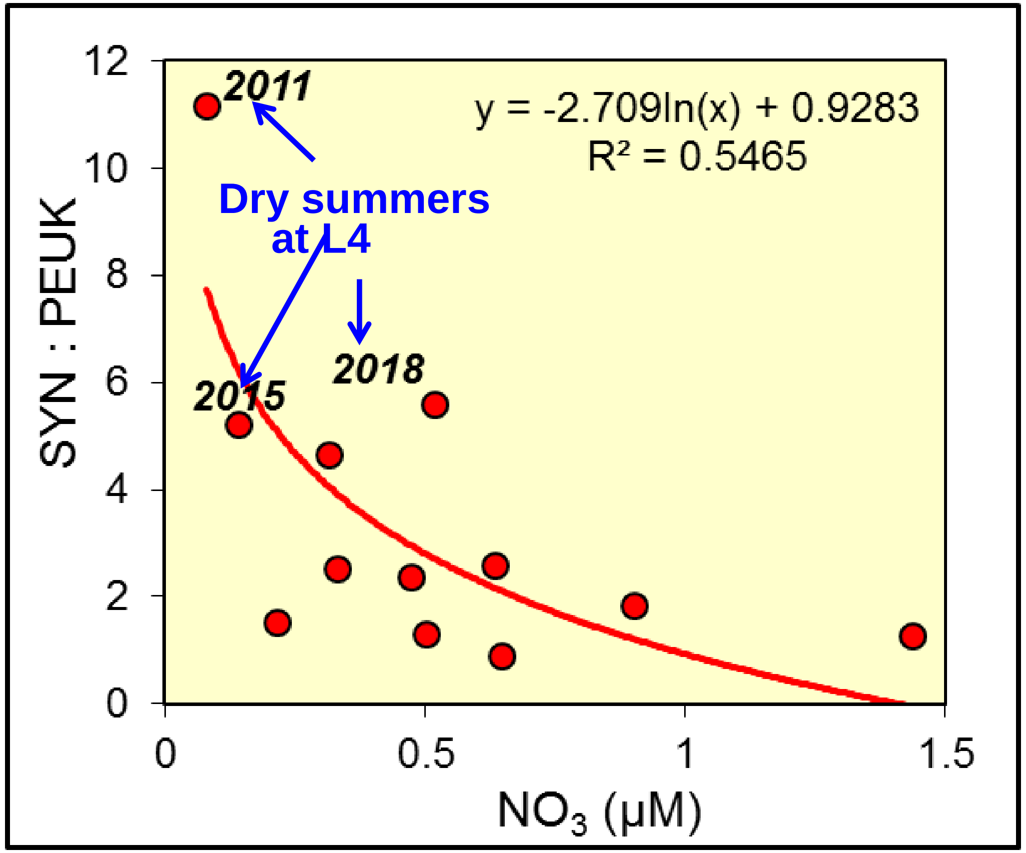
Taxonomic replacements may be unseen by size spectra



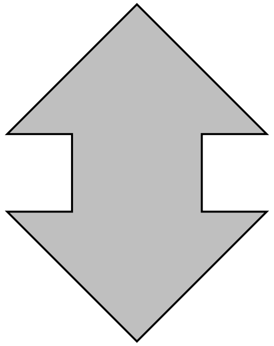
Glen Tarran
Malcolm Woodward
Carolyn Harris

Synechococcus

Wins under low Fe, NO_3 & light

PUFA-deficient

POOR FOOD QUALITY



Picoeukaryotes:

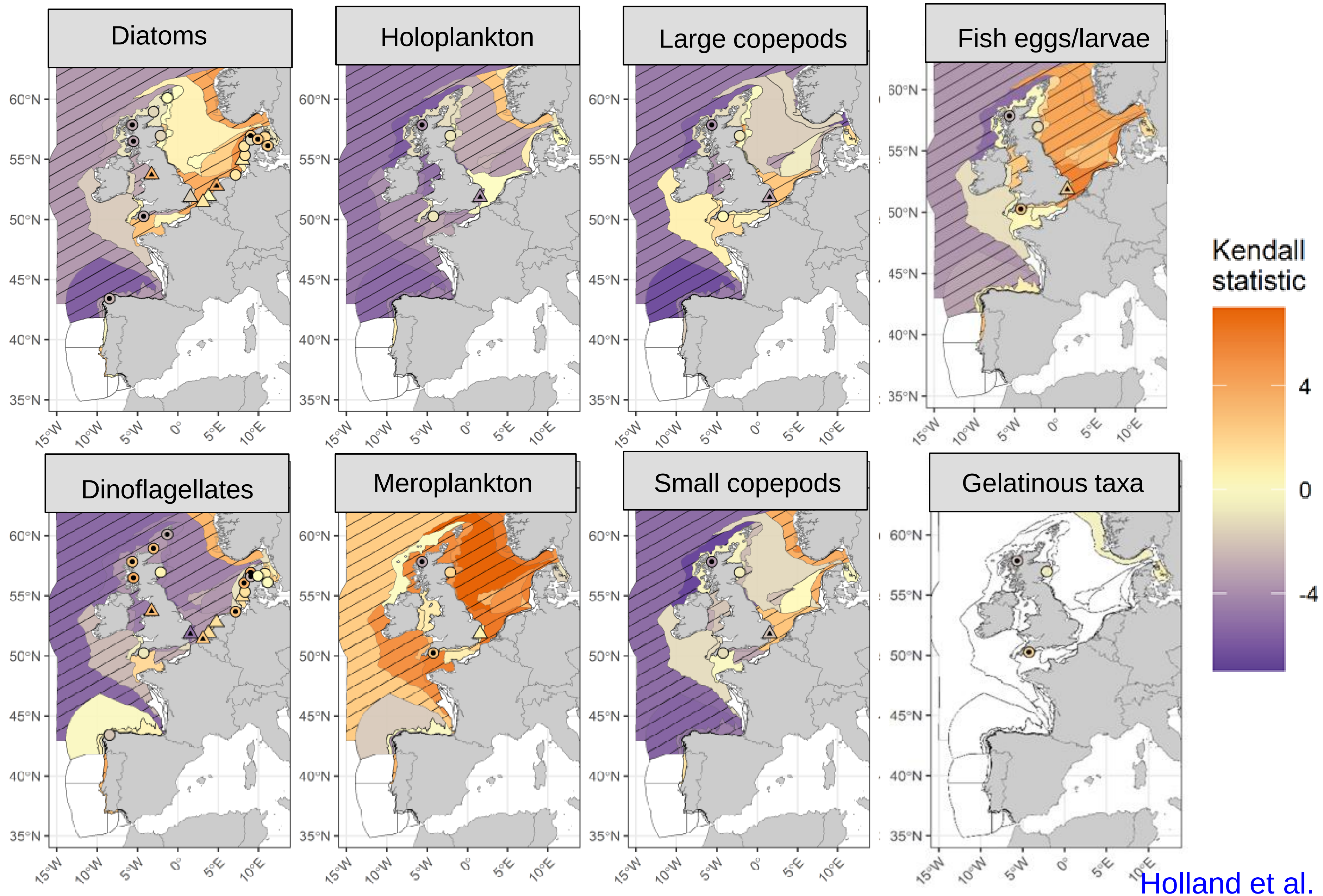
same size as *Synechococcus*

Contain PUFA

BETTER FOOD QUALITY

Schmidt et al.(2020) *Global Change Biology*

Long-term change revealed by networks of time series



INCREASES

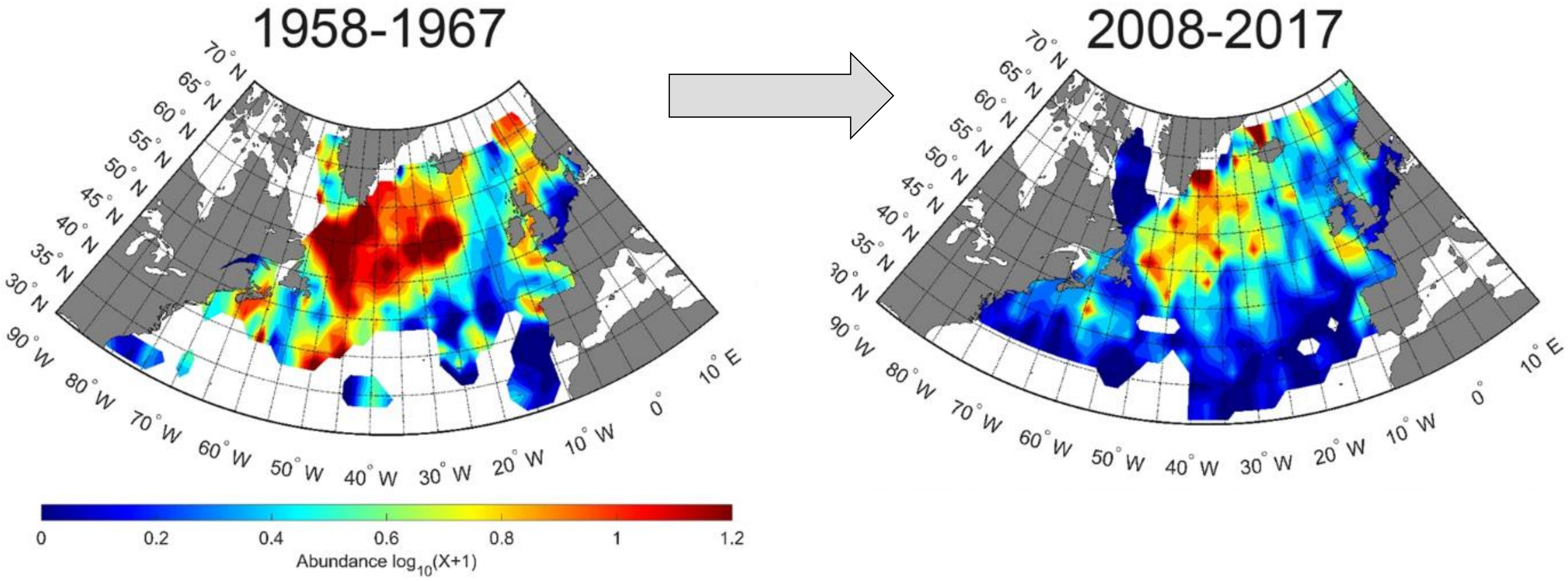
- North Sea
- Meroplankton
- Gelatinous taxa?

DECREASES

- West of UK
- Crustaceans

Holland et al. (2023) *Science of the Total Env*

Atlantic-scale declines in multiple krill species: CPR data

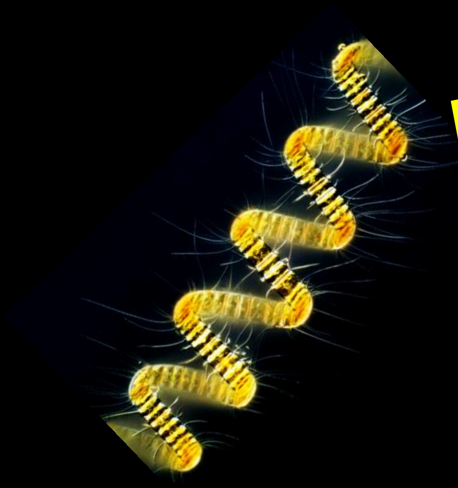


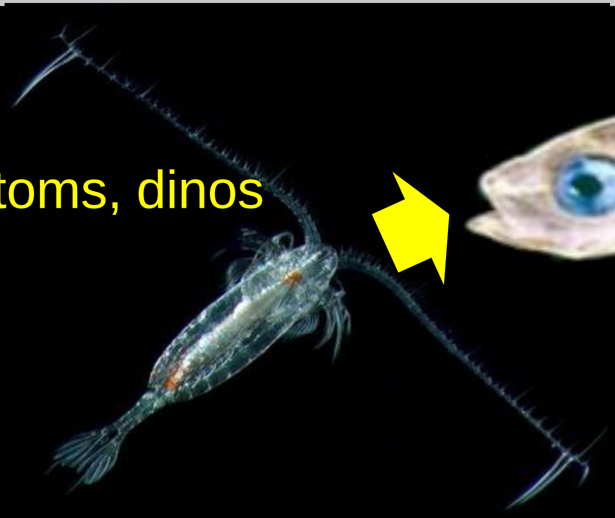
Edwards et al. (2021) *Comms Biology*

Various hypotheses for the changes we are seeing

Higher Fe and NO_3

Classic “efficient” food chain from
LARGE omega-3 fatty acid -rich diatoms, dinos





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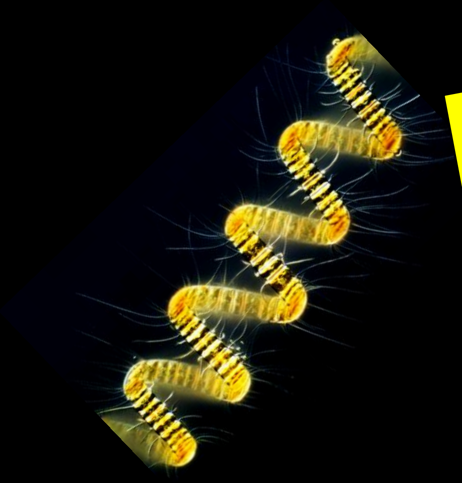
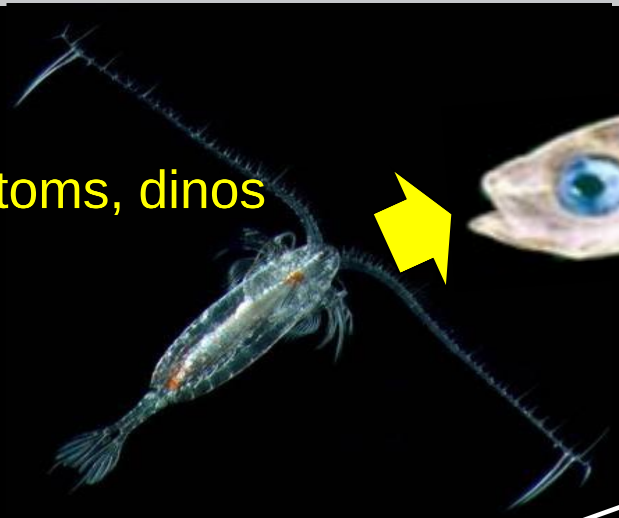
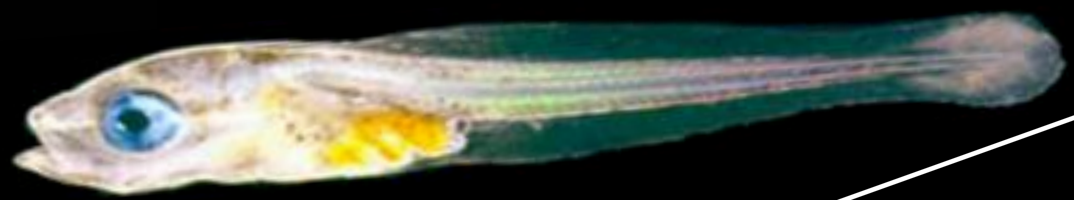
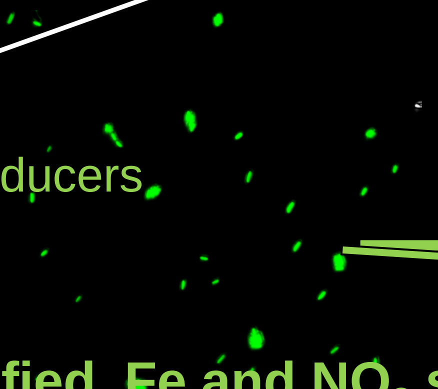






SMALLER producers
Picoplankton

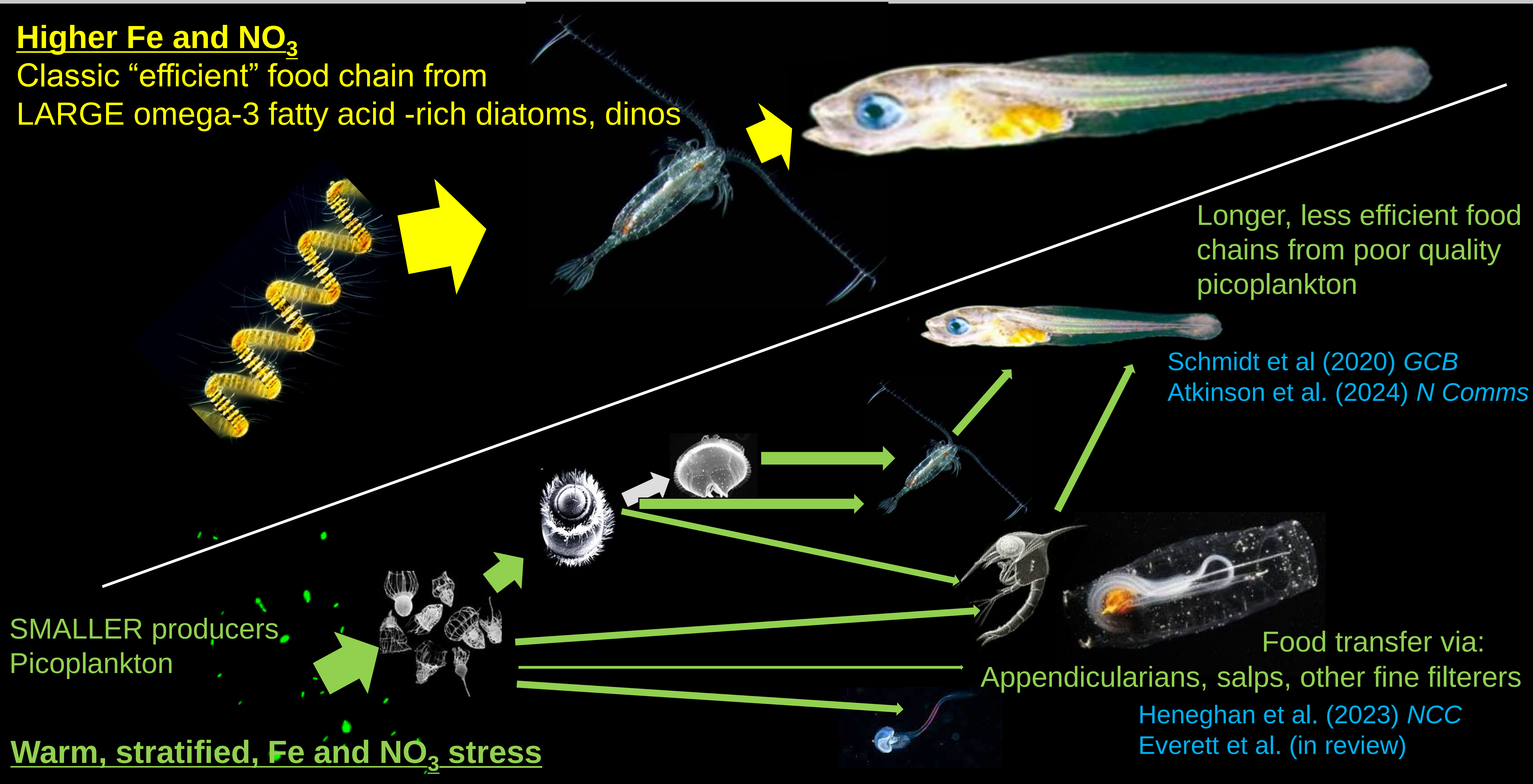


Food transfer via:
Appendicularians, salps, other fine filterers

Heneghan et al. (2023) *NCC*
Everett et al. (in review)

Warm, stratified, Fe and NO_3 stress

Various hypotheses for the changes we are seeing



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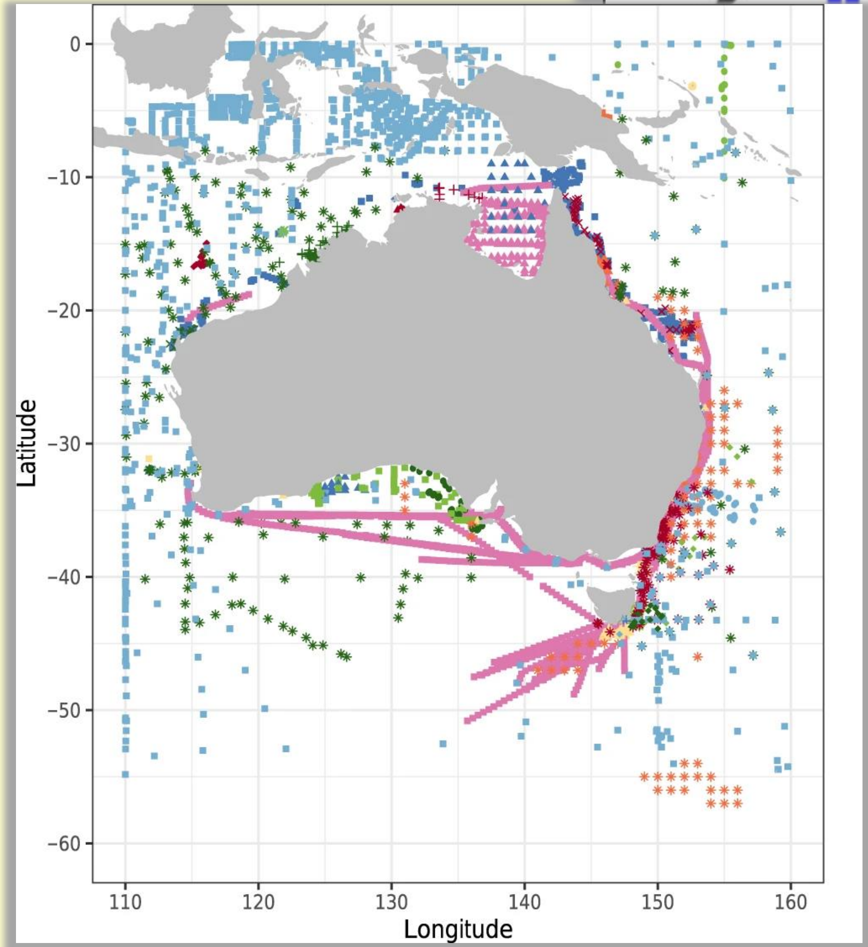
The value of data mining and data compilation



Todd O'Brien: COPEPOD project is now 20 years old!

McEnnulty et al. (2021) *Sci Data* (zooplankton biomass)

The KRILLBASE project

2000

KRILLBASE-abundance (krill and salp abundance~16,000 records, 1926-2016)

Data in BAS Polar Data Center – see Atkinson et al. (2017) *ESSD*

Started in 1999 by A. Atkinson, E. Pakhomov, V Siegel

2005

KRILLBASE-length frequency

(Length, sex, maturity stage, >600,000 measured post-larval krill, 1926-2016)

Perry et al. (2019) *PIO*

Data in BAS Polar Data Center http://apex.nerc-bas.ac.uk/f?p=198:1:0

2010

2015

KRILLBASE-larvae (Abundance of krill larval stages, 1926-2016)

Data in SI of Perry et al. (2019) *PIO*

AWR funding to write data paper and improve accessibility

KRILLBASE-mesozooplankton biomass

2020

2909 stations, 1932-2020

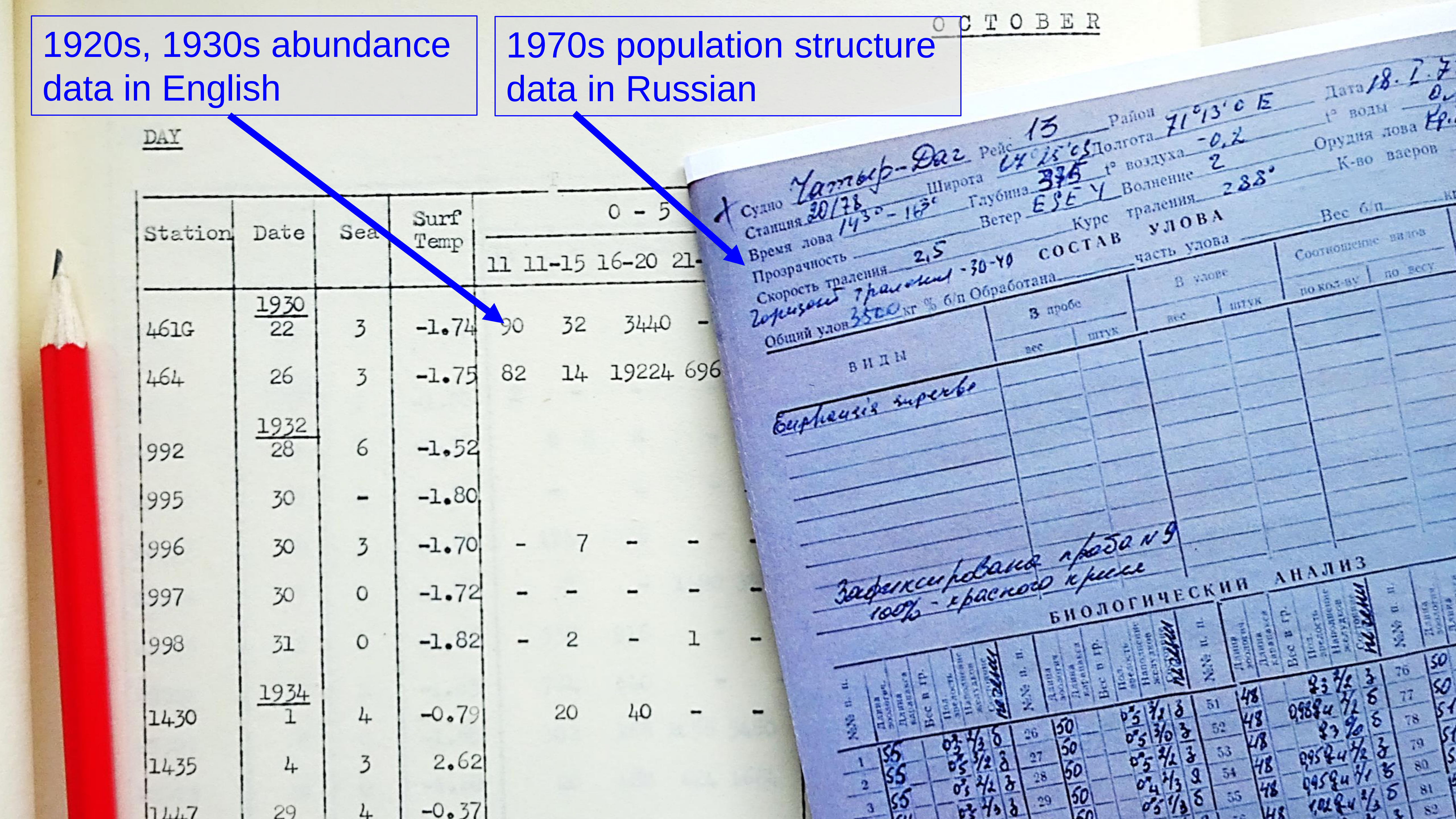
Data in SI of Yang et al. (2022) L&O

2025

SUPPORTING INFORMED CONSERVATION OF ANTARCTIC WILDLIFE

1920s, 1930s abundance data in English

1970s population structure data in Russian



Lessons from history……………………

Well-documented people (for their time)

Rameses II (1303-1213 BC)
Jesus of Nazareth (~4 BC-33 AD)
Joan of Arc (1412-1431 AD)

“*Hey scribe…….write that down!!*”

Mysterious centuries

King Arthur and the Dark Ages
Viking explorations

“*We thought we would remember this…*”

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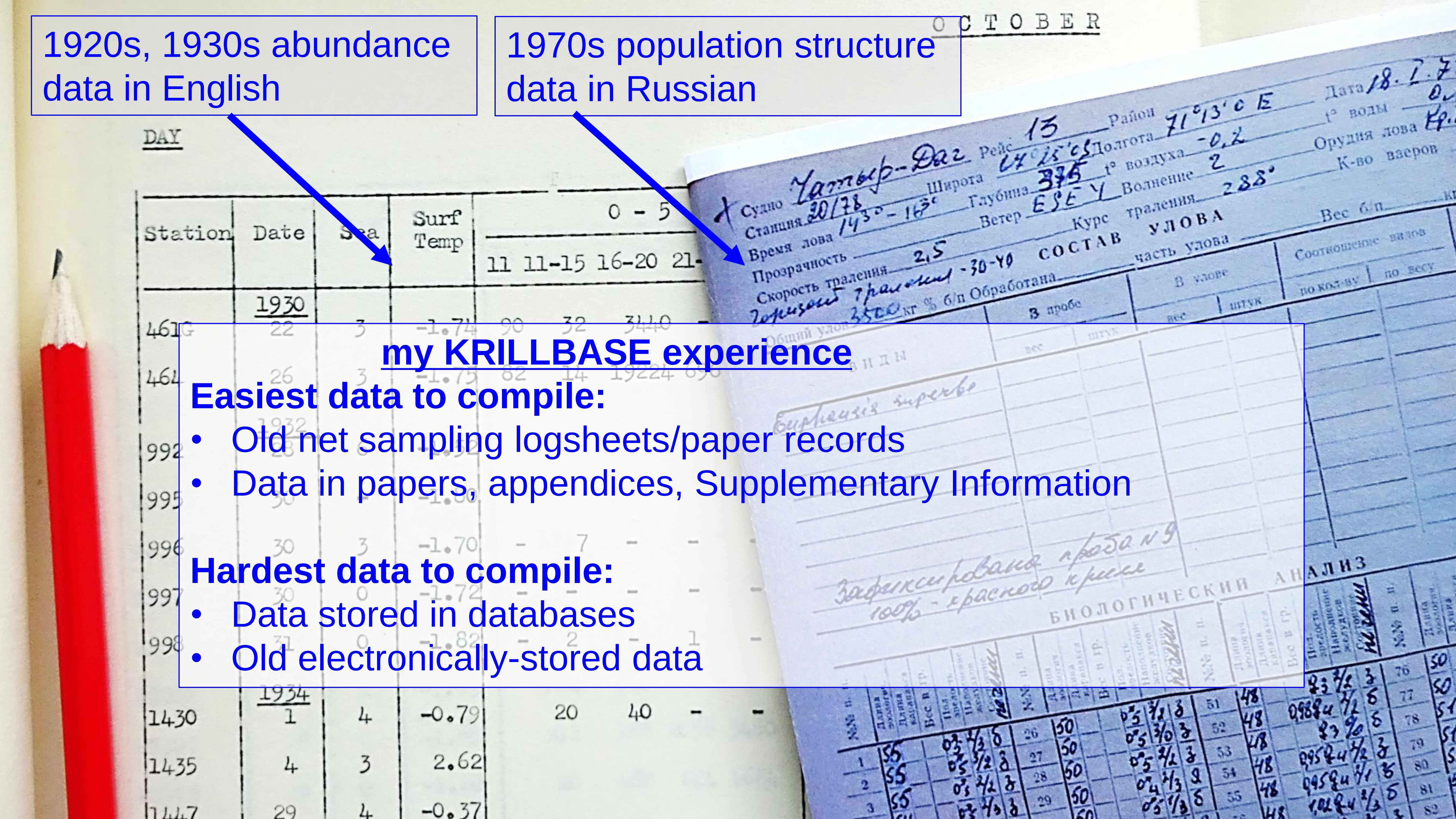
1970s population structure data in Russian



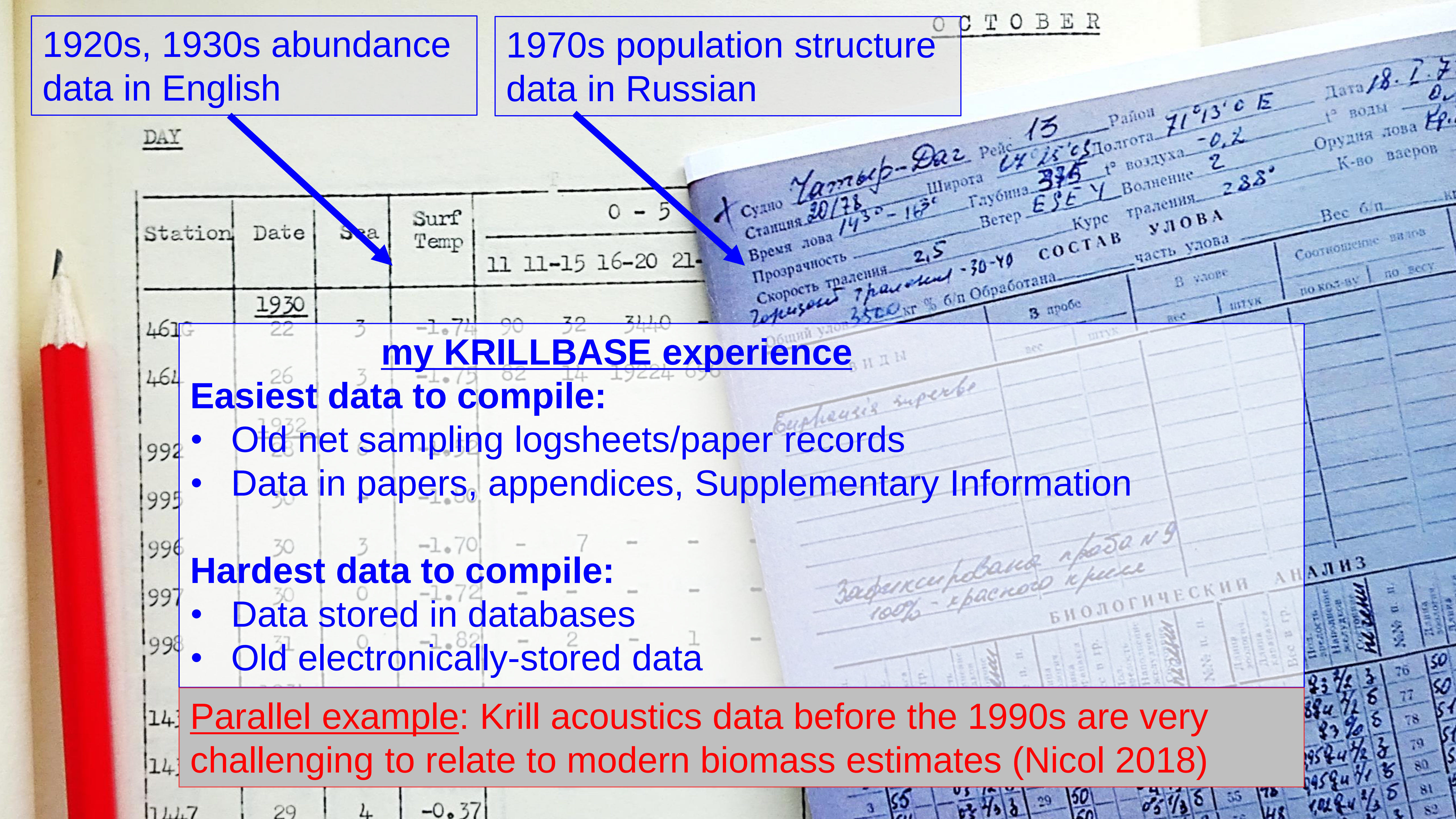
my KRILLBASE experience

Easiest data to compile:

- Old net sampling logsheets/paper records
- Data in papers, appendices, Supplementary Information

Hardest data to compile:

- Data stored in databases
- Old electronically-stored data



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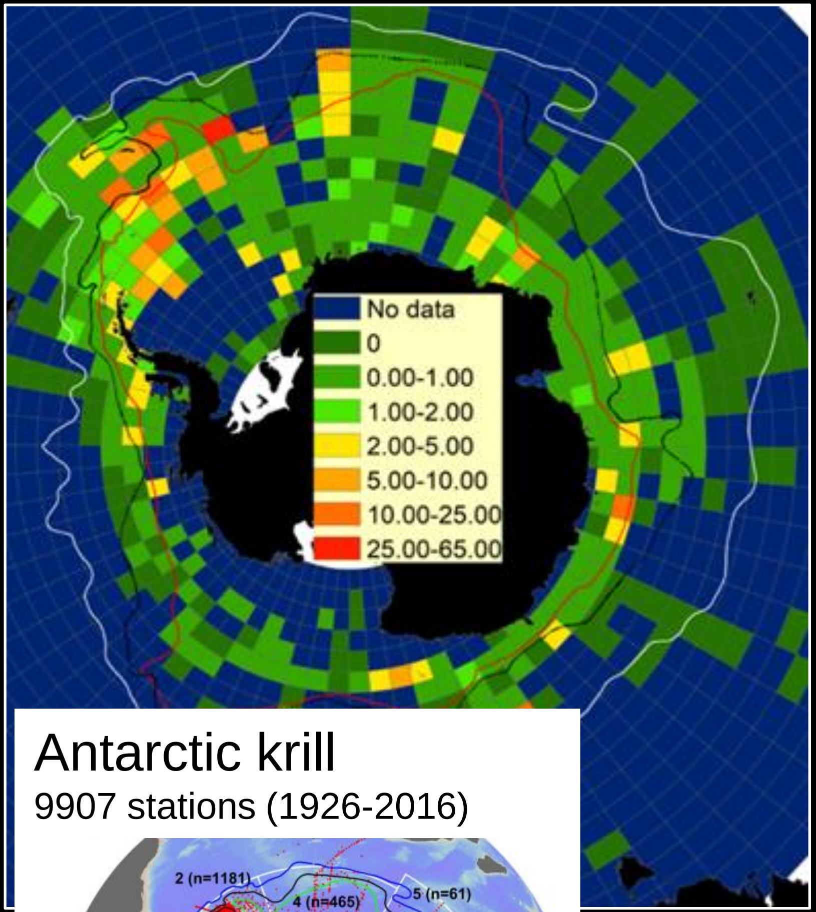
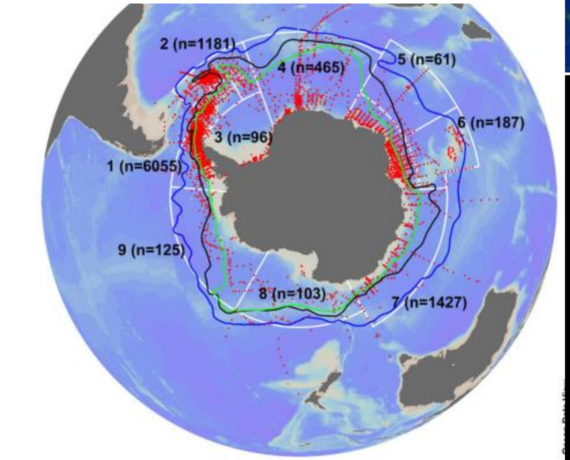
Parallel example: Krill acoustics data before the 1990s are very challenging to relate to modern biomass estimates (Nicol 2018)

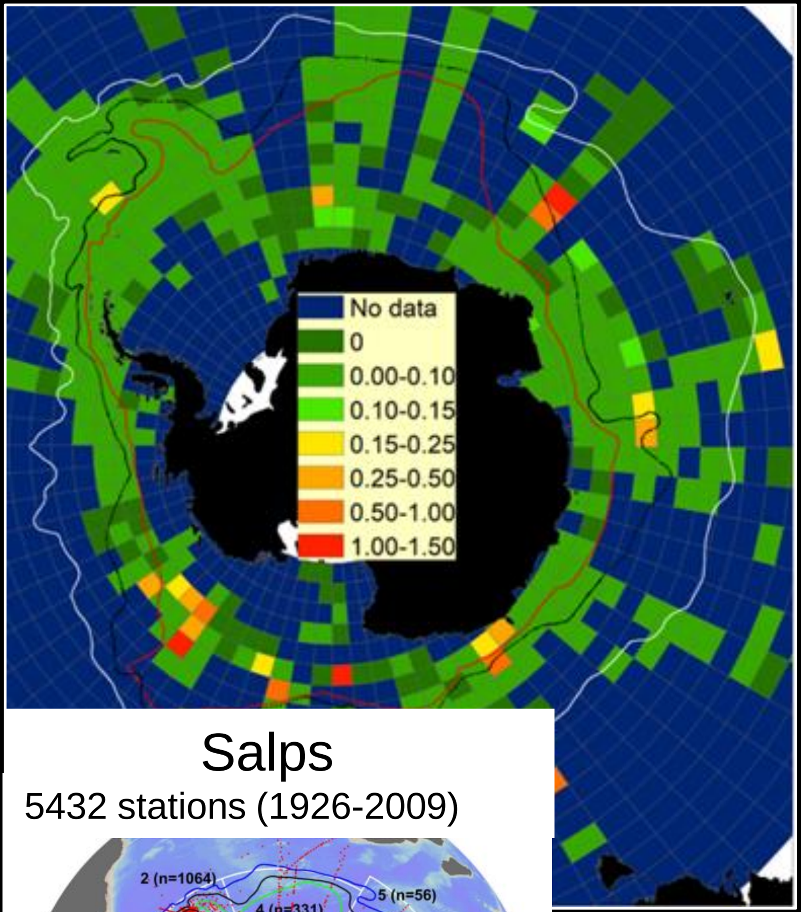
Circumpolar distribution of zooplankton carbon



Antarctic krill

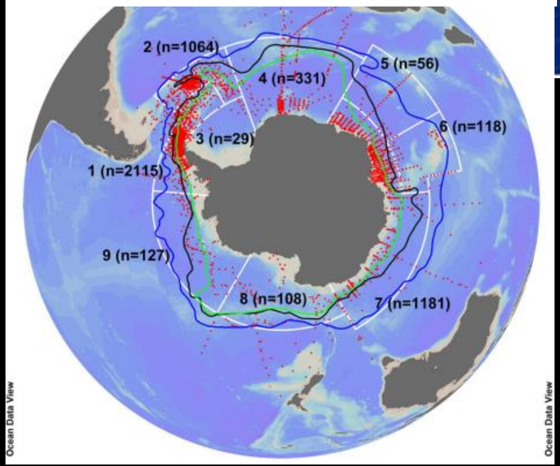
9907 stations (1926-2016)

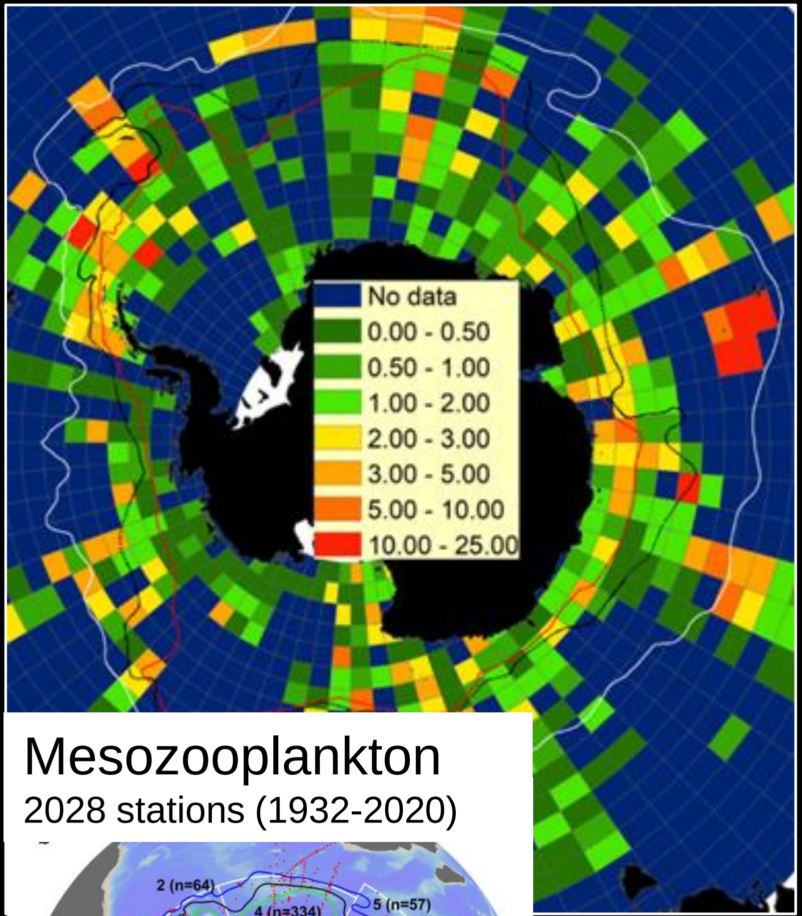




Salps

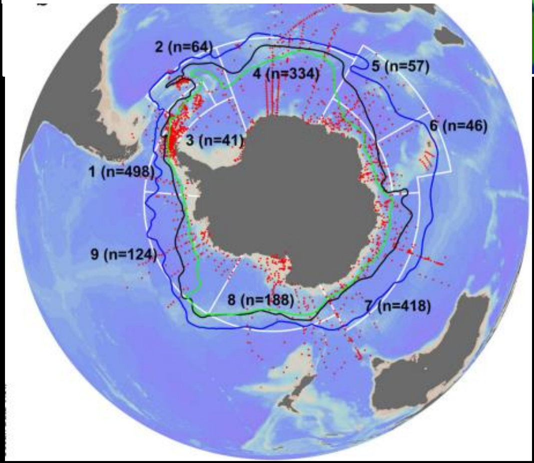
5432 stations (1926-2009)





Mesozooplankton

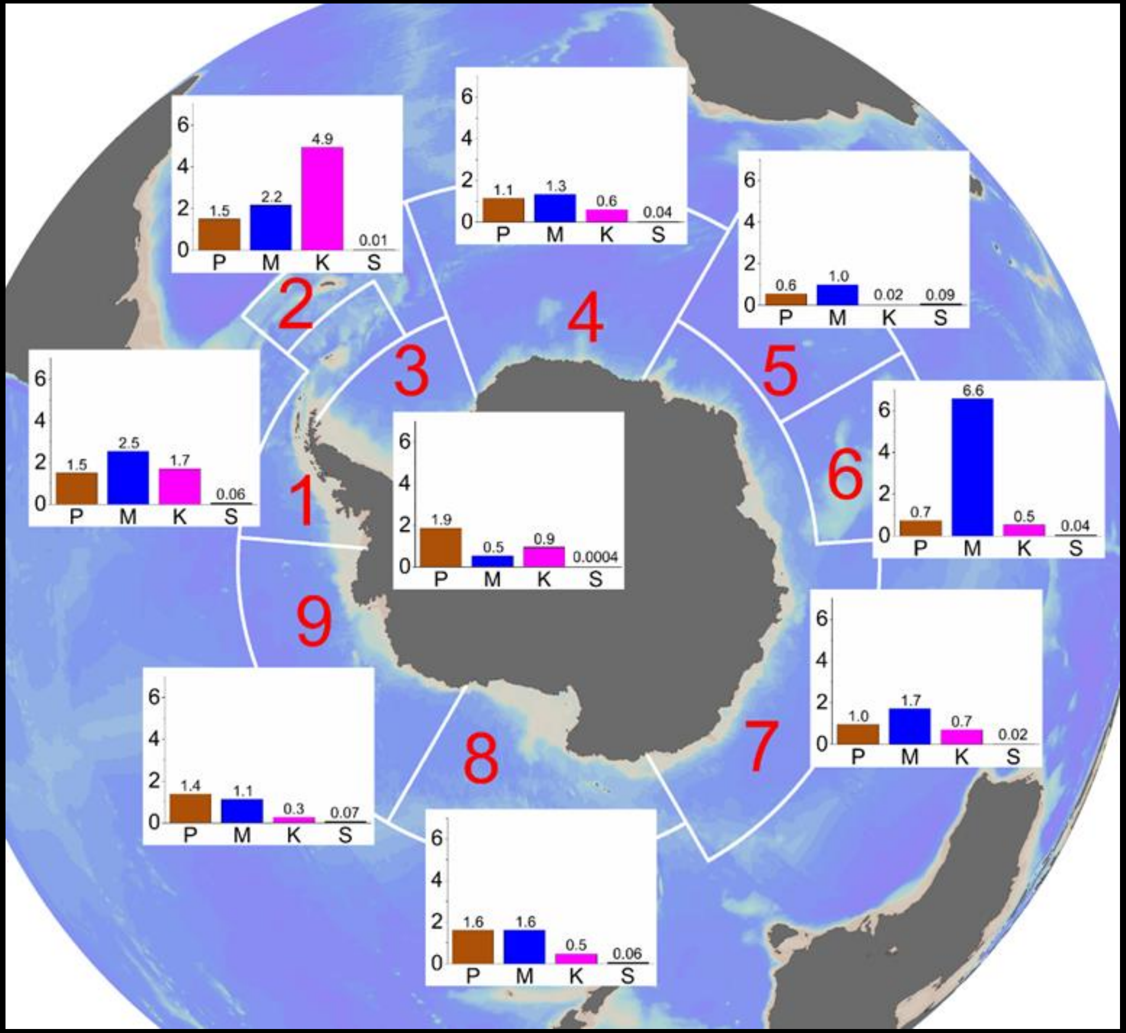
2028 stations (1932-2020)



Yang et al. (2022)
Limnol Oceanogr

Massive total zooplankton biomass in Southern Ocean

Biomass density estimated in MPA planning domains (g C m^{-2})
P = phytoplankton, M = mesozooplankton, K = Antarctic krill, S = salps



Total Carbon Biomasses

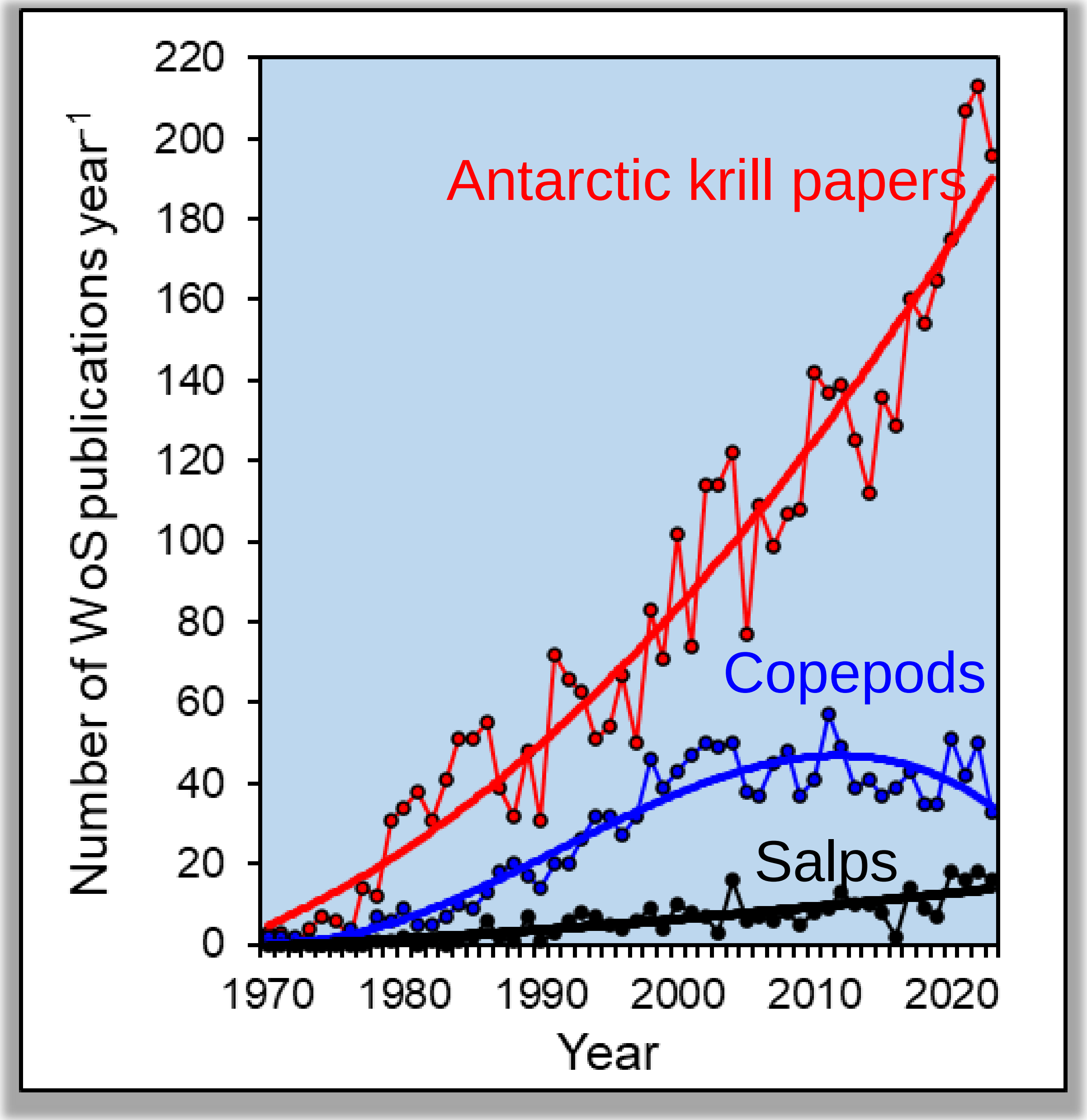
Mesozooplankton
67 million tonnes

Antarctic krill
30 million tonnes

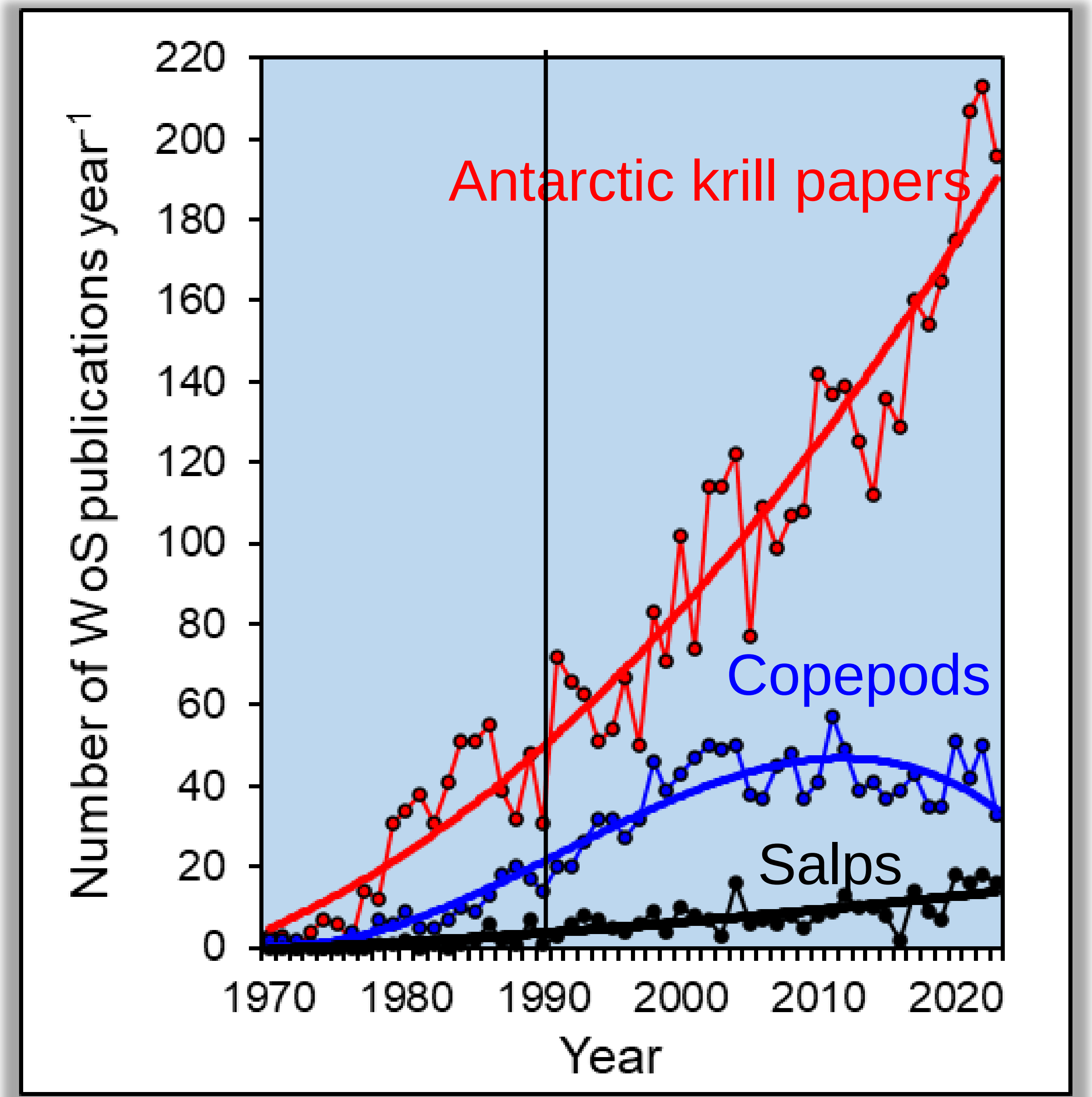
Salps
1.7 million tonnes

Yang et al. (2022)
Limnol Oceanogr

Why is Southern Ocean copepod research neglected?



Why is Southern Ocean copepod research neglected?

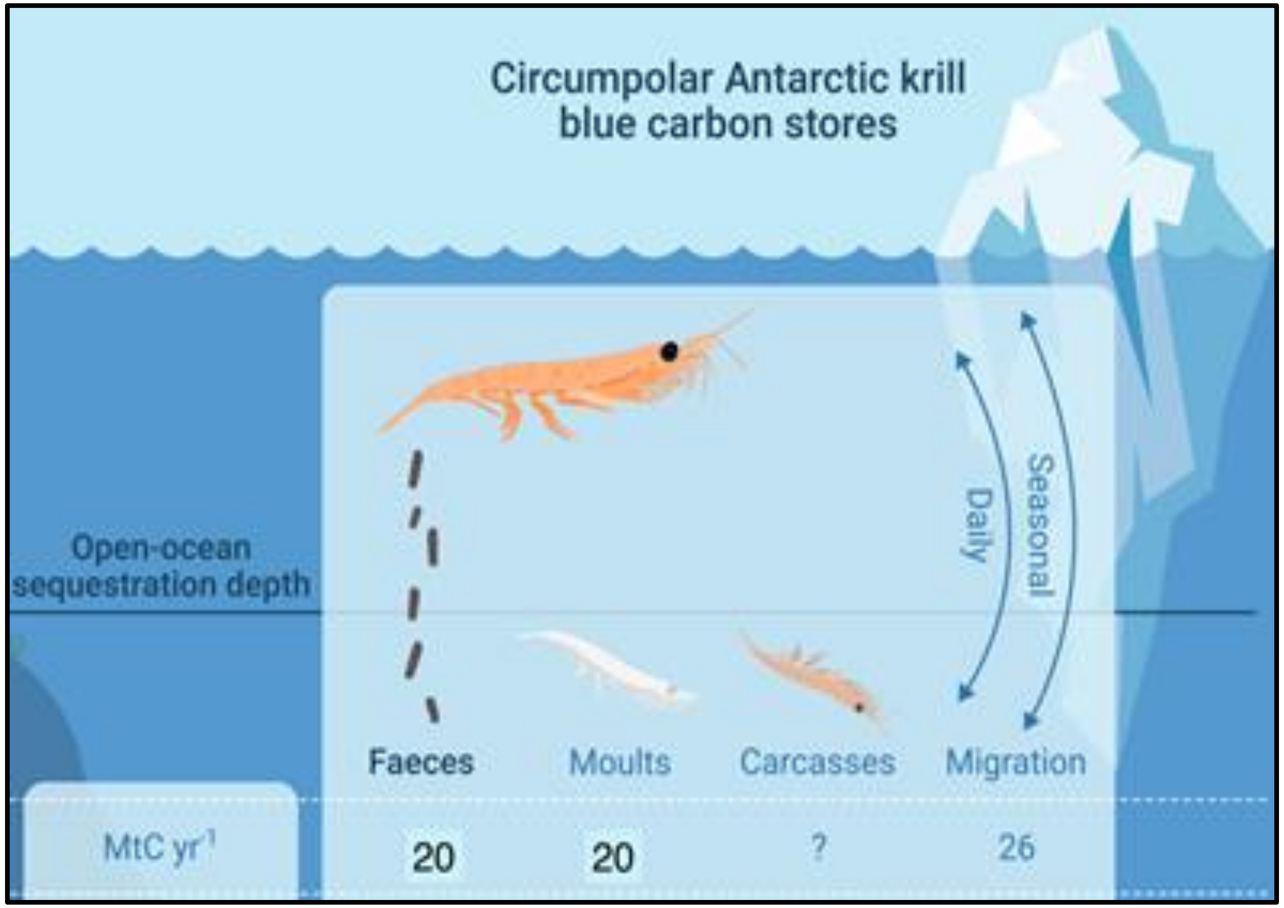


"Those few investigators who…. have fought the tide of Antarctic krill worship to ferret out some of the essentials of copepod biology ….should be applauded for their efforts because….it may turn out that copepods are key to….trophic transfer in Antarctic waters"

Conover and Huntley (1991) *J Mar Sys*

Big role of SO zooplankton in Carbon sequestration

Cavan et al. in review https://www.biorxiv.org/content/biorxiv/early/2023/10/17/2023.10.13.562177.full.



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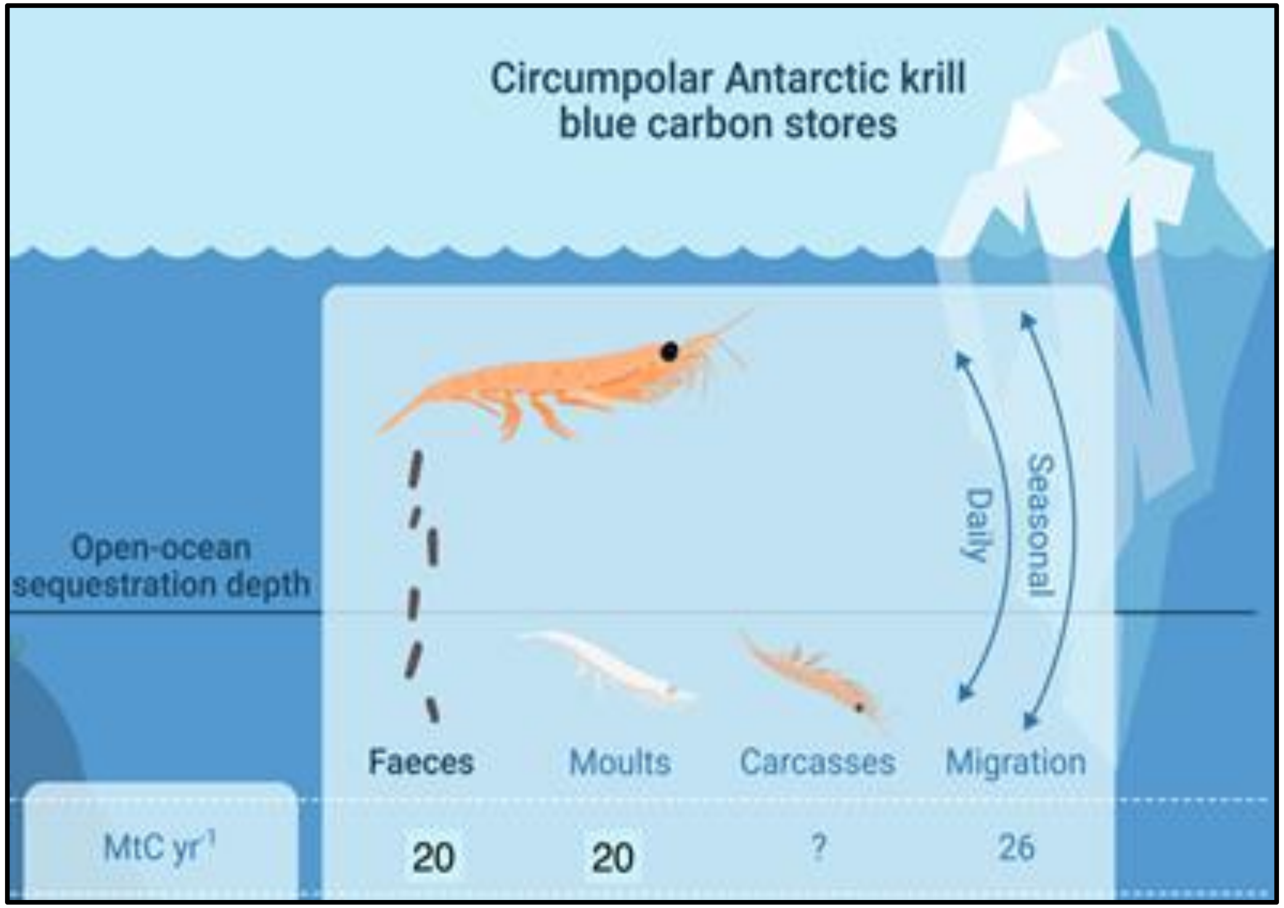
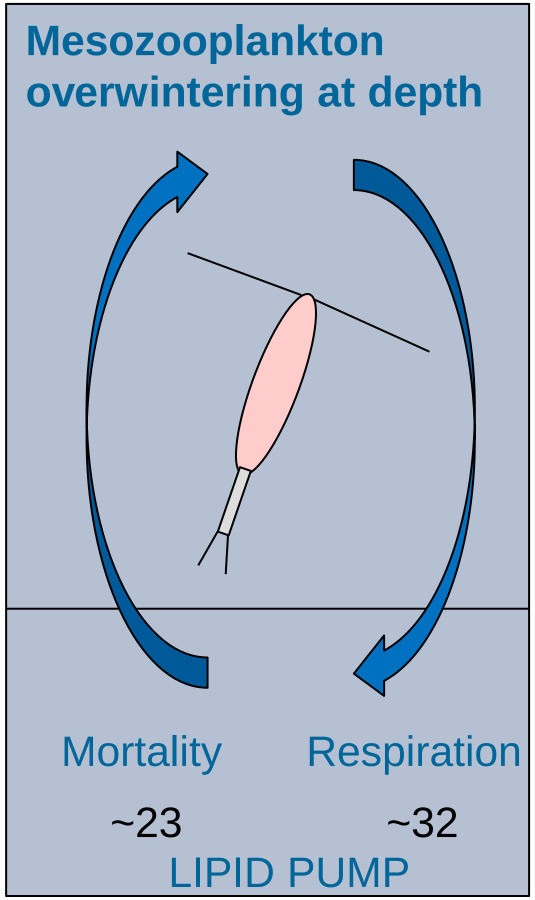


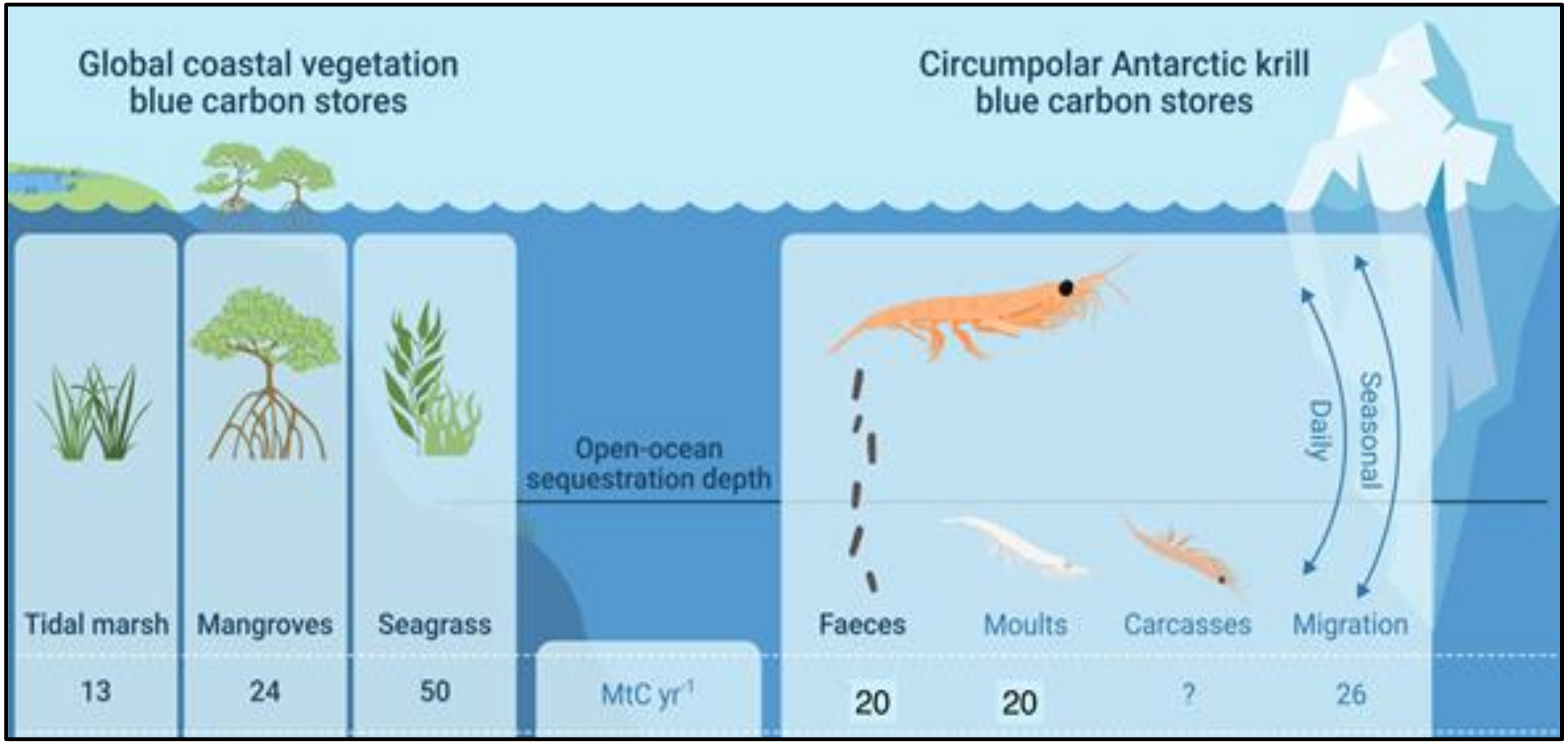
Yang et al. in prep



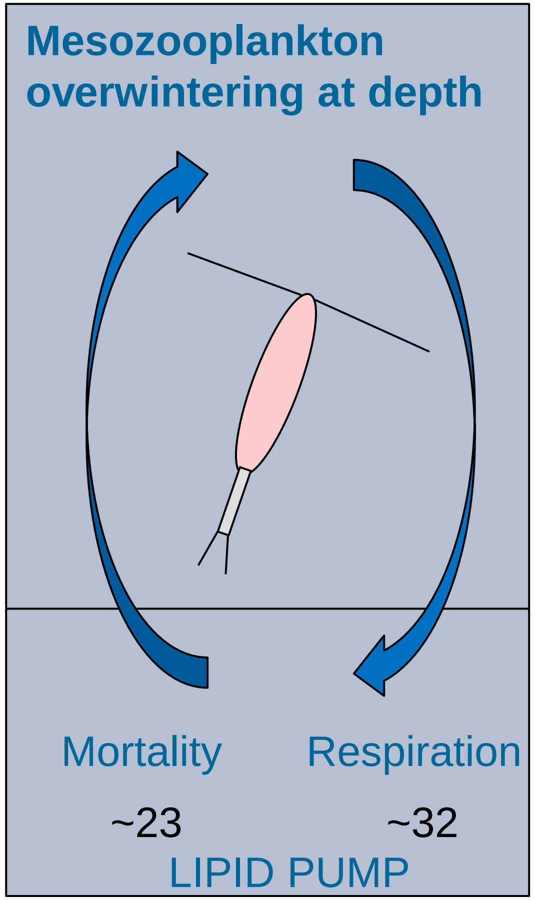
Big role of SO zooplankton in Carbon sequestration

PML Plymouth Marine Laboratory

Cavan et al. in review https://www.biorxiv.org/content/biorxiv/early/2023/10/17/2023.10.13.562177.full.



Yang et al. in prep

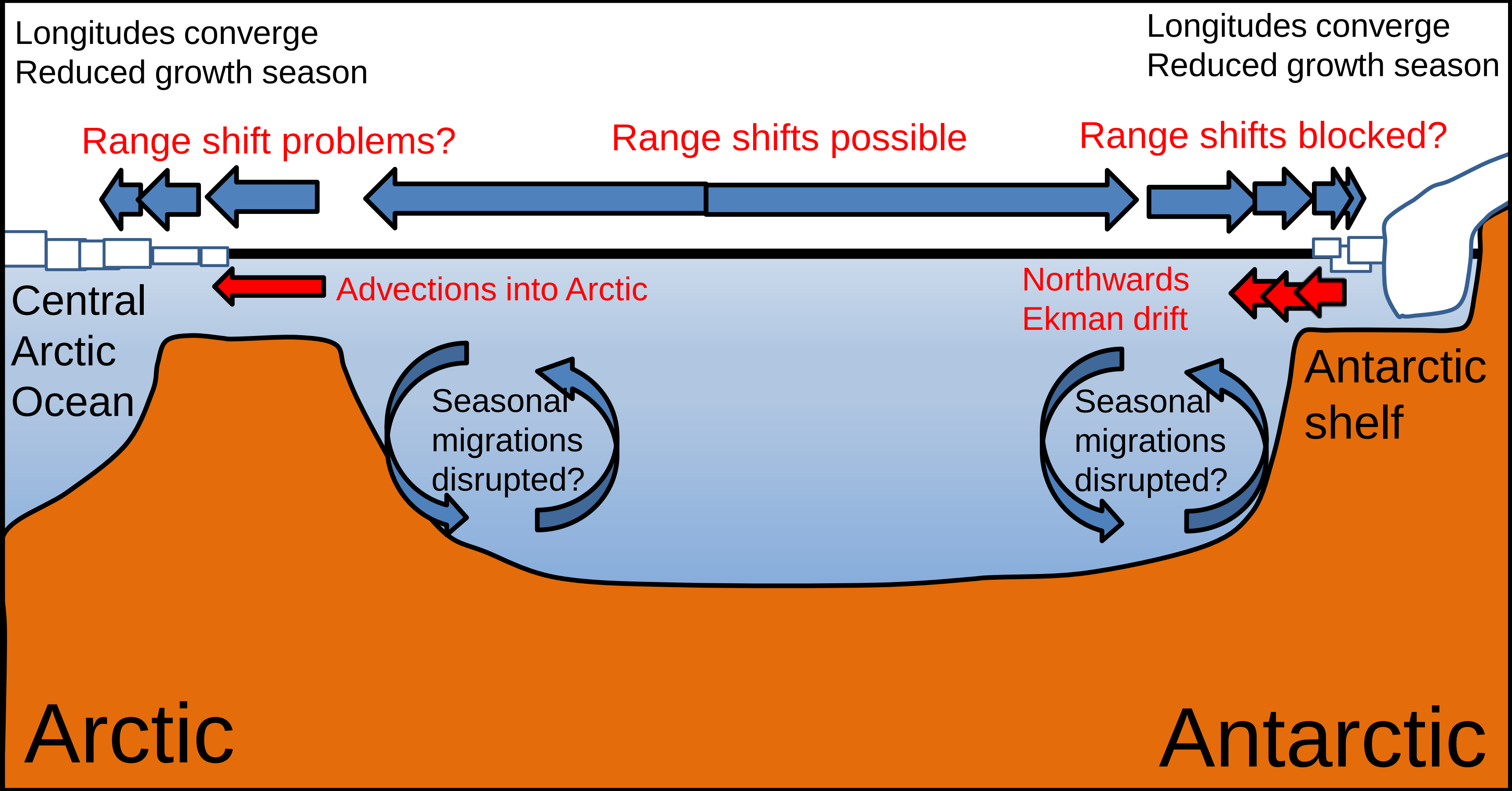


87 Mt C y^{-1}

>120 Mt C y^{-1}

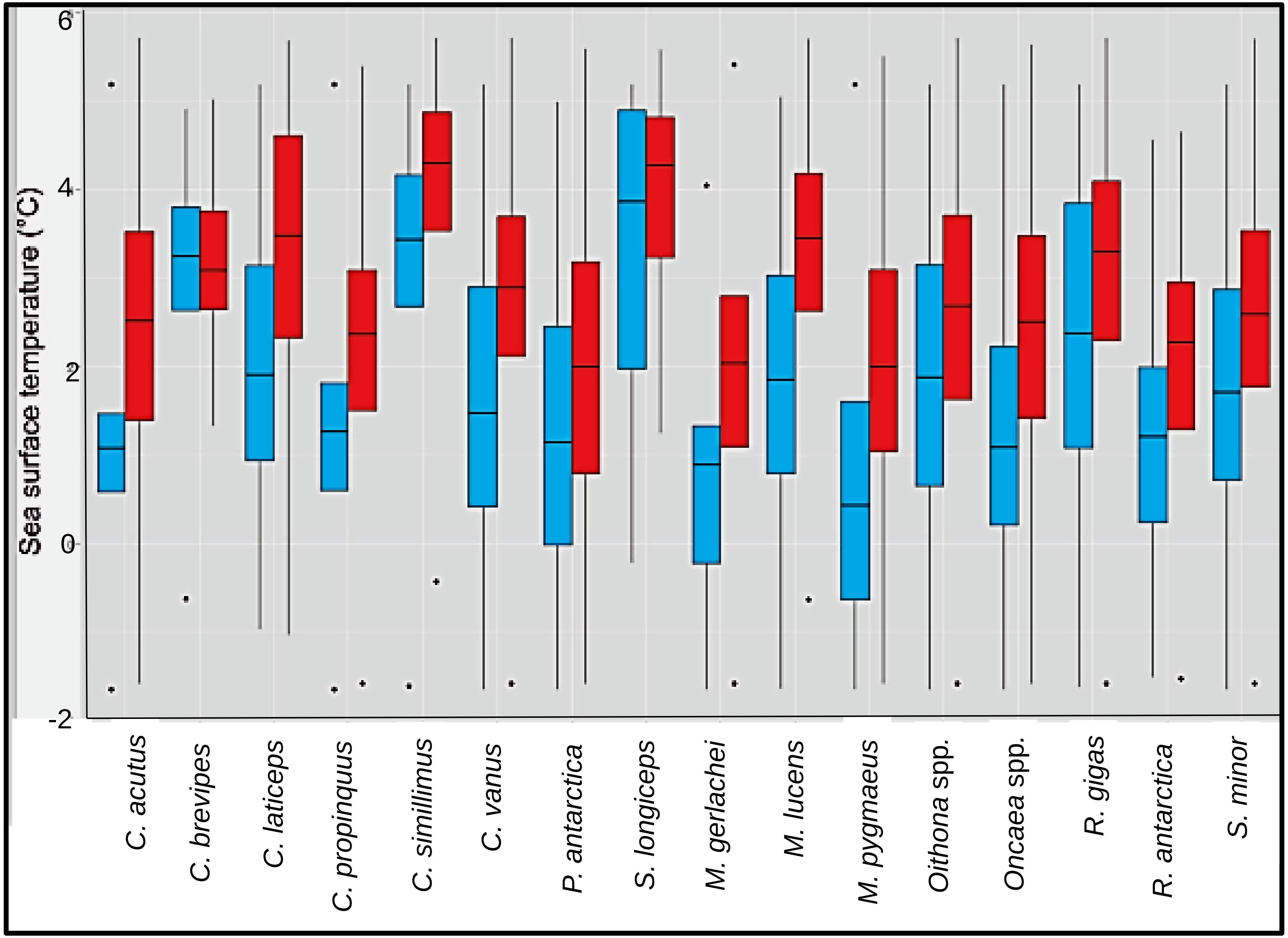
Range shifts: multiple barriers in the Southern Ocean

- Data - scarce
- Models, reviews, speculation – super-abundant !!



Polar range shifts are not a foregone conclusion

Ranges of Antarctic copepods have been resilient to warming



Ranges in SW Atlantic sector have changed little despite warming

Discovery era (1926-1938)

Contempory era (1996-2013)

Tarling et al. (2017) *Global Change Biology*

Krill did shift range, but it was during a pause in warming!

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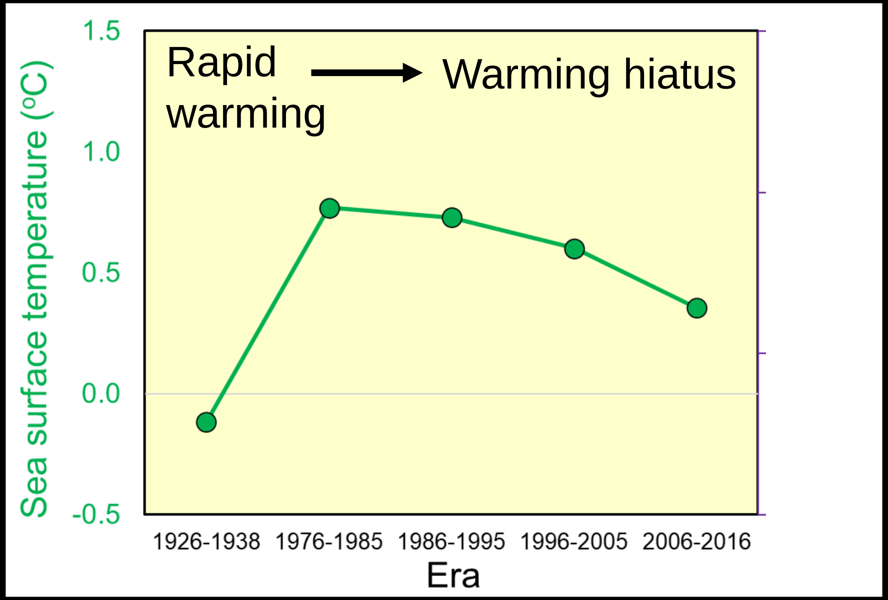

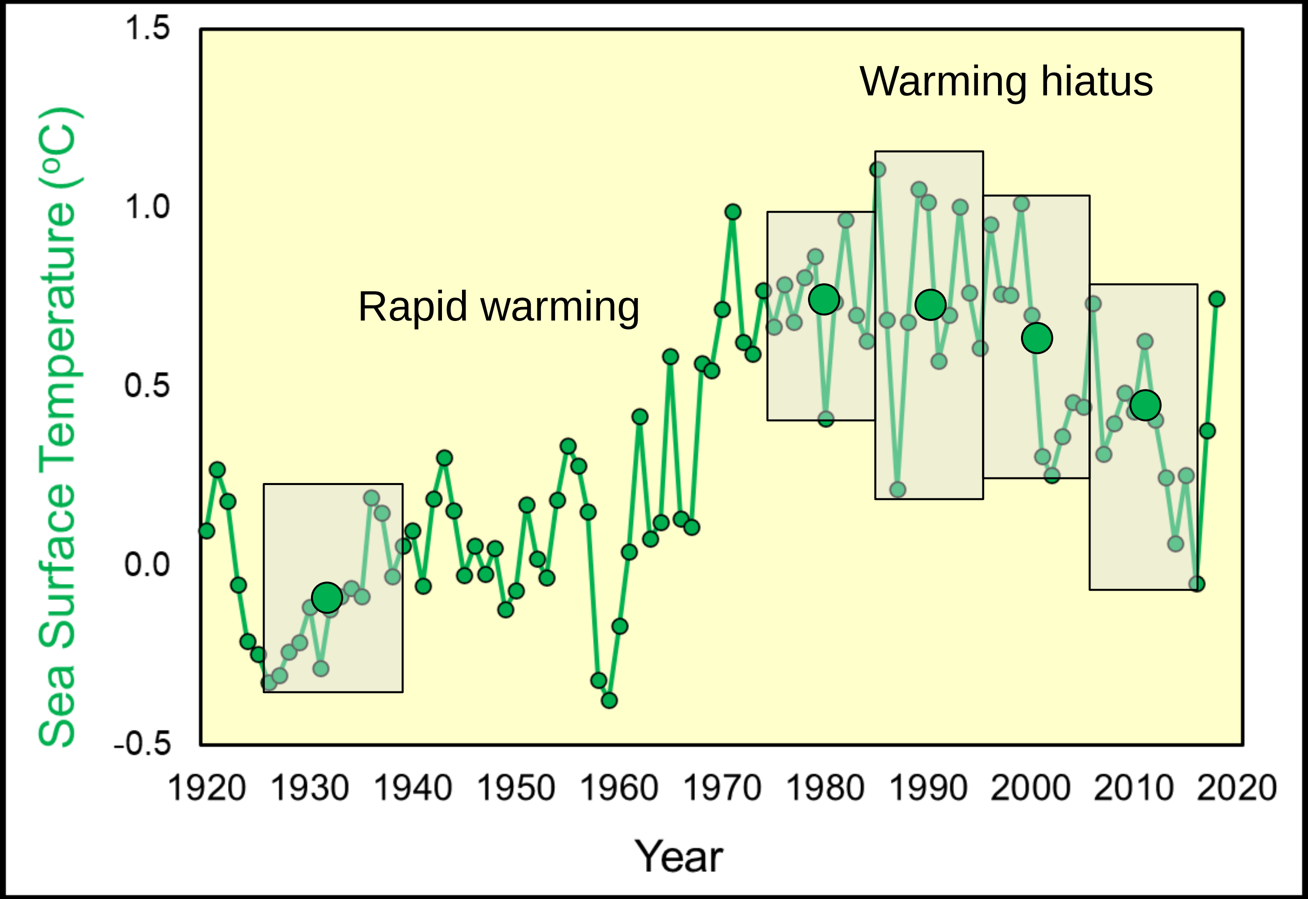

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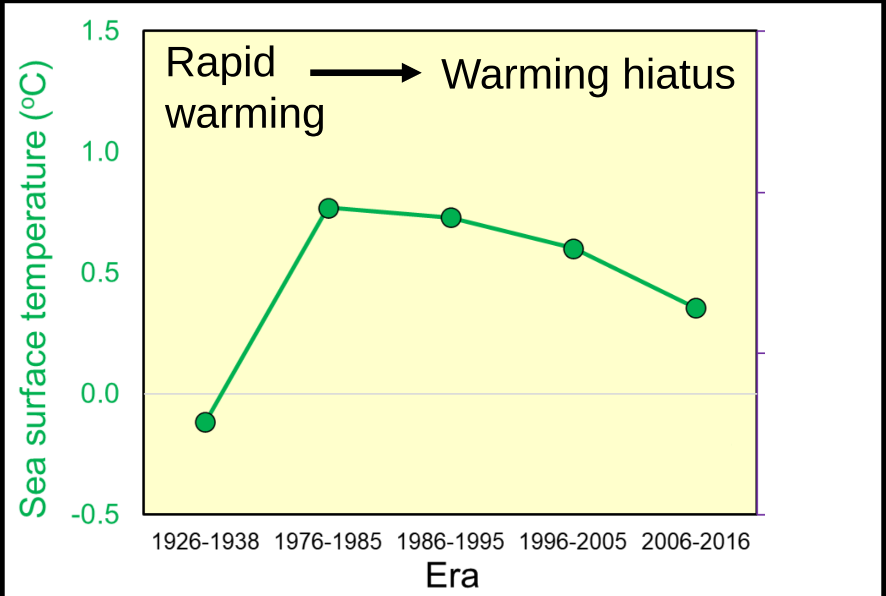
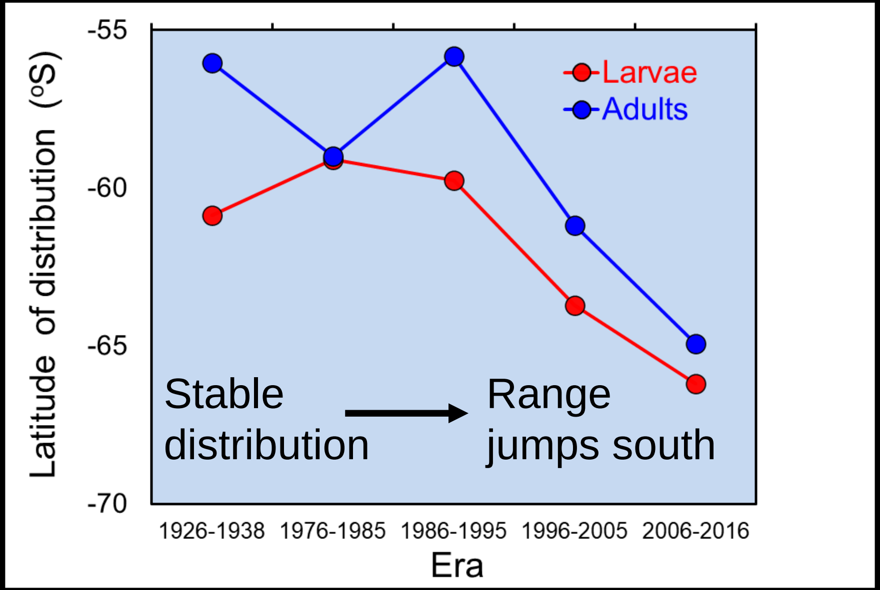
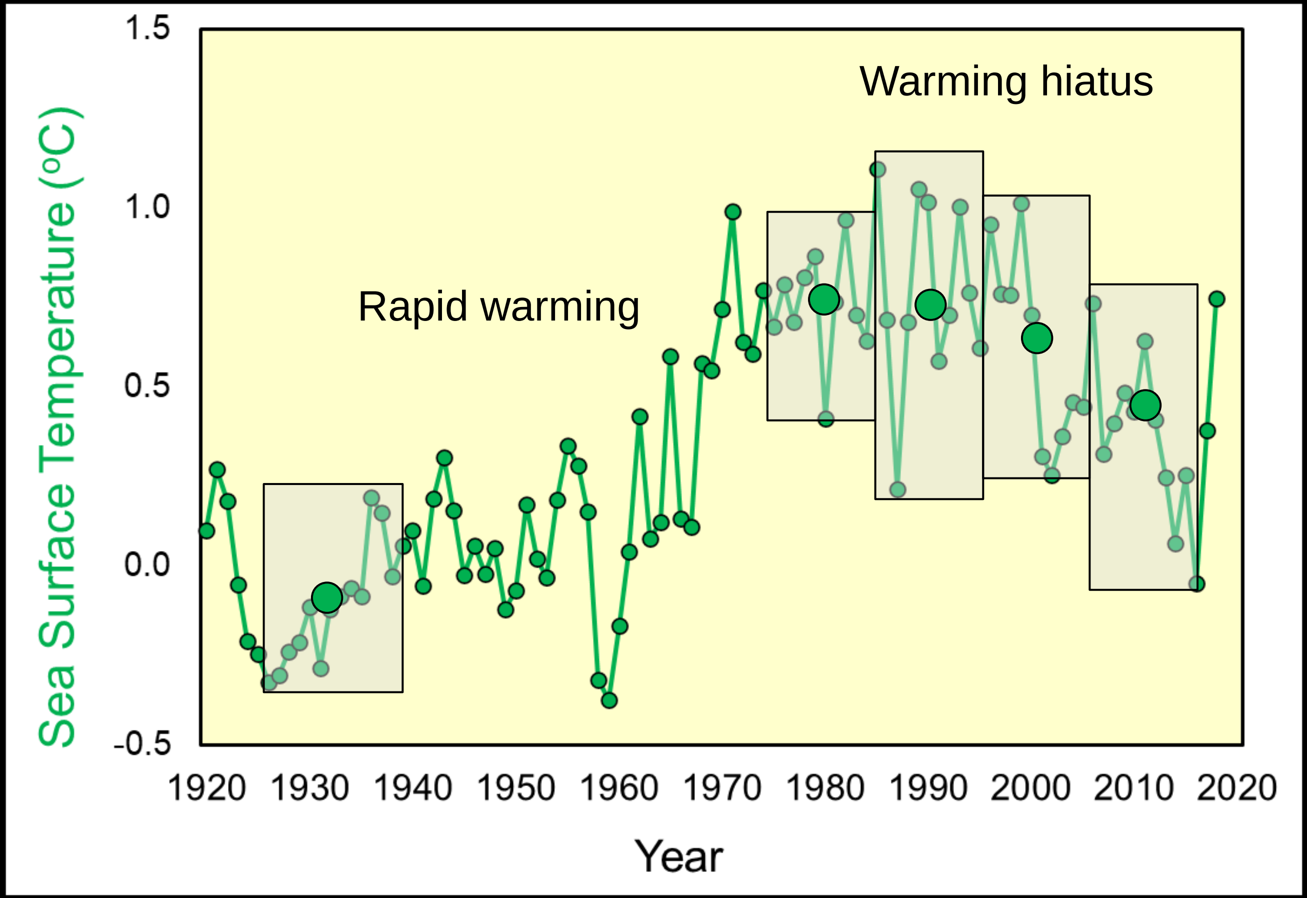
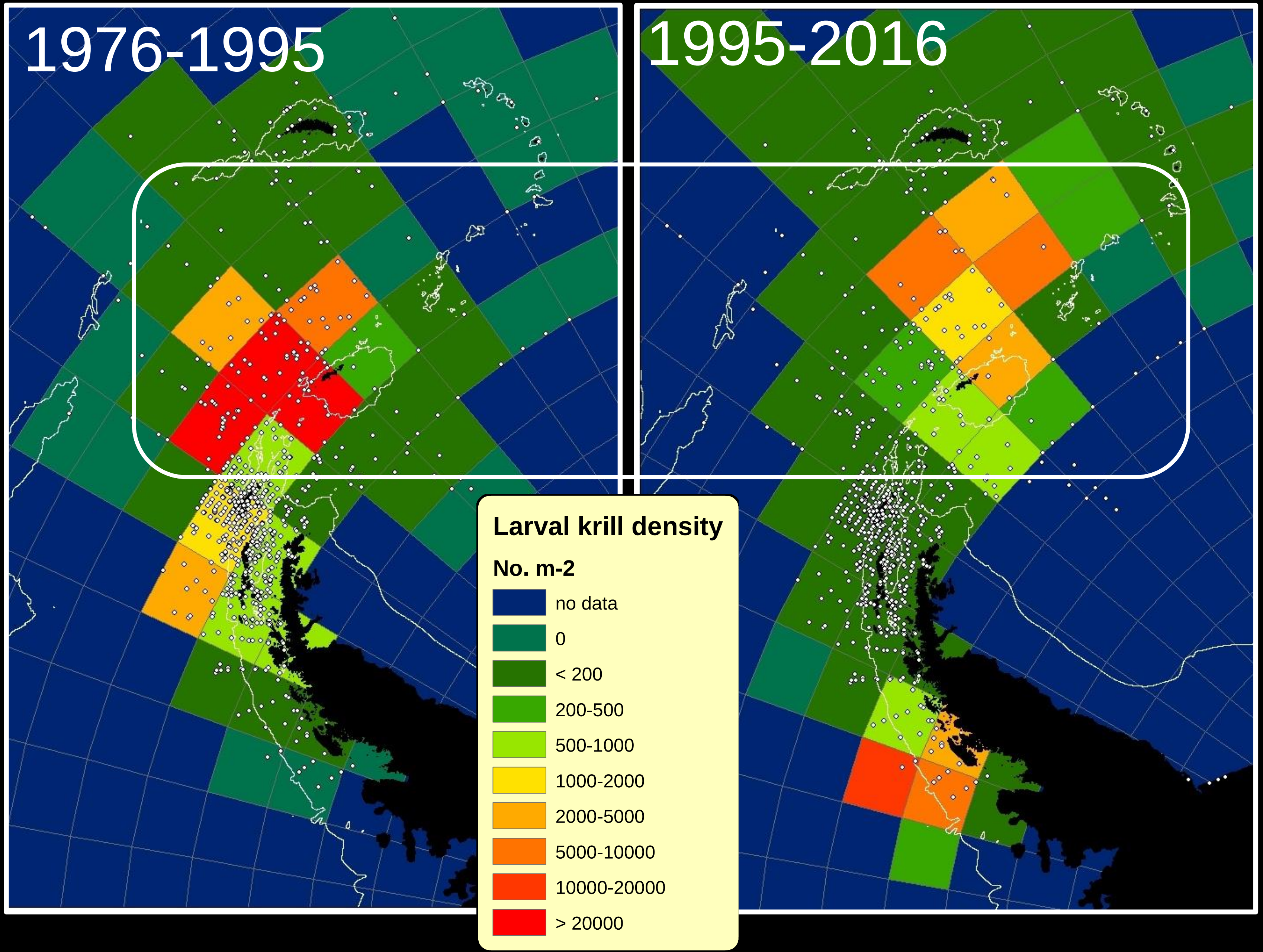


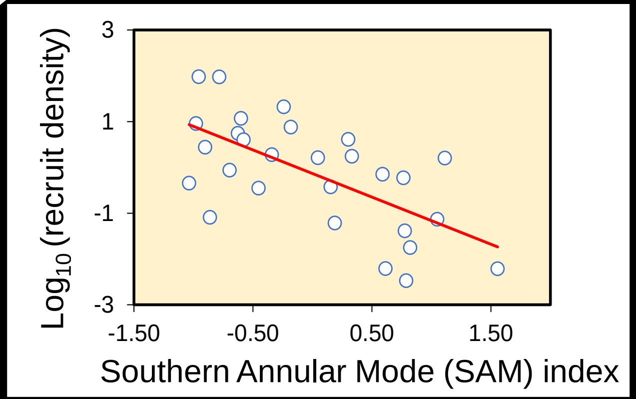




Krill adult and larval distributions jumped 1000 km upstream in a few decades, and during a pause in warming

The mechanism? ……..larvae provide some clues





Increasingly positive SAM impacts main spawning ground, cutting supply of young krill to the north

Atkinson et al.
(*Global Change Biology* 2022)

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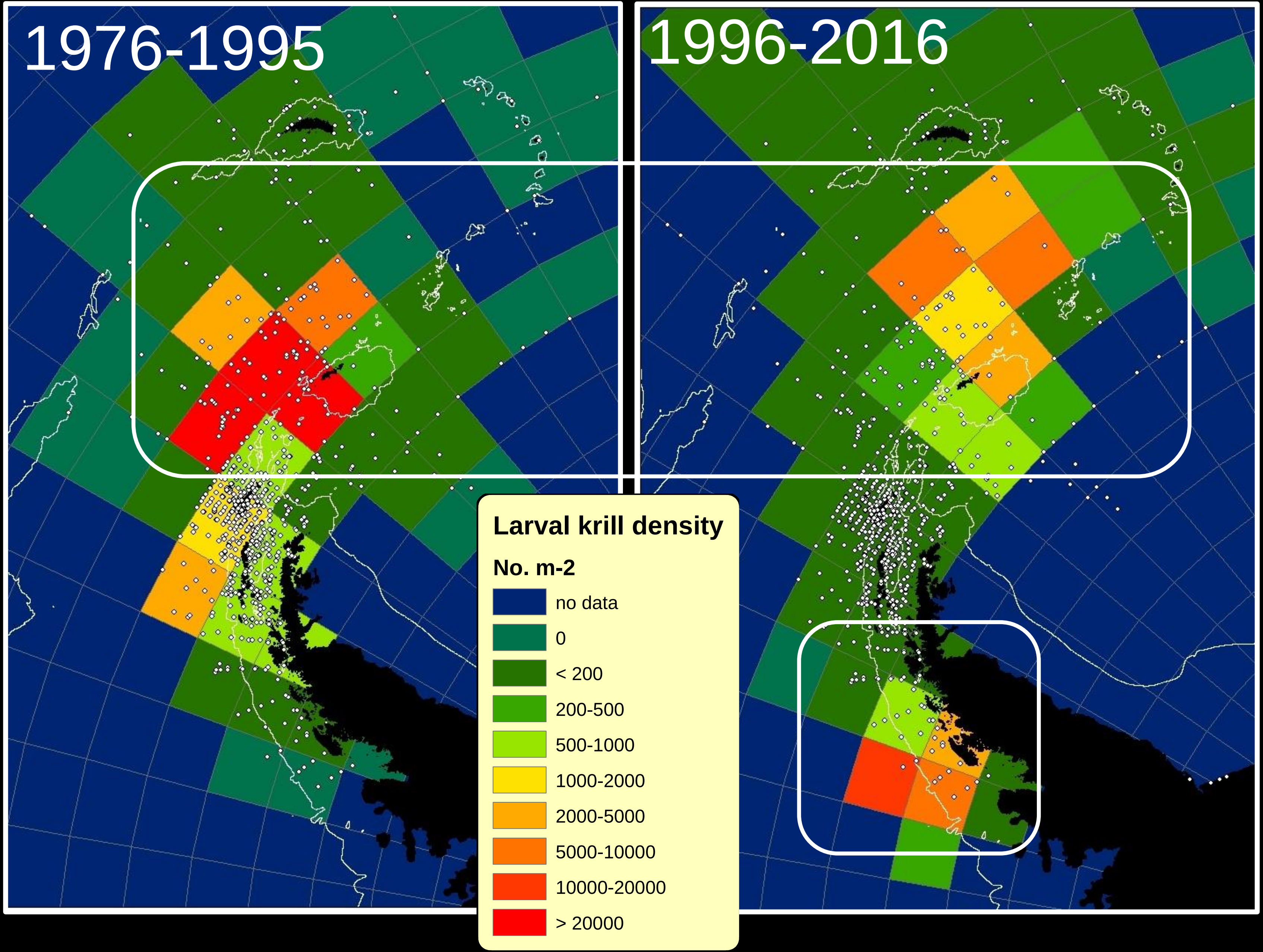
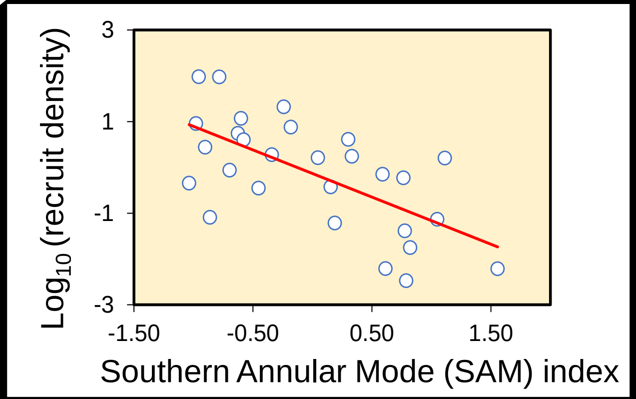


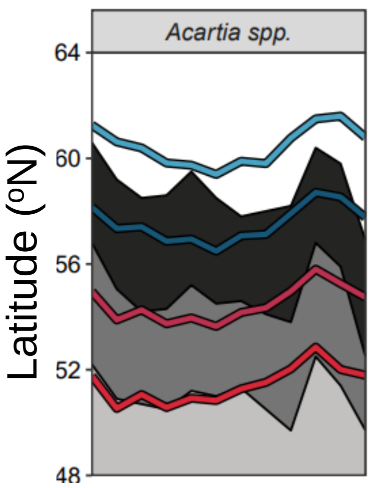


Increasingly positive SAM impacts main spawning ground, cutting supply of young krill to the north

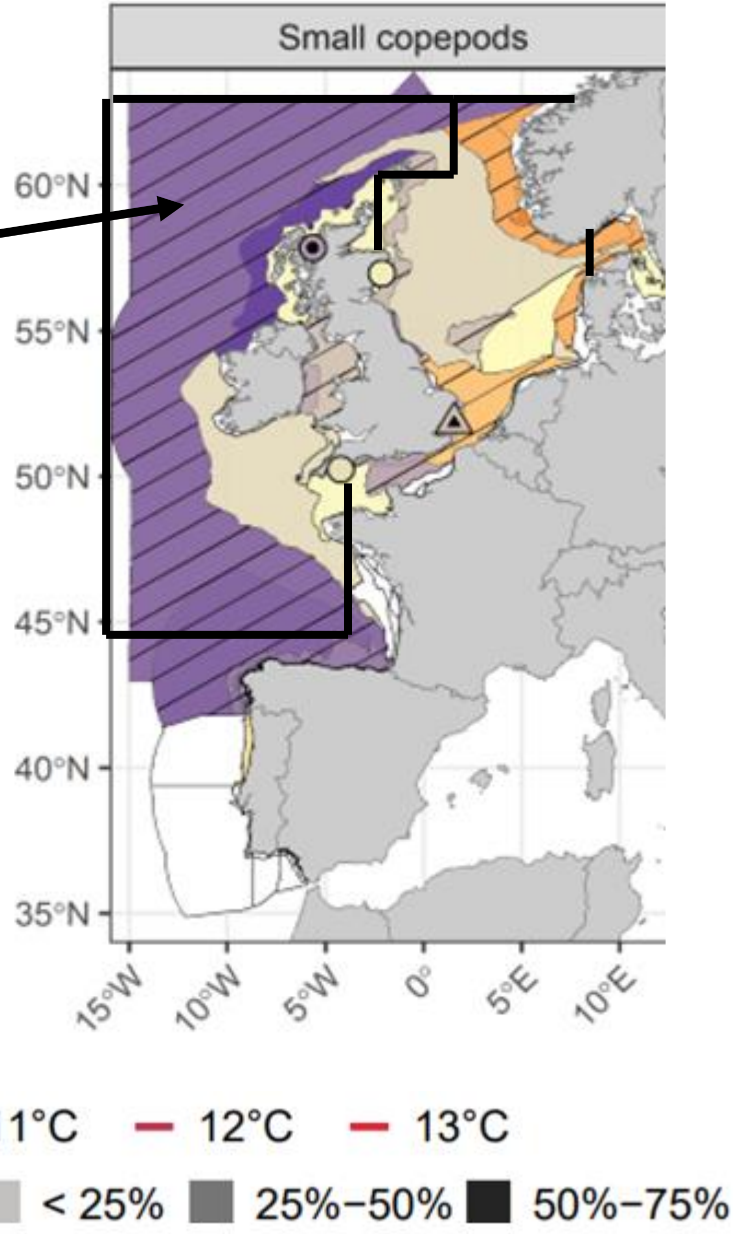
Importance of an alternative, southern spawning ground increases

Atkinson et al.
(*Global Change Biology* 2022)

Regional differences in resilience to warming

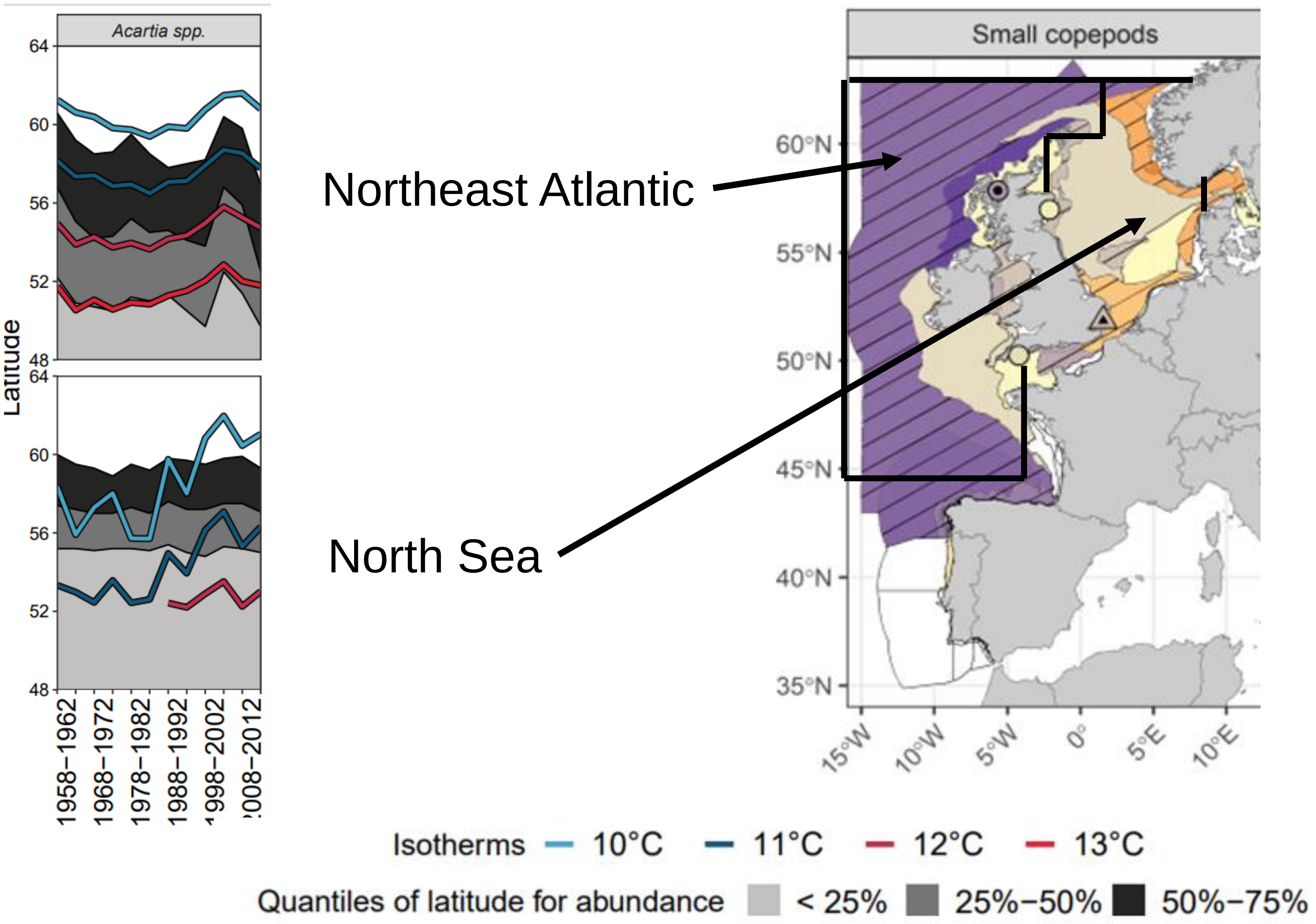


Northeast Atlantic



Corona et al. (in prep)

Regional differences in resilience to warming



Corona et al. (in prep)

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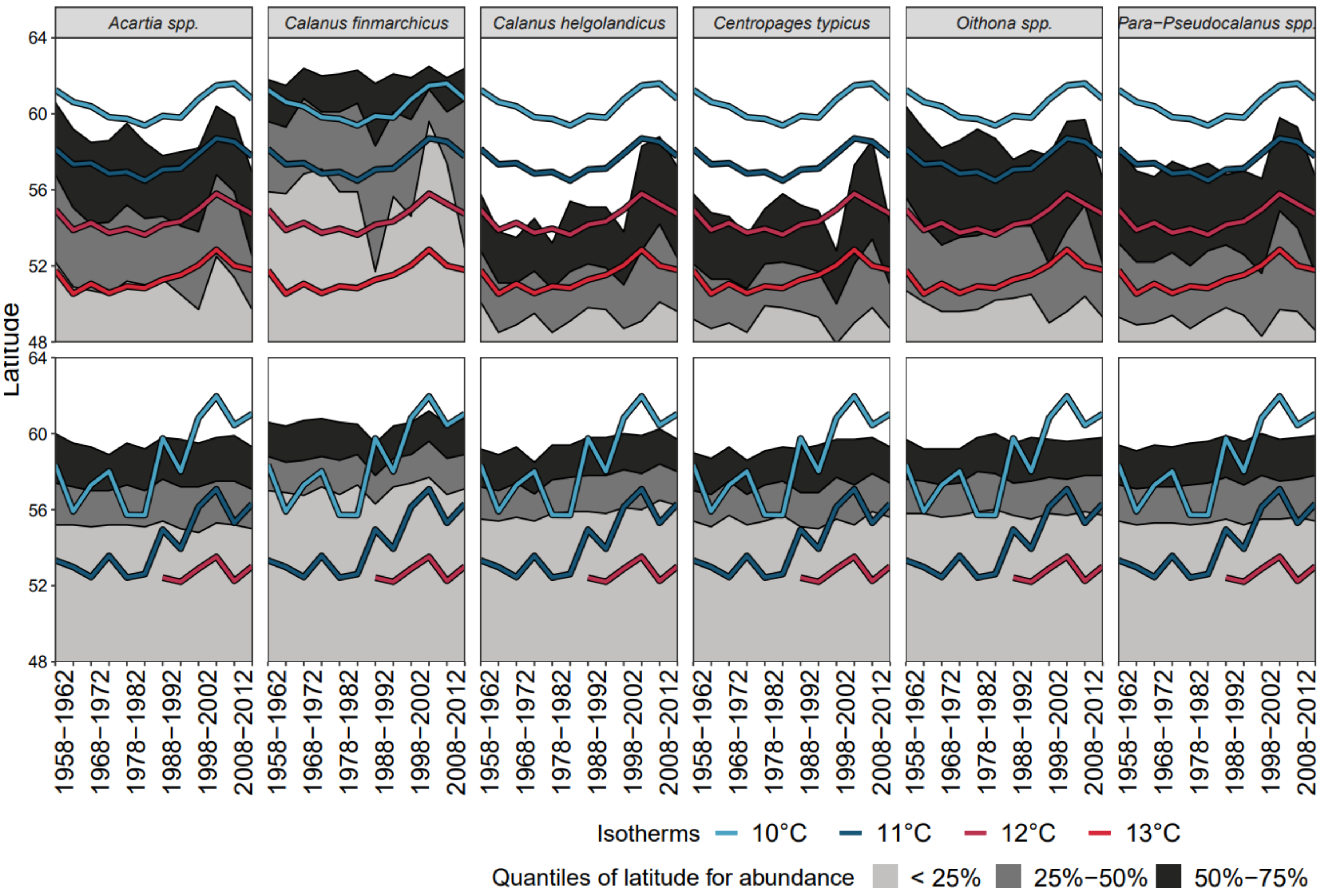


Northeast Atlantic

Moving with isotherms
Maintaining fixed thermal niche

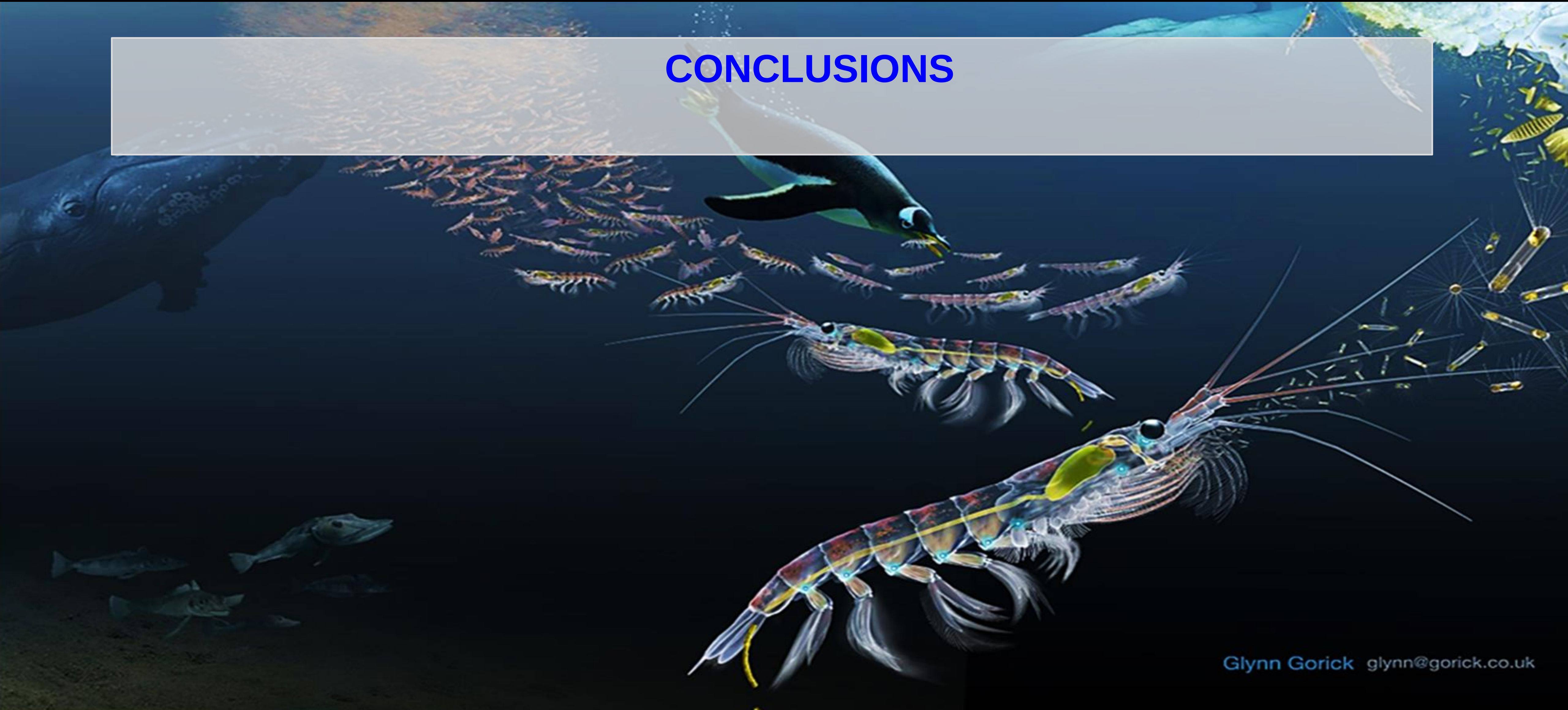
North Sea

Rapid warming
Fixed distribution
Resilience to warming

Corona et al. (in prep)

New dawn fades: returning to dark data amid a zooplankton technology revolution

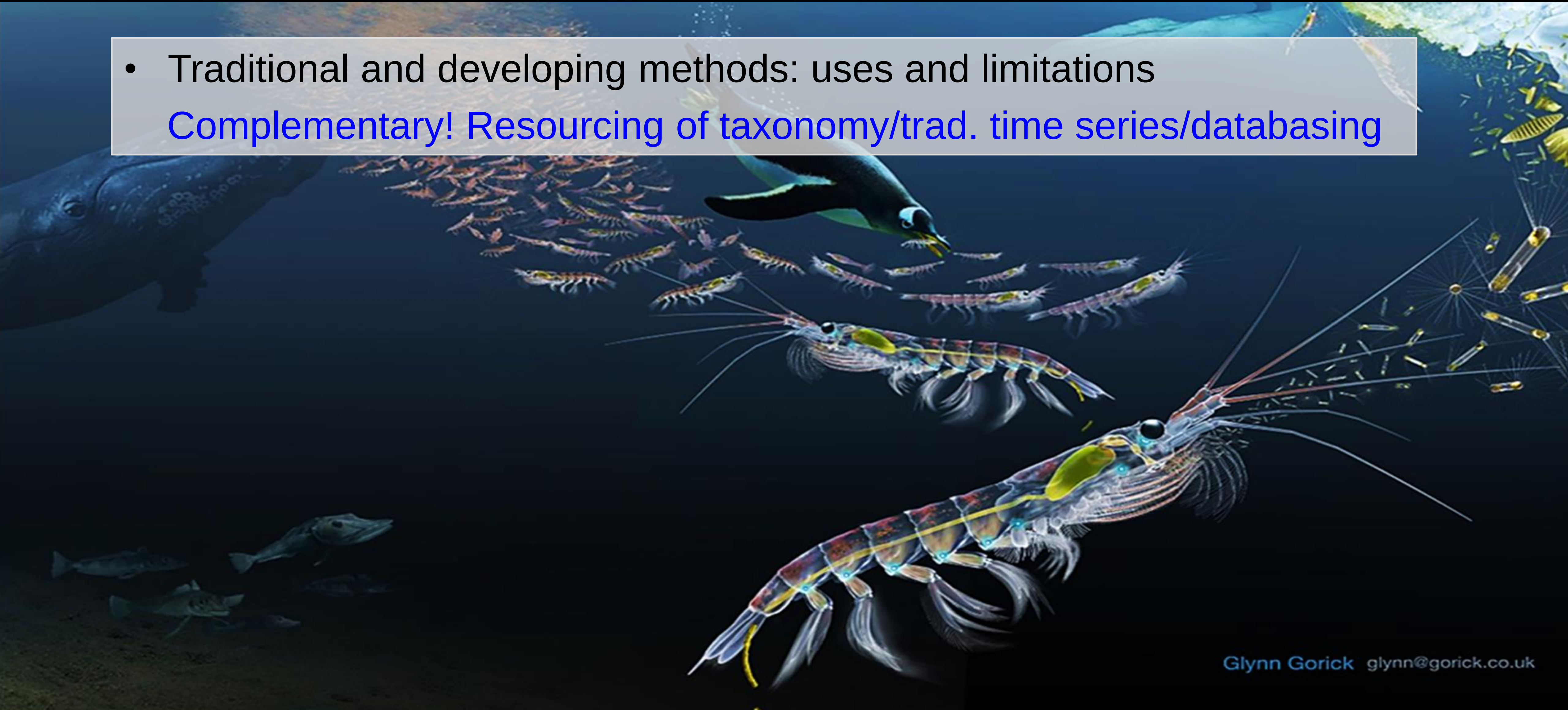
CONCLUSIONS



New dawn fades: returning to dark data amid a zooplankton technology revolution

- Traditional and developing methods: uses and limitations

  Complementary! Resourcing of taxonomy/trad. time series/databasing



New dawn fades: returning to dark data amid a zooplankton technology revolution

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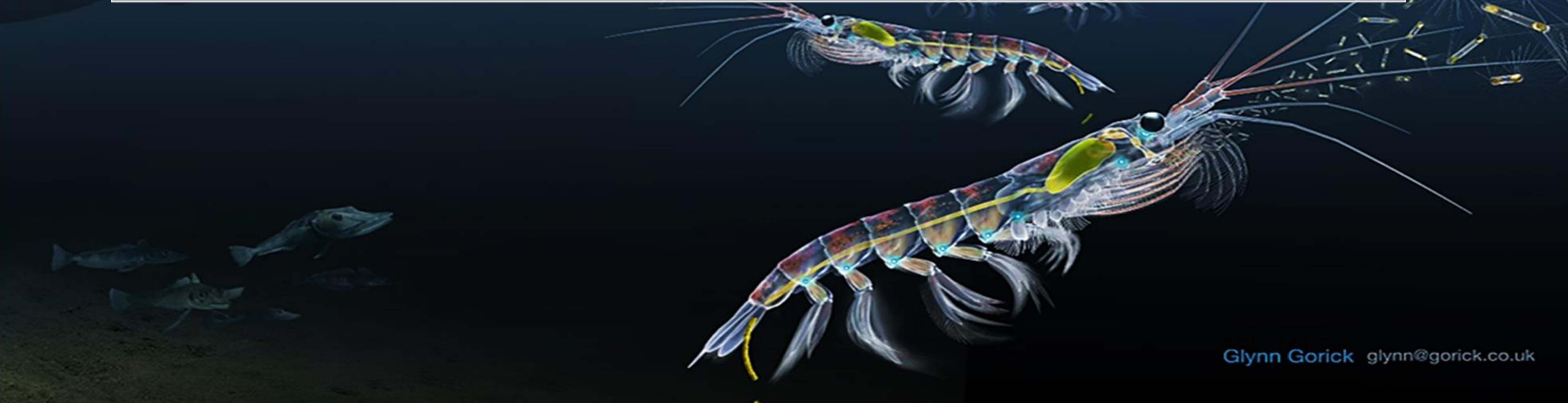
- Size- versus taxonomic-based approaches

  Highly complementary approaches to complex ecology



New dawn fades: returning to dark data amid a zooplankton technology revolution

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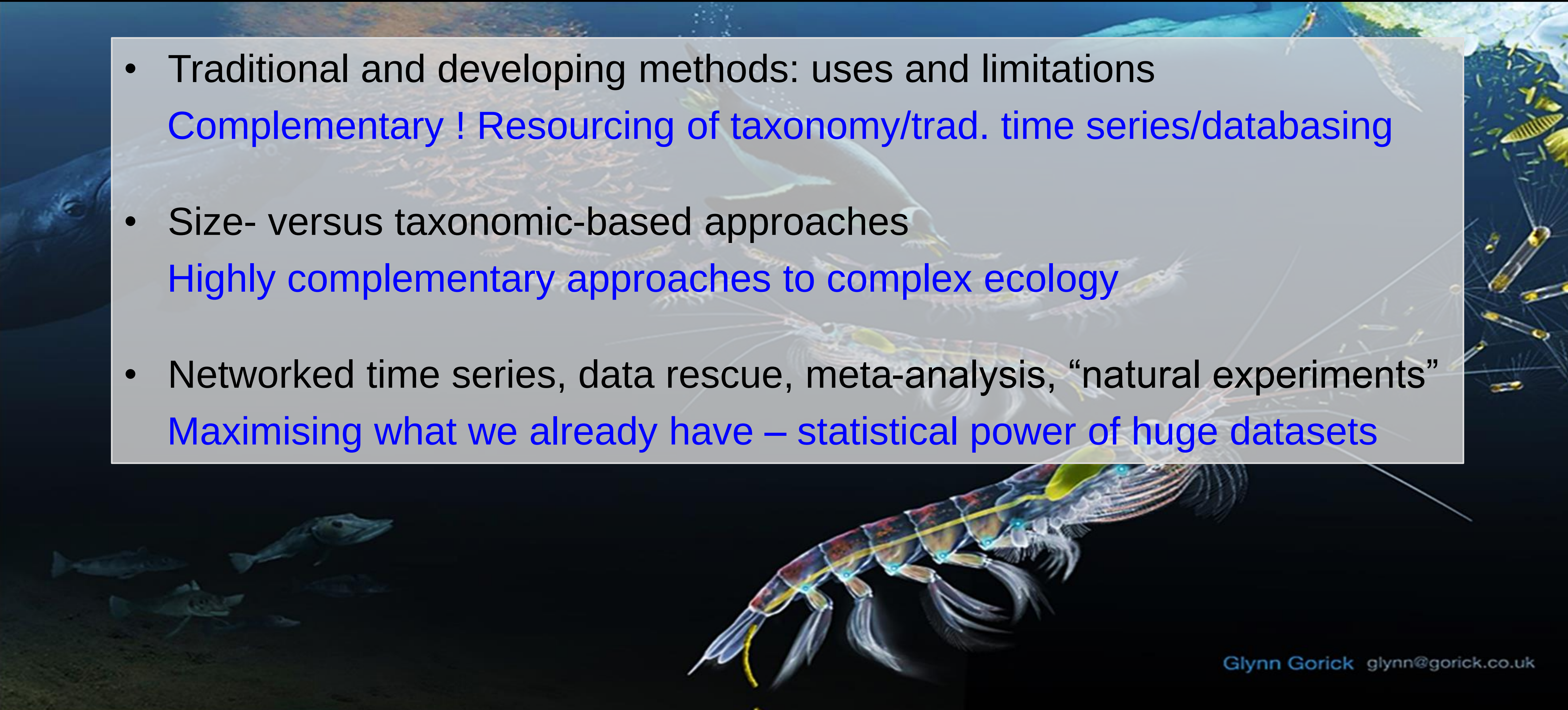
- Networked time series, data rescue, meta-analysis, “natural experiments”
  Maximising what we already have – statistical power of huge datasets



New dawn fades: returning to dark data amid a zooplankton technology revolution

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- Networked time series, data rescue, meta-analysis, “natural experiments”

  Maximising what we already have – statistical power of huge datasets

- Resilience/acclimation/adaptation to warming

  Indirect temperature effects, many examples of resilience/nonlinearities