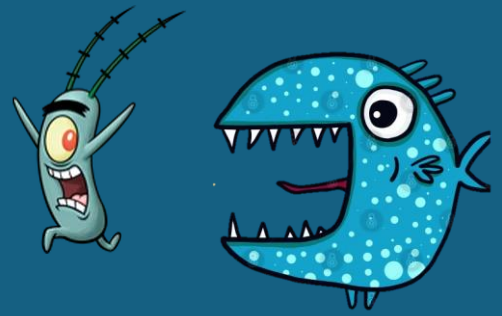
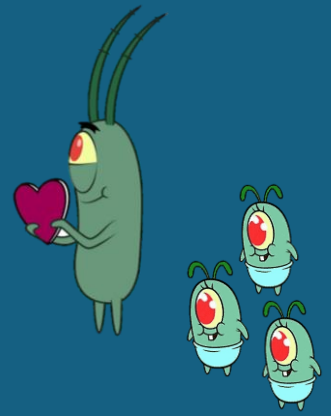




EAT PREY LOVE

Can **functional traits** provide insight into **bottom-up** vs **top-down** forcing and long-term **distribution** patterns of **copepods** on the **Agulhas Bank**?

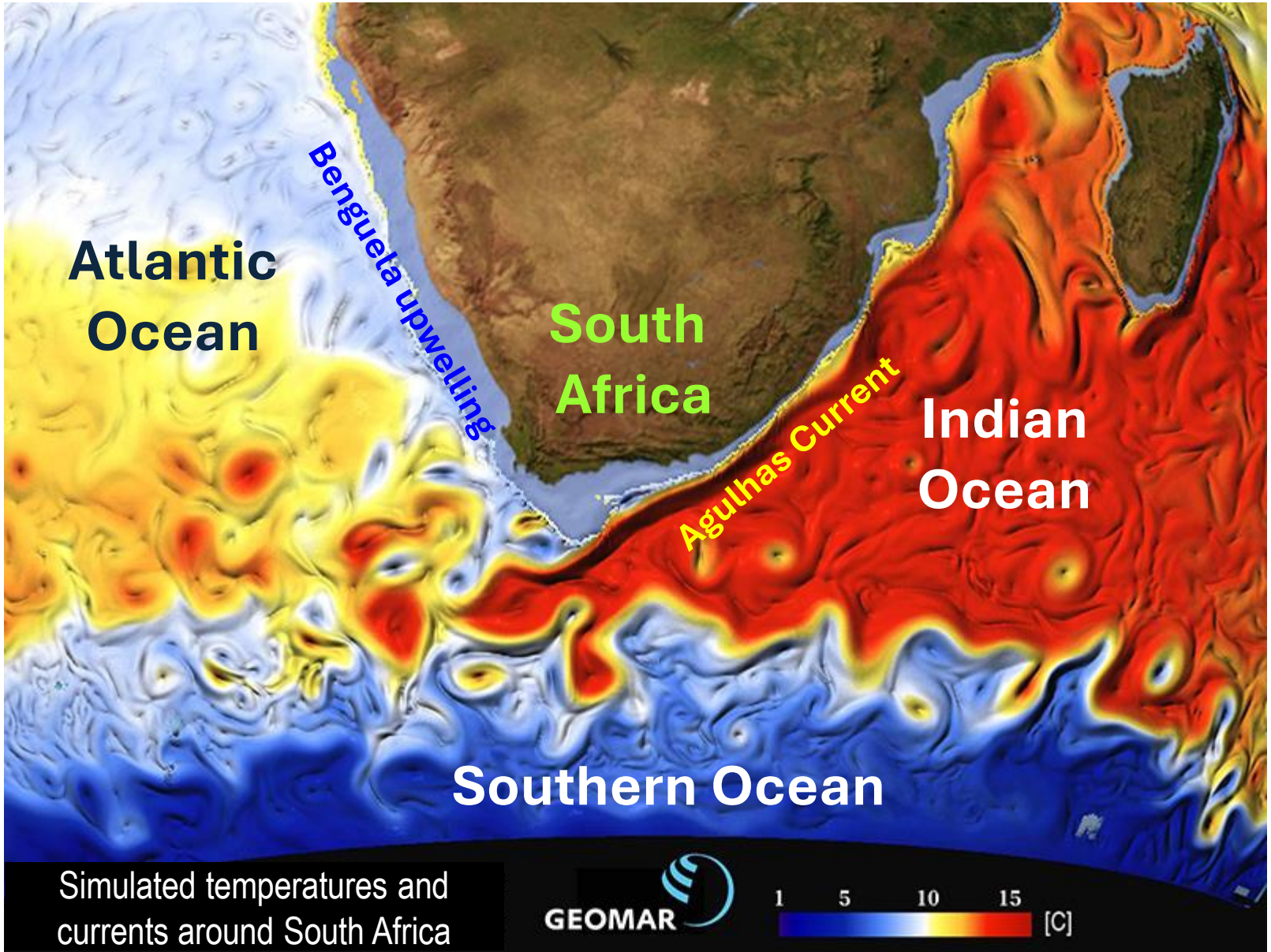
forestry, fisheries and the environment
Department:
Forestry, Fisheries and the Environment
REPUBLIC OF SOUTH AFRICA

Jenny Huggett
Tarron Lamont
Janet Coetzee

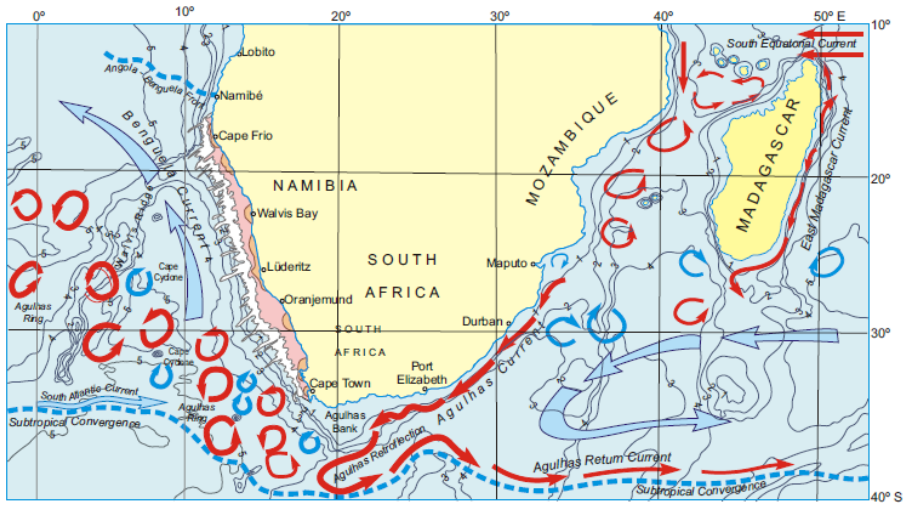
Jacob Carstensen
Hans Jakobsen
Eva Friis Moller

AARHUS UNIVERSITY

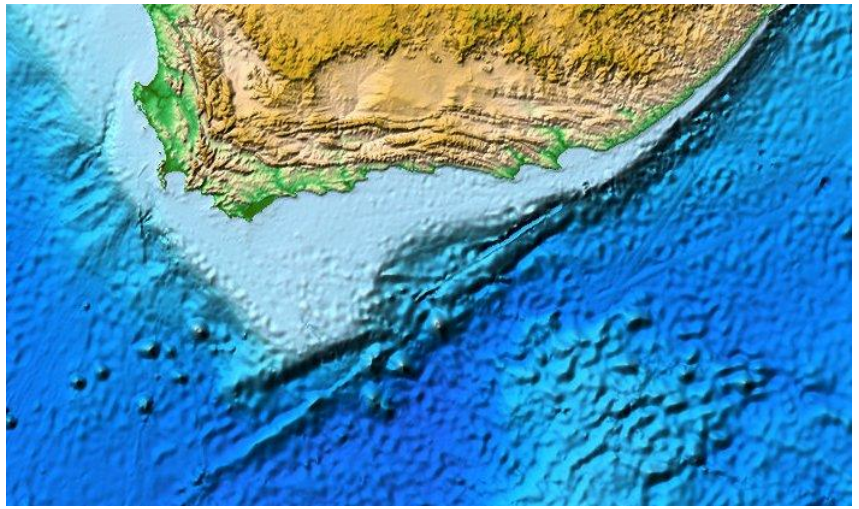
The Agulhas Bank – influenced by 3 oceans



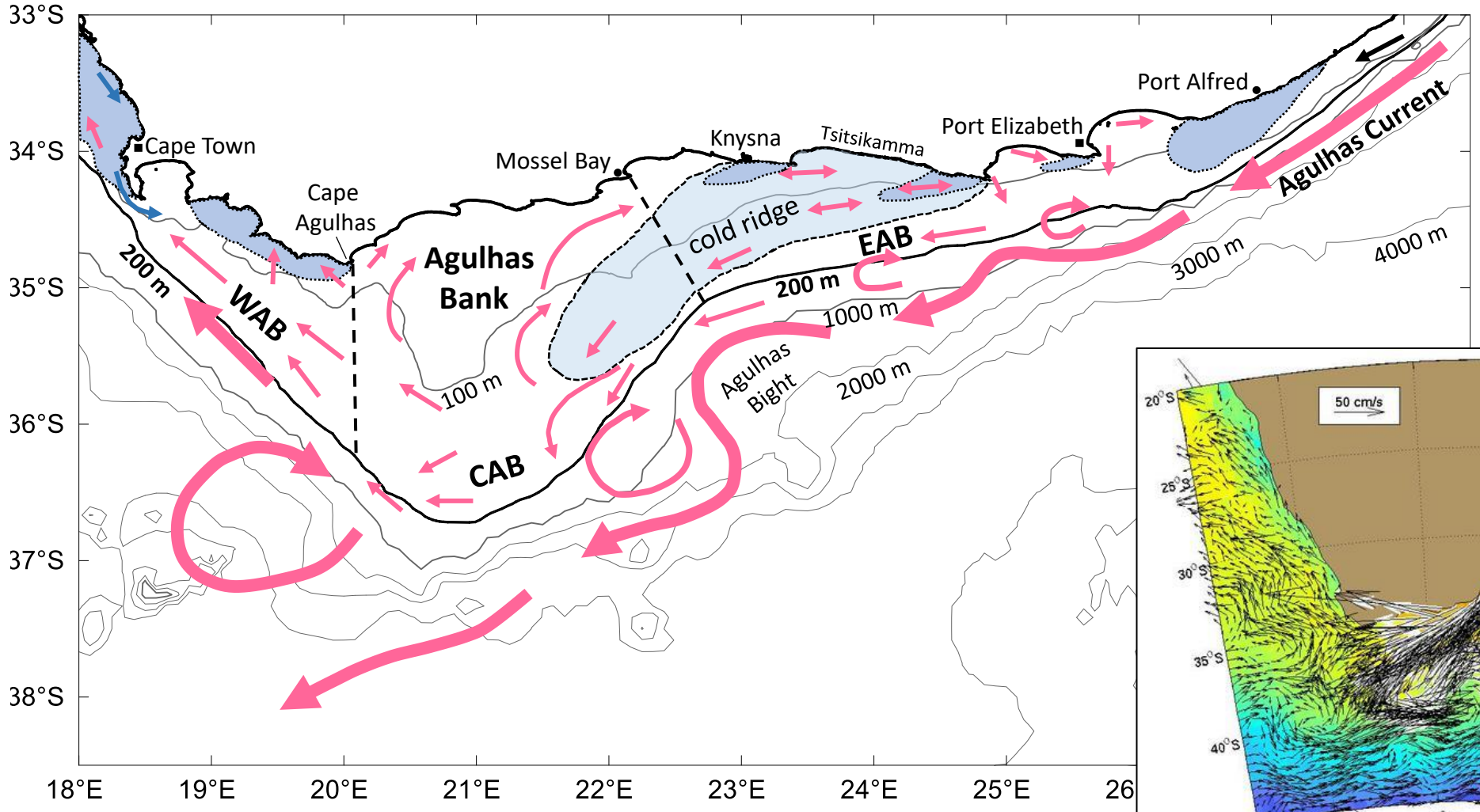
Simulated temperatures and currents around South Africa

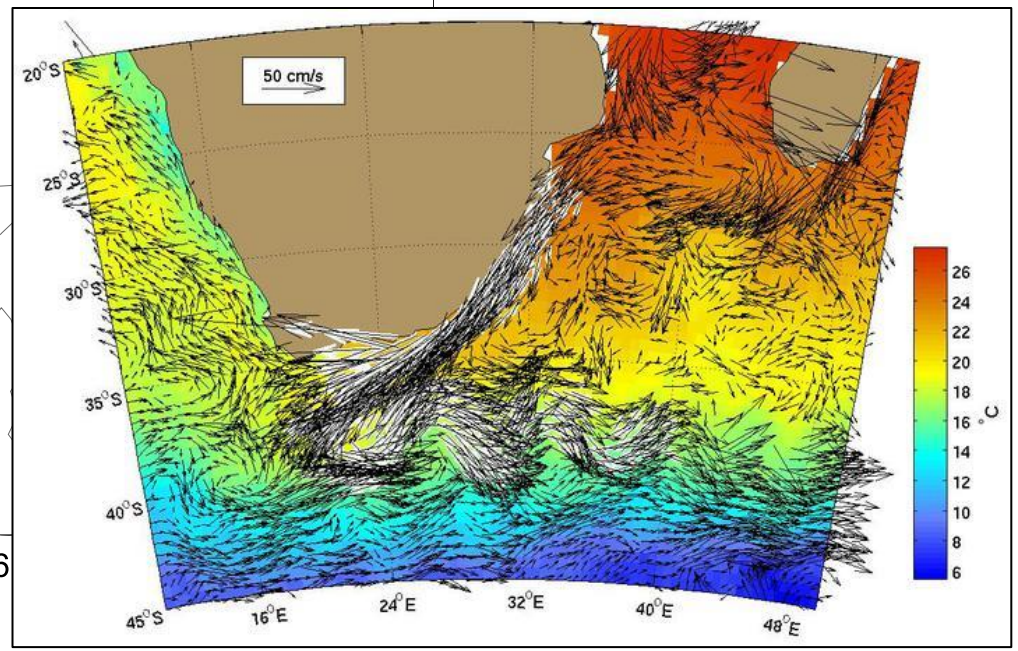


Agulhas Current = strongest WBC



The Agulhas Bank – circulation patterns





Huggett et al. (2023) – Deep-Sea Res **208**: 105265.

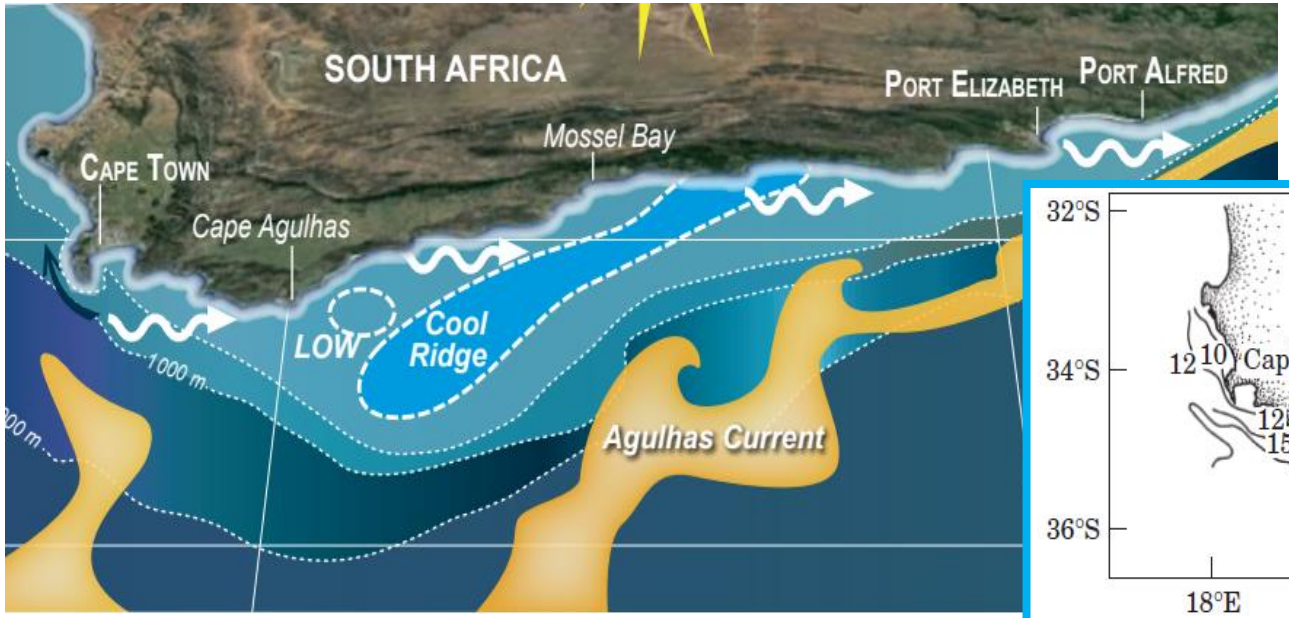
https://oceancurrents.rsmas.miami.edu/atlantic/agulhas_2.html

Calanus & the cold ridge

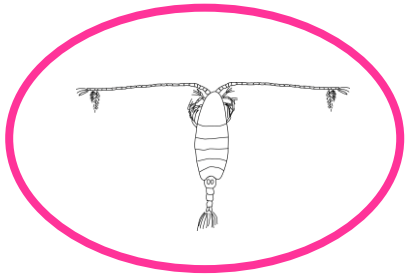
- Seasonal, subsurface ridge of cool, upwelled water
- ***Calanus agulhensis*** concentrated on Agulhas Bank
- Centre of distribution associated with the cold ridge*
- Higher Chl *a* -> enhanced copepod production
- Cyclonic flow around ridge -> enhanced retention

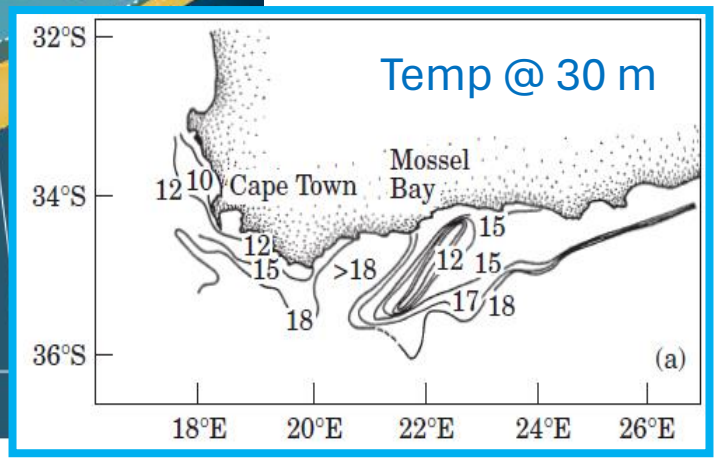
*<17°C water at 30 m

MODIS Aqua, 12 December 2018 © NASA Worldview.

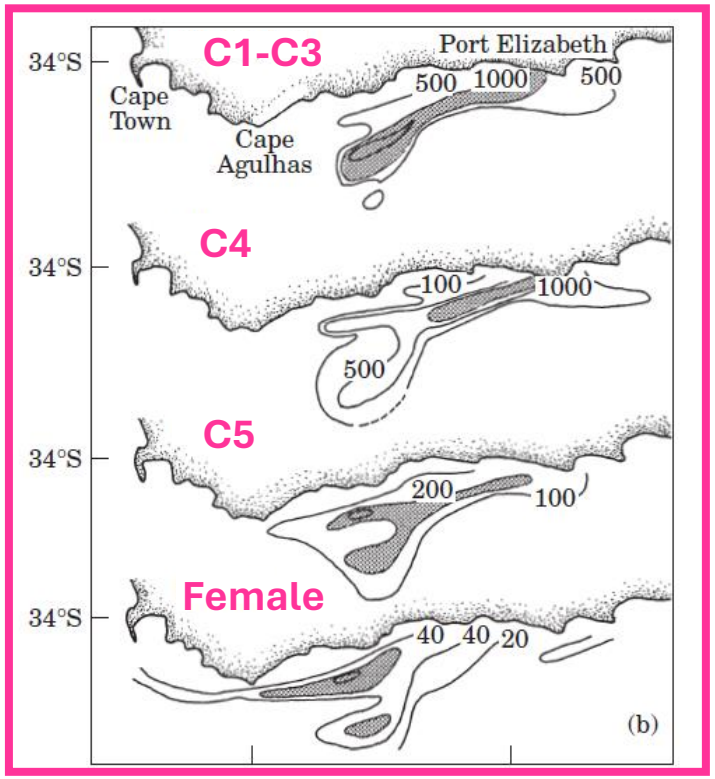


Kirkman et al. (2016) *Afr. J. Mar Sci* **38**: 7-22.





Huggett & Richardson (2000) *ICES J mar Sci.* **57:** 1834–1849
[after Peterson et al., 1992; Largier et al., 1992]



Env changes / ecosystem shifts on Agulhas Bank

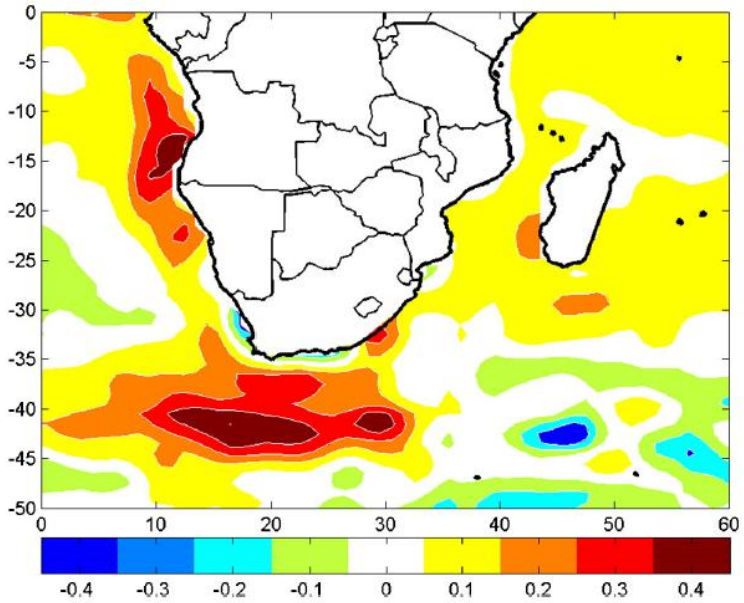
Abrupt environmental shift associated with changes in the distribution of Cape anchovy *Engraulis encrasicolus* spawners in the southern Benguela

C Roy[1*], CD van der Lingen[2,3], JC Coetzee[2] and JRE Lutjeharms[4]

Broadening not strengthening of the Agulhas Current since the early 1990s

Lisa M. Beal[1] & Shane Elipot[1]

Linear trend in Reynolds SST
(°C per decade; 1982-2012)



Rouault et al. 2010; Blamey et al. 2015

Long-term decline in *Calanus agulhensis* (1988-2011)

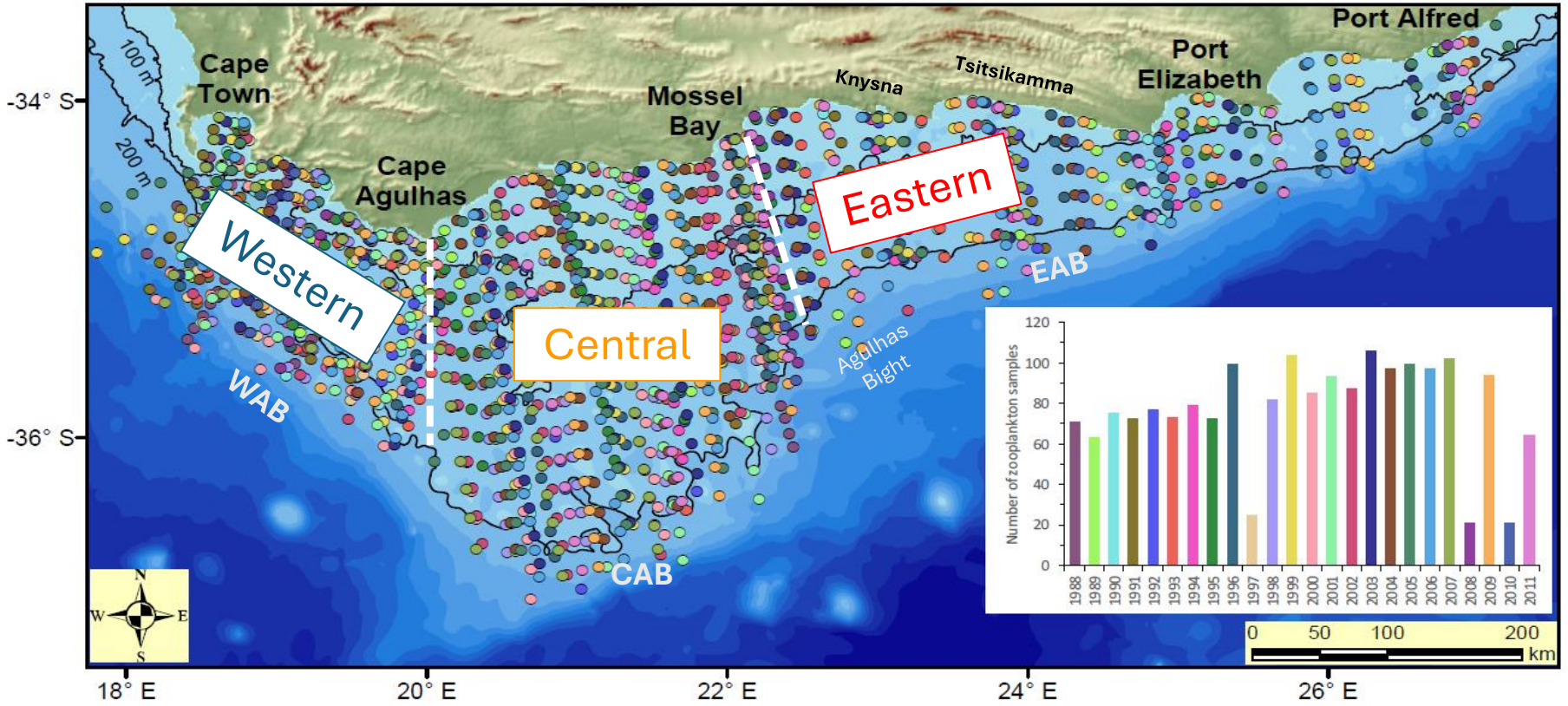
What about the other copepod species?

Cooling inshore
Warming offshore

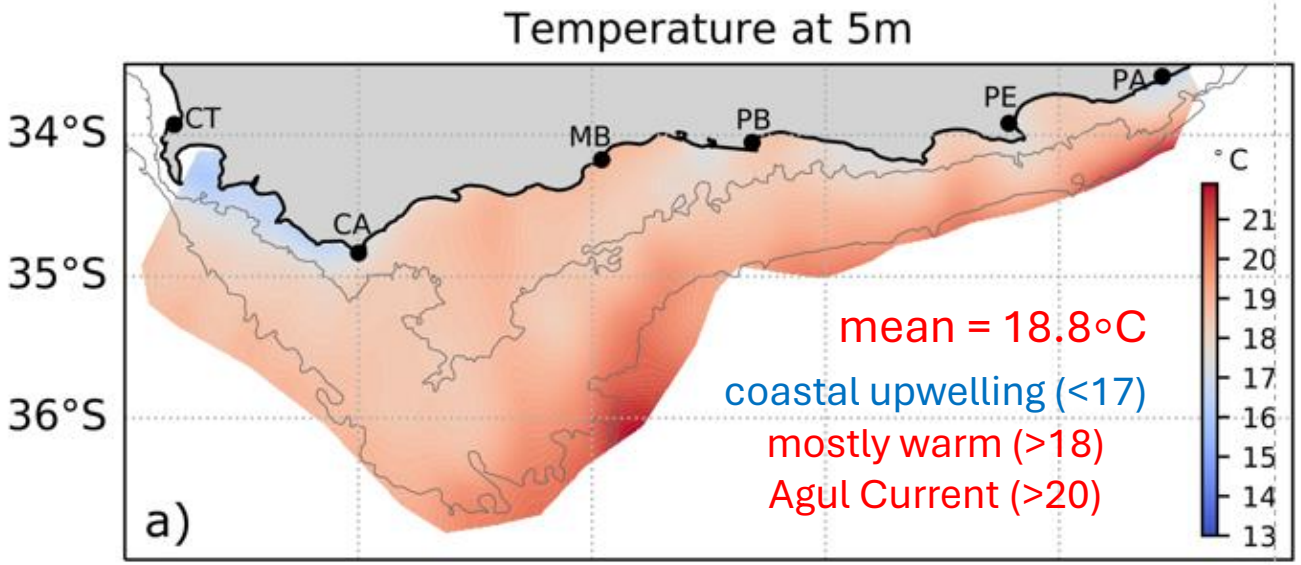
Distribution patterns & long-term variability ?

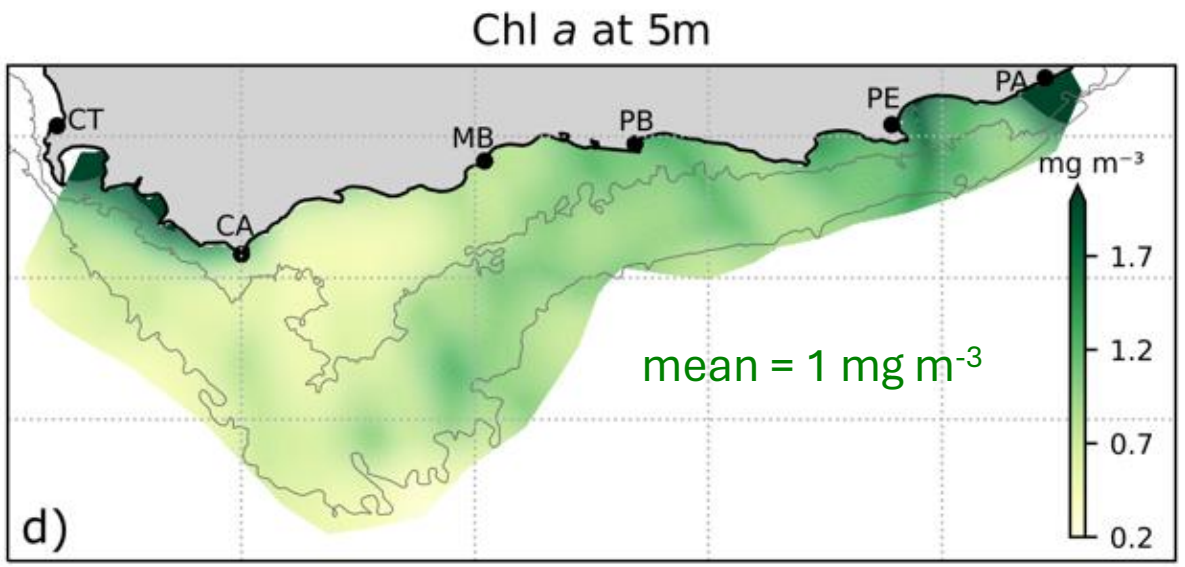
Sampling & data processing

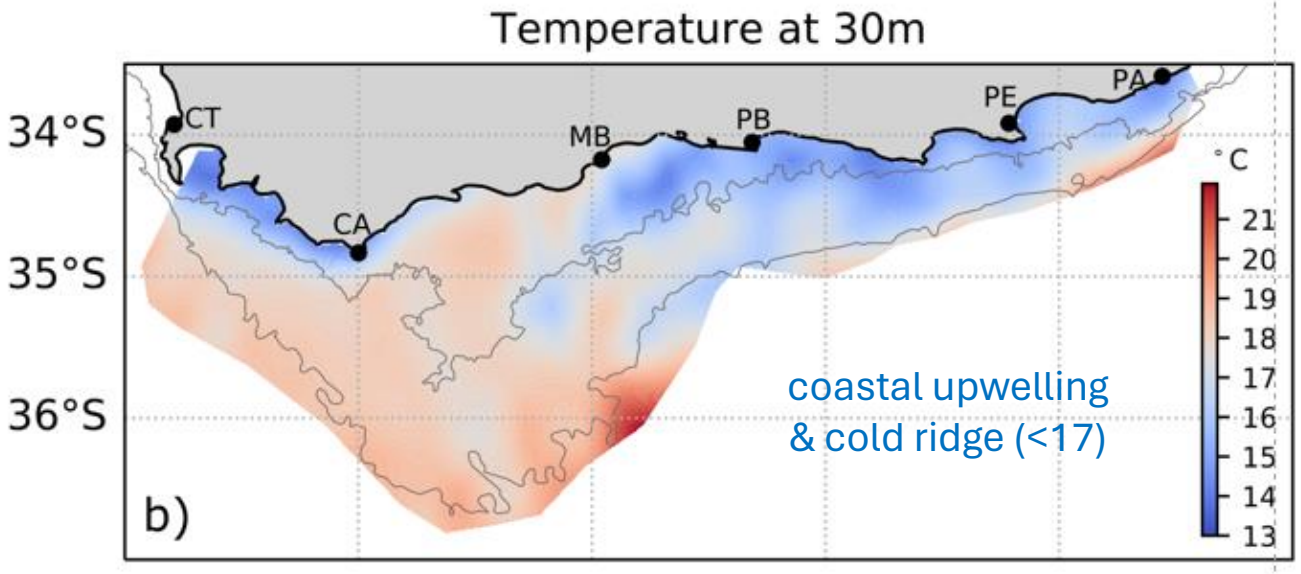
- **Annual** pelagic fish surveys in ~**November** (late spring) from **1988-2011 (24 years)**
- Vertical Bongo net (200 µm-mesh) hauls in upper 200 m (focus on copepods)
- GAMs (Generalised Additive Models) -> mean spatial distributions
- Ordinary Kriging analysis of residuals -> distribution maps for individual years
- Environmental data - in situ temperature & fluorescence (vertical profiles)

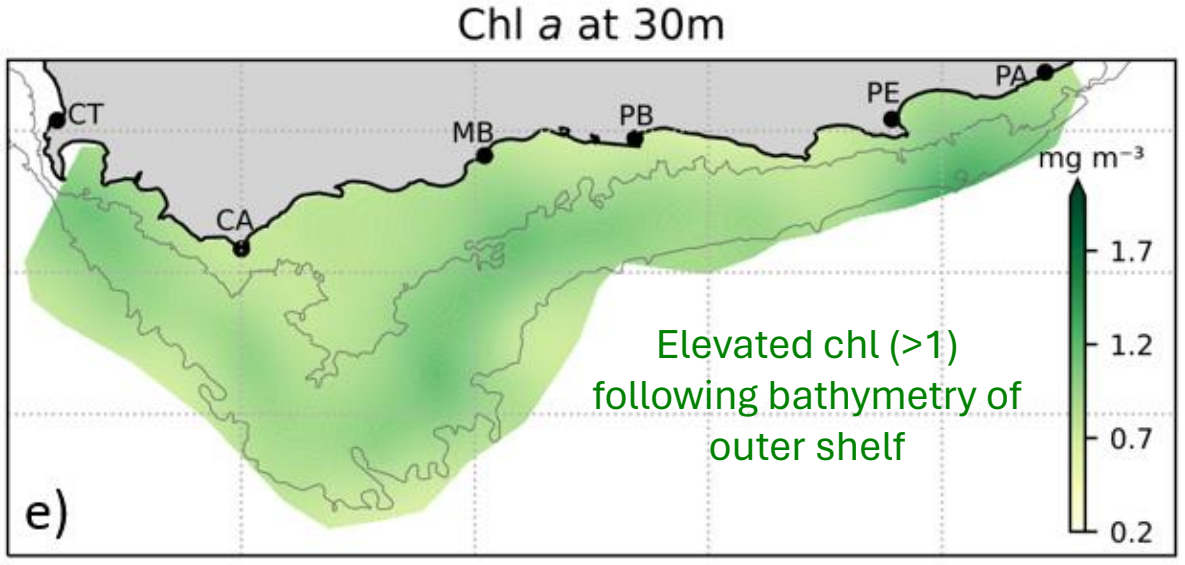


In situ data confirms cold ridge-driven production



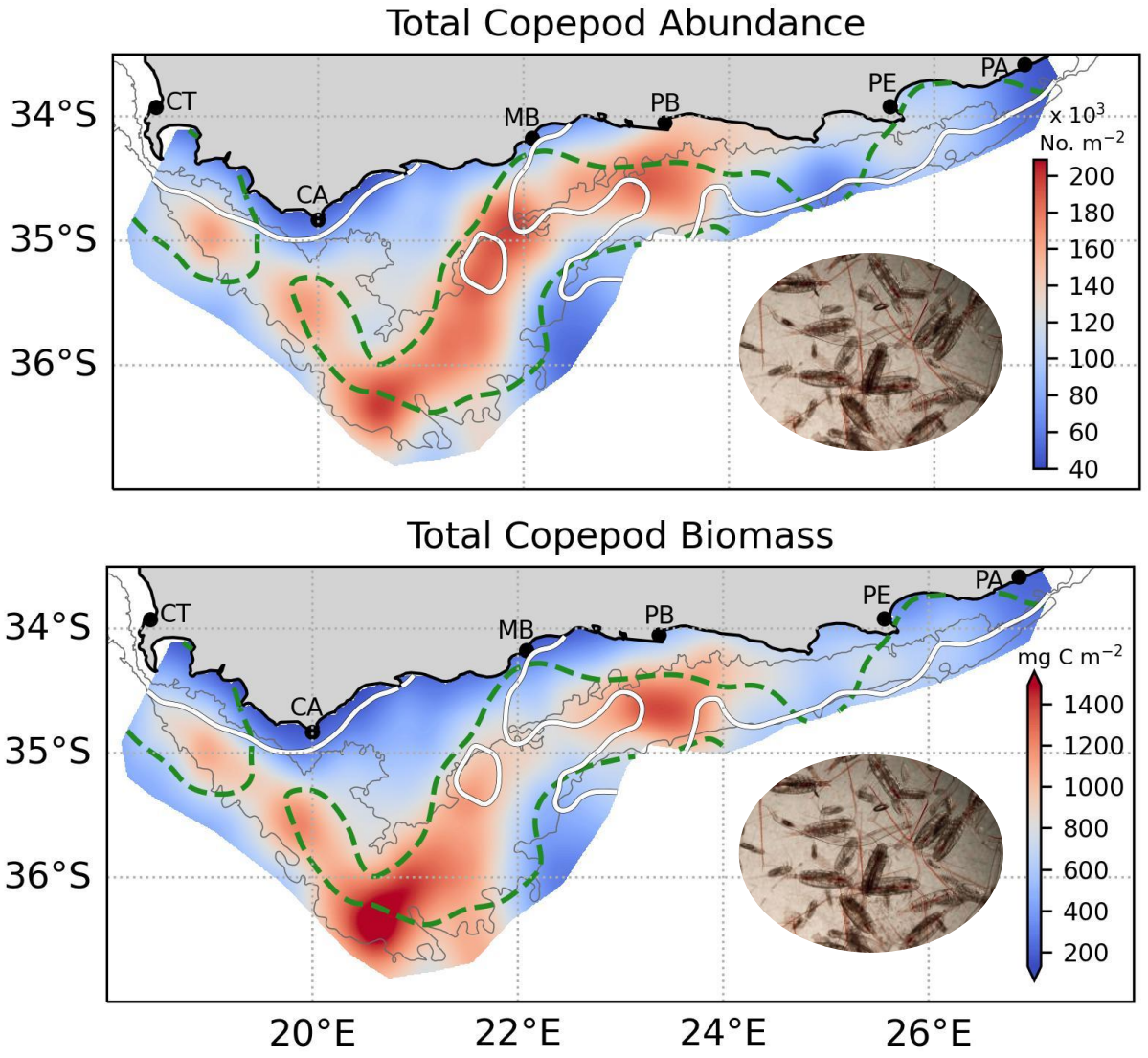






Huggett et al. (2023) – Deep-Sea Res **208**: 105265.

Mean distribution patterns – all copepods



Key:

mean 17°C isotherm at 30 m

mean 0.9 mg m^{-3} chl *a* isoline at 30 m

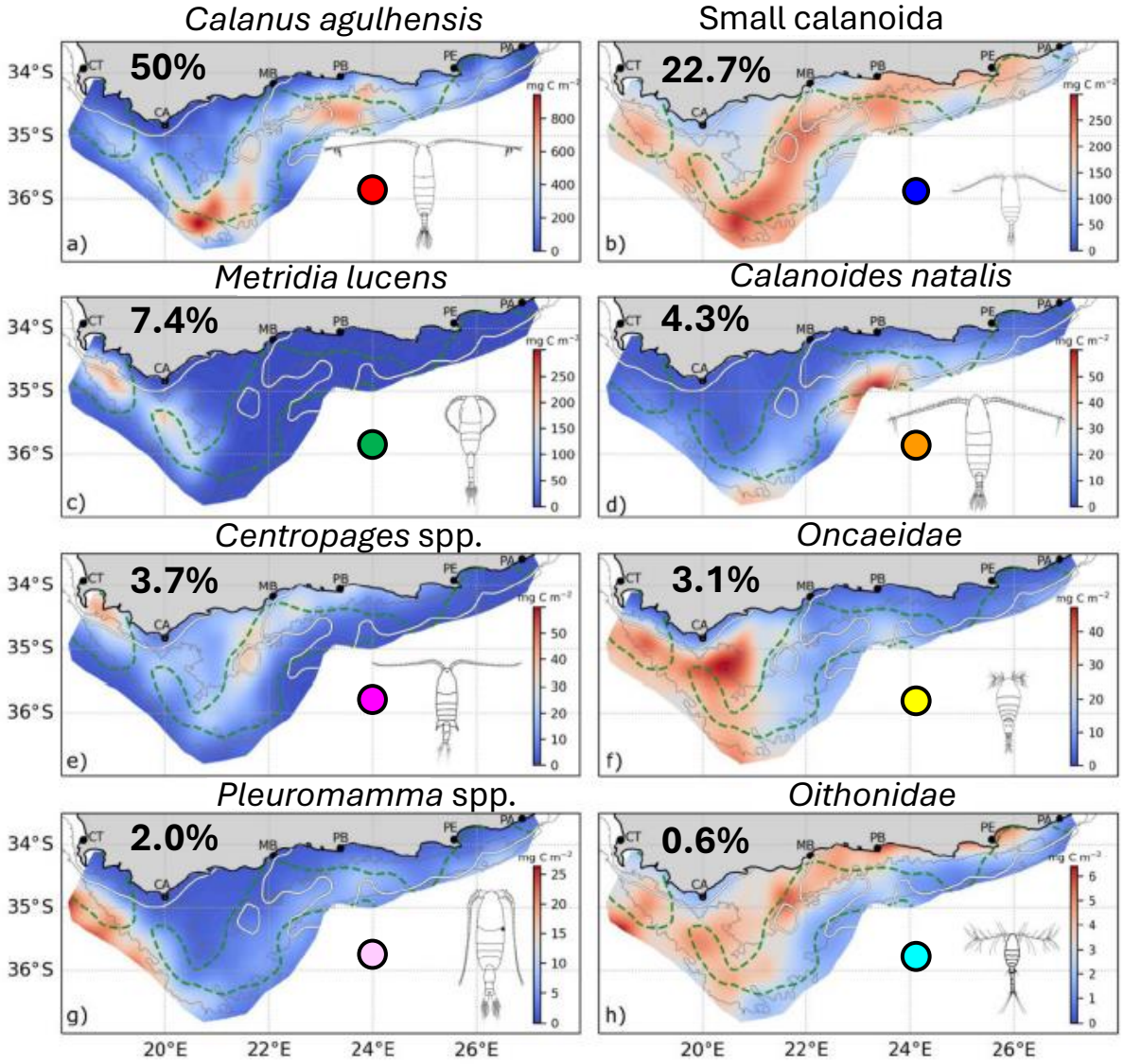
- Concentrated along 100 m isobath (EAB)
- Further offshore W of Mossel Bay (CAB)
- Follows flow path over outer shelf (WAB)

Areas of greatest abundance and biomass overlapped broadly with the region of elevated chl *a* at 30 m depth

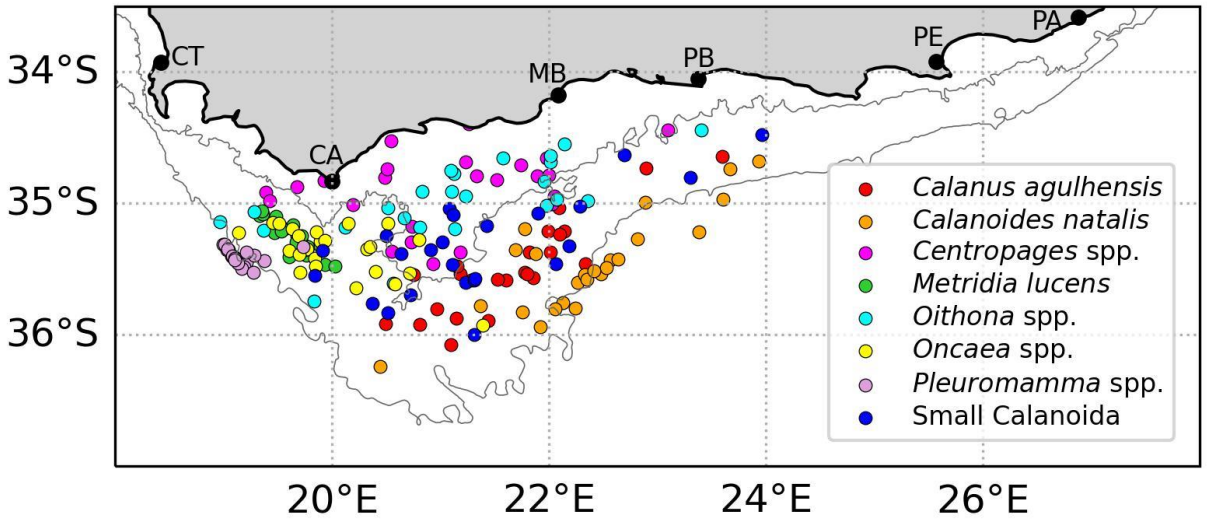
- Similar to abundance, most concentrated beyond 100 m
- Peak biomass near southern tip of AB

Huggett et al. (2023) – Deep-Sea Res **208**: 105265.

Dominant taxa* show varying spatial patterns



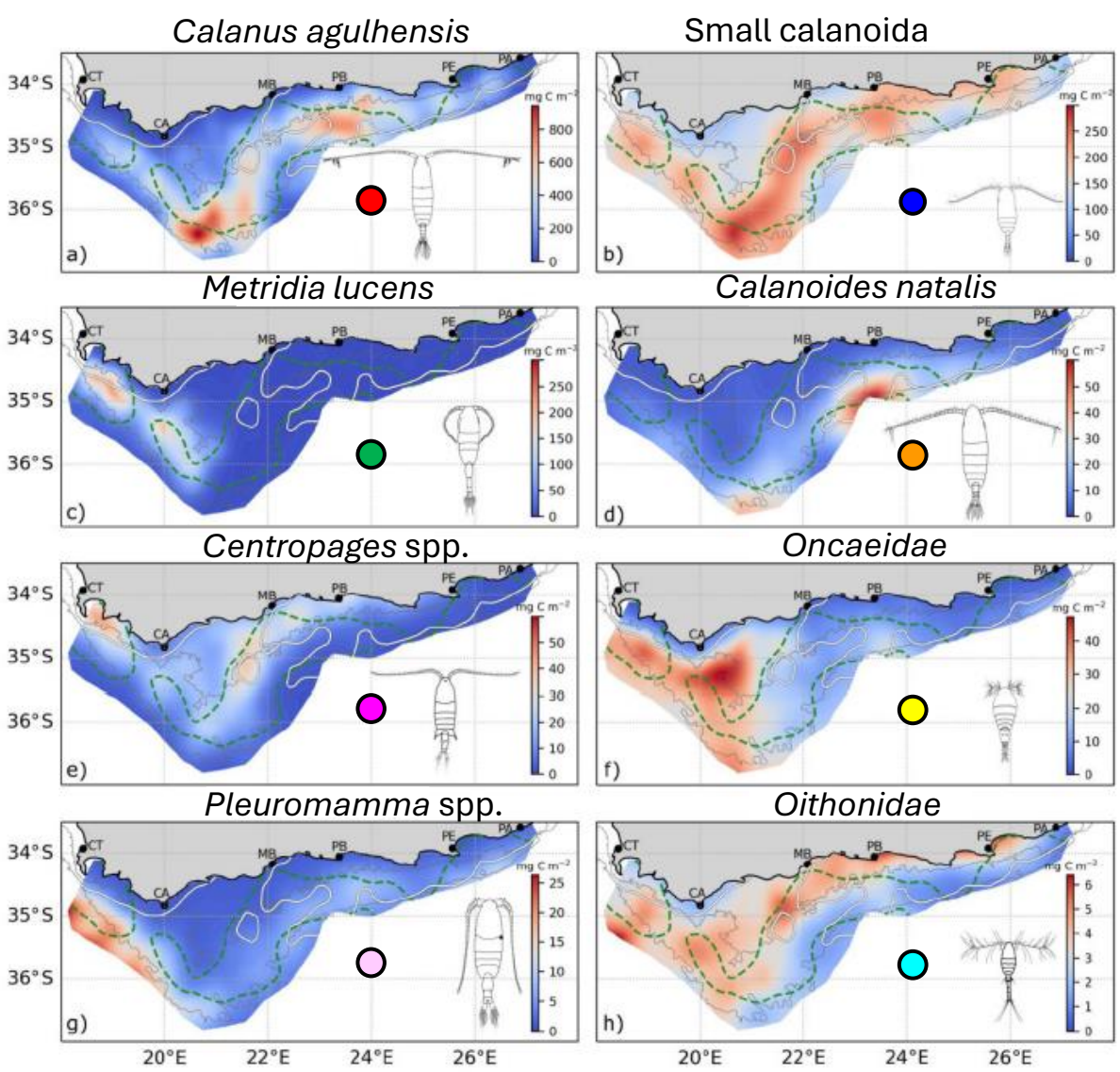
Centre of gravity of upper 10% of highest biomass values for the dominant copepod taxa during November-December 1988 to 2011 (each dot represents one survey)



* These 8 taxa together comprise 98% total copepod abundance & **94% total copepod biomass**

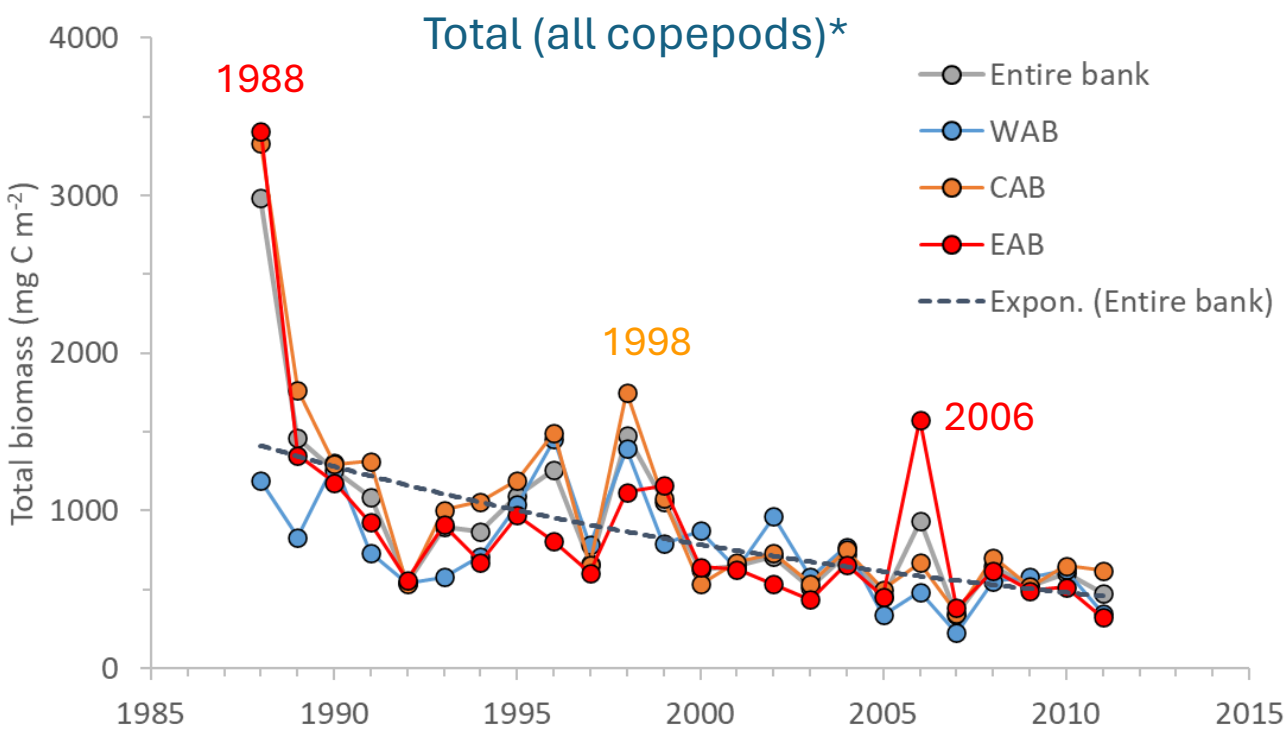
Huggett et al. (2023) – Deep-Sea Res **208**: 105265. **[% total copepod biomass]**

Dominant taxa show varying interannual variability

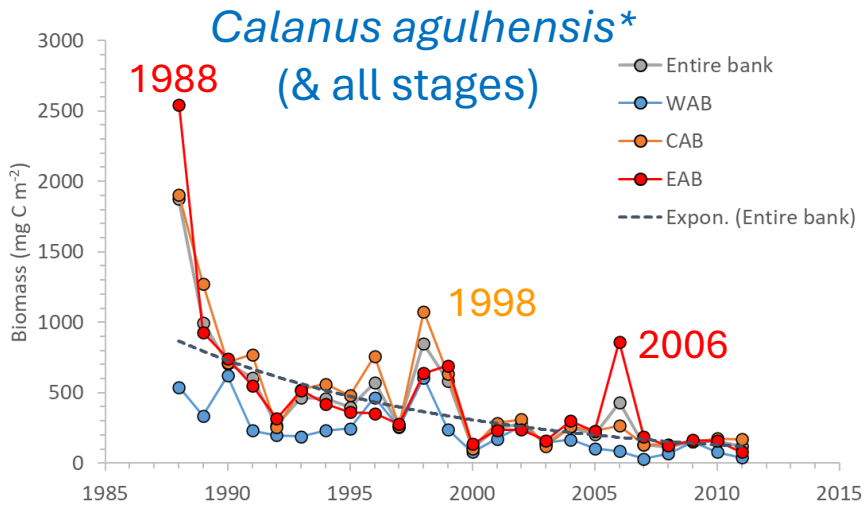


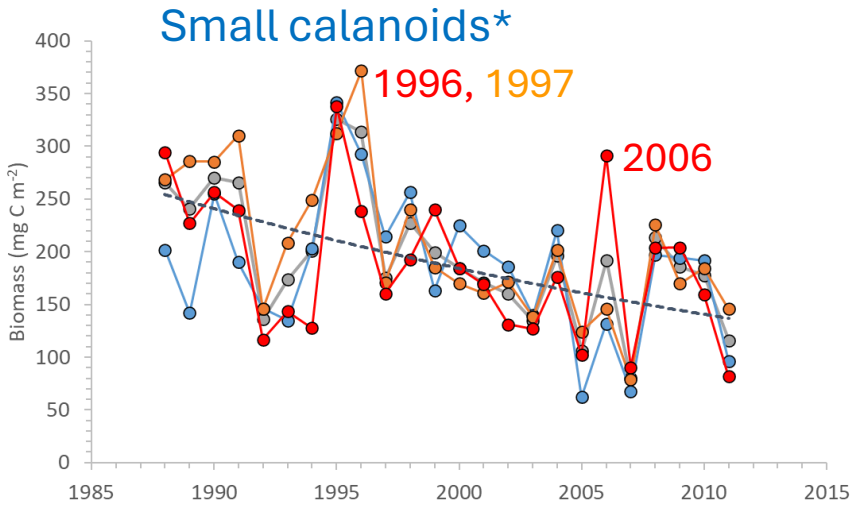
WAB
CAB
EAB
Entire bank

Significant* decline in total copepod biomass



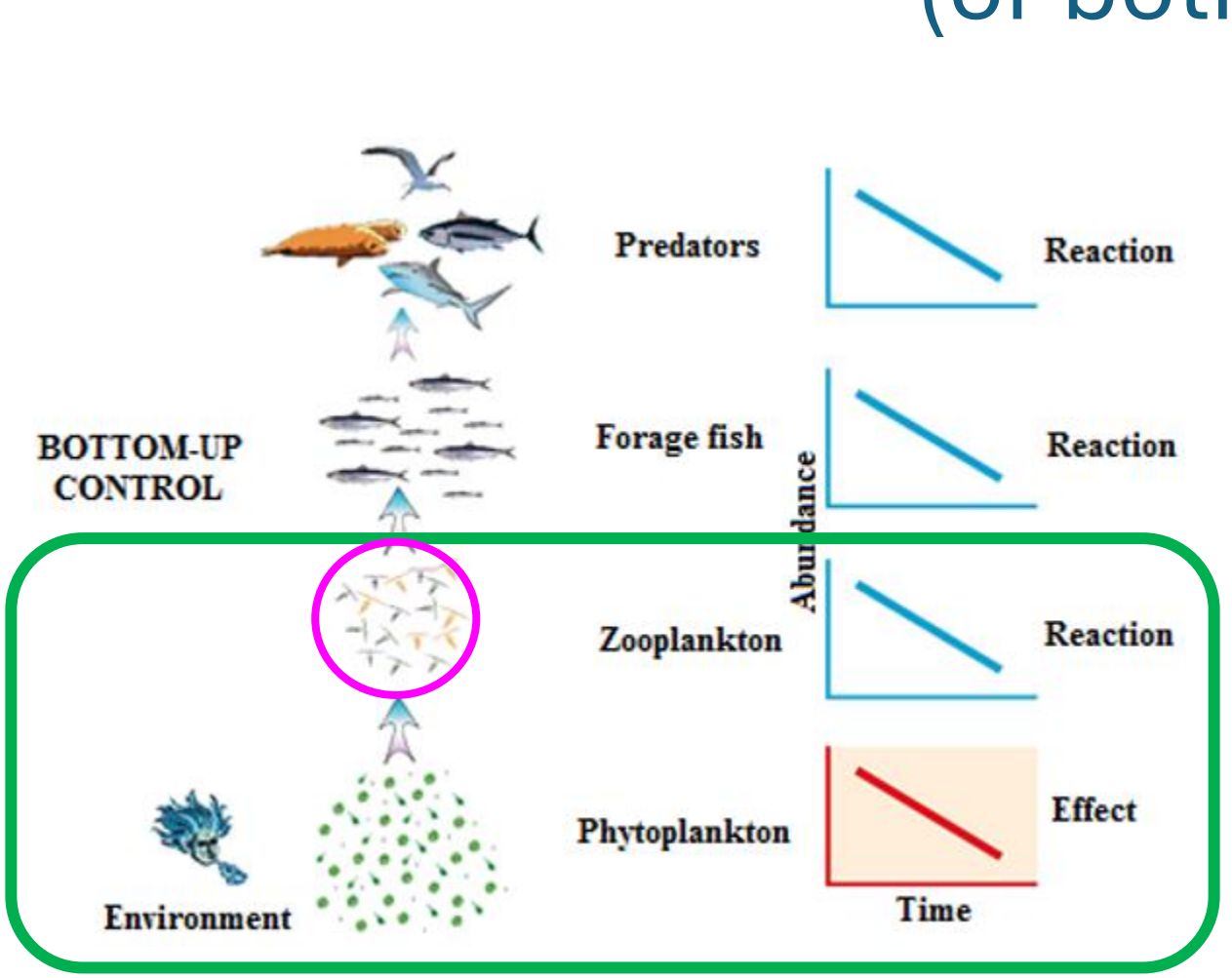
(Whether 1988 is included or excluded)

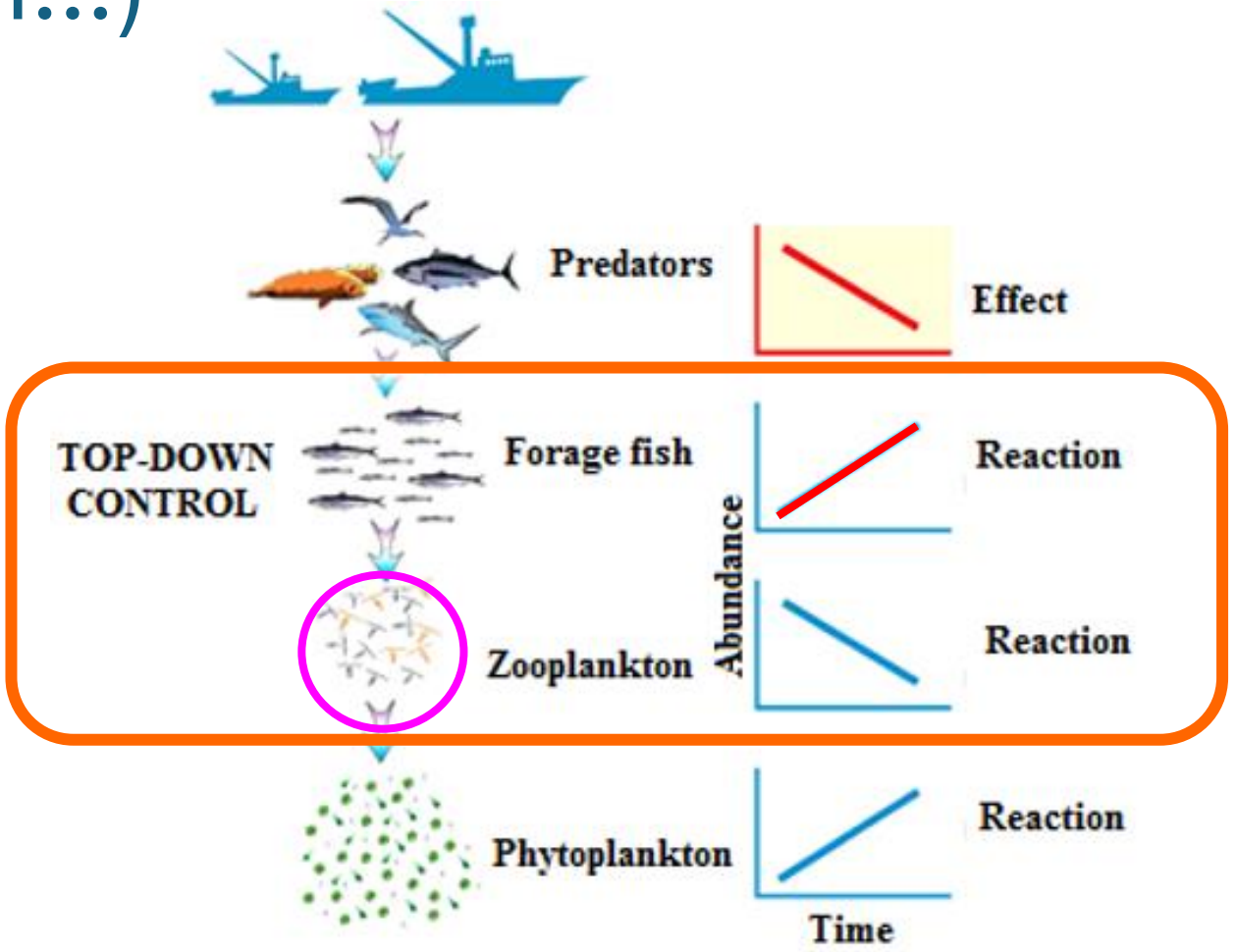




Bottom-up or top-down control of copepods?

(or both…)

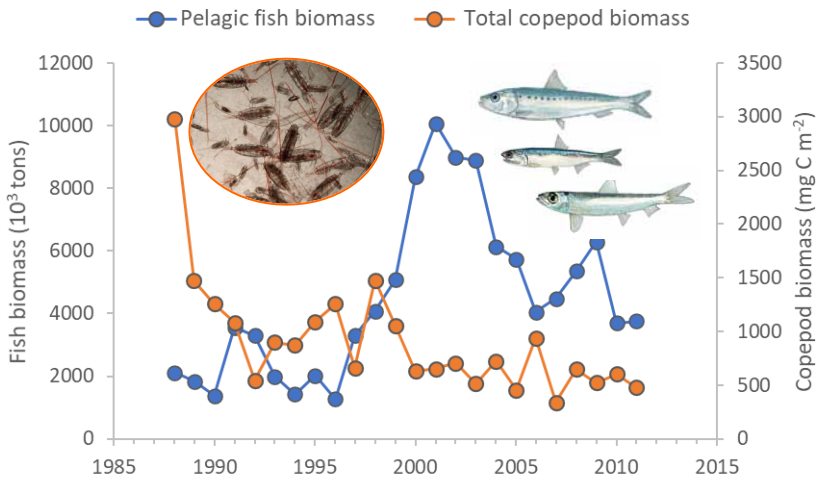


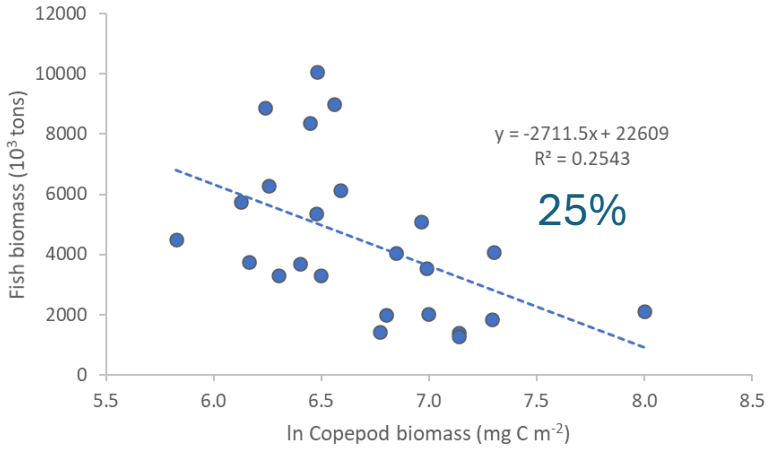


Cury et al. (2016) The Ecosystem Approach to Fisheries: Reconciling Conservation and Exploitation.

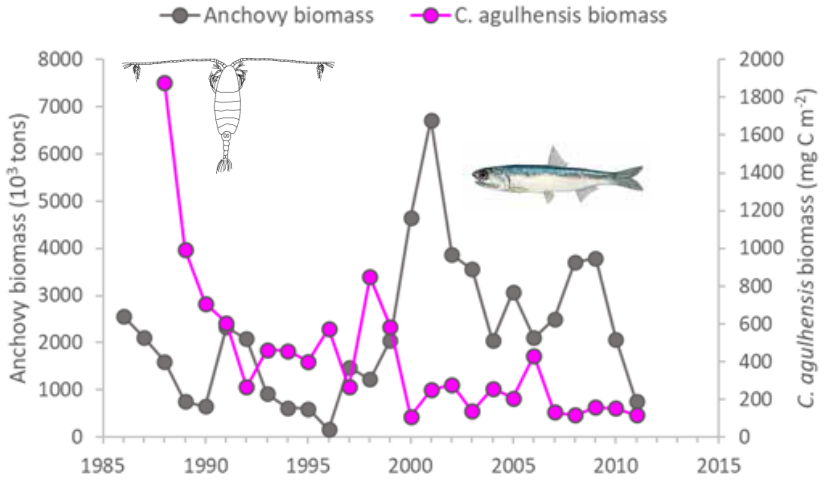
Top-down forcing – clear relationships

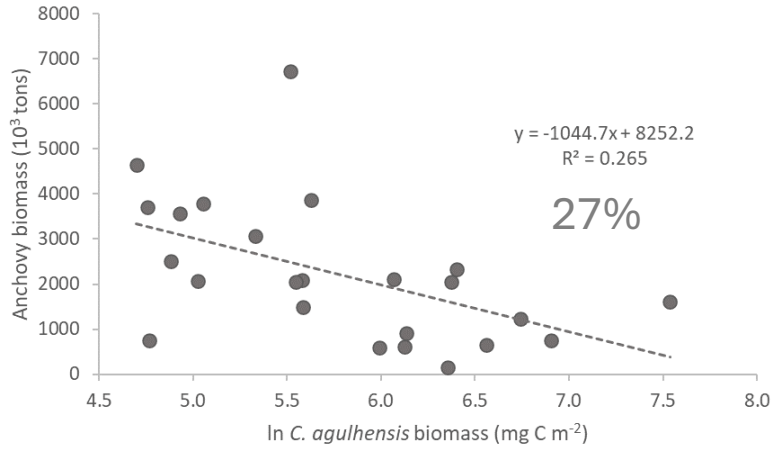
Total pelagic fish vs Total copepods



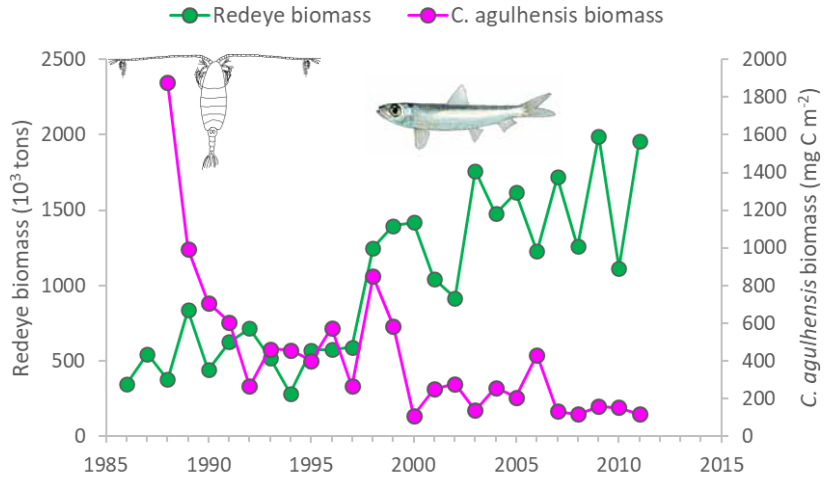


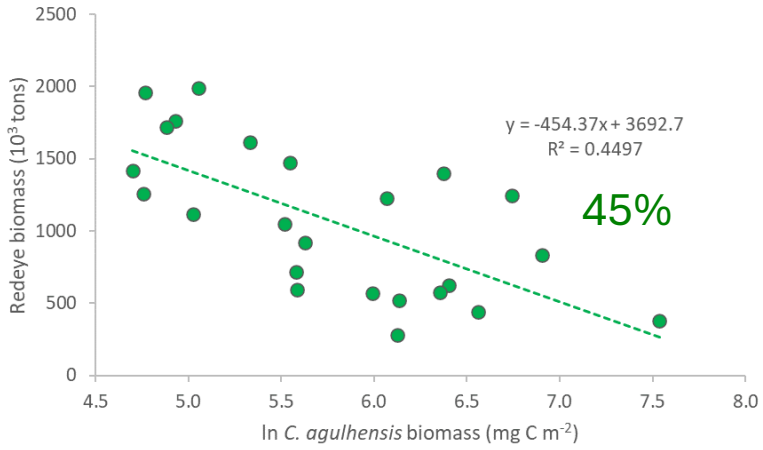
Anchovy vs Calanus





Redeye vs Calanus

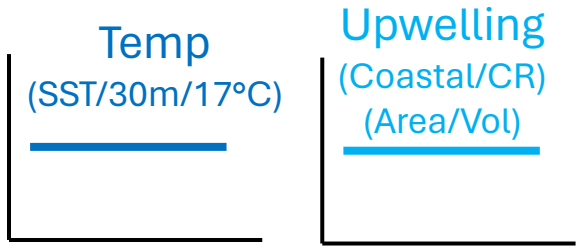




High interannual variability but significant negative relationships between pelagic fish and copepod biomass

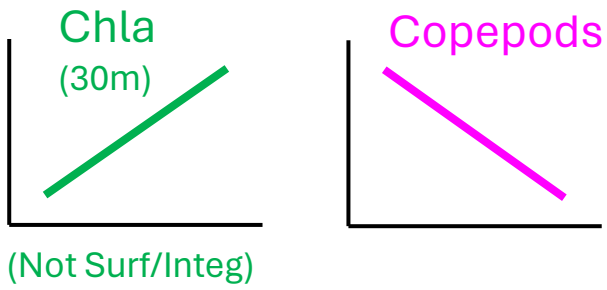
Bottom-up forcing

In situ: No trends in temperature or the area or volume of coastal upwelling or cold ridge over the TS (**Oct/Nov/Dec 1988-2011**)



spring / summer

In situ: significant increase in mean chl *a* at 30 m over TS



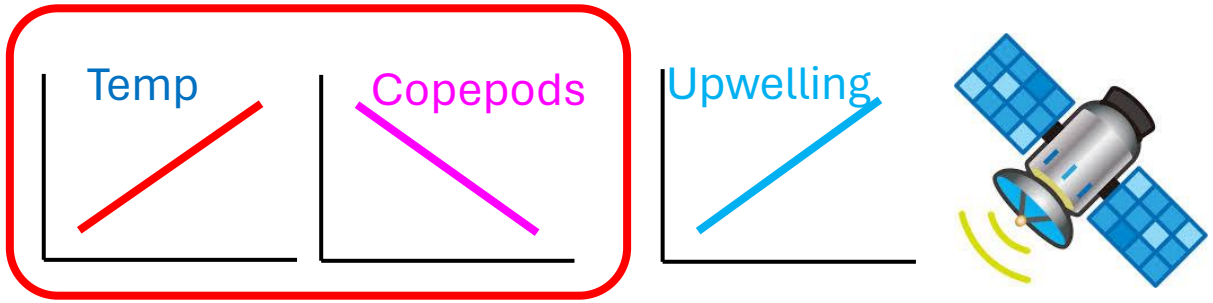
spring / summer

It's complicated!

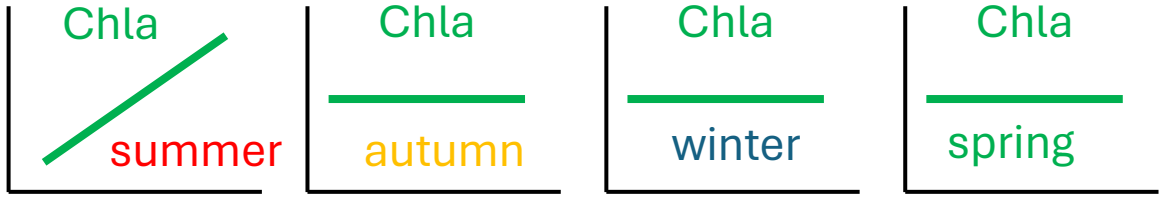
Remotely-sensed data:

(1) long-term **warming trend** for the **Agulhas Current system** over the past 3-4 decades (Roualt et al., 2010; Blamey et al., 2015; Sweijd and Smit, 2020), particularly along the Agulhas Bank shelf edge.

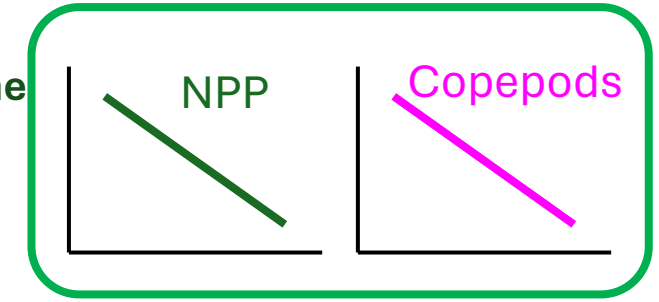
(2) Significant **increase in cumulative upwelling** & no. upwelling days per year for **Agulhas Bank** (1979-2012; Lamont et al. 2018)



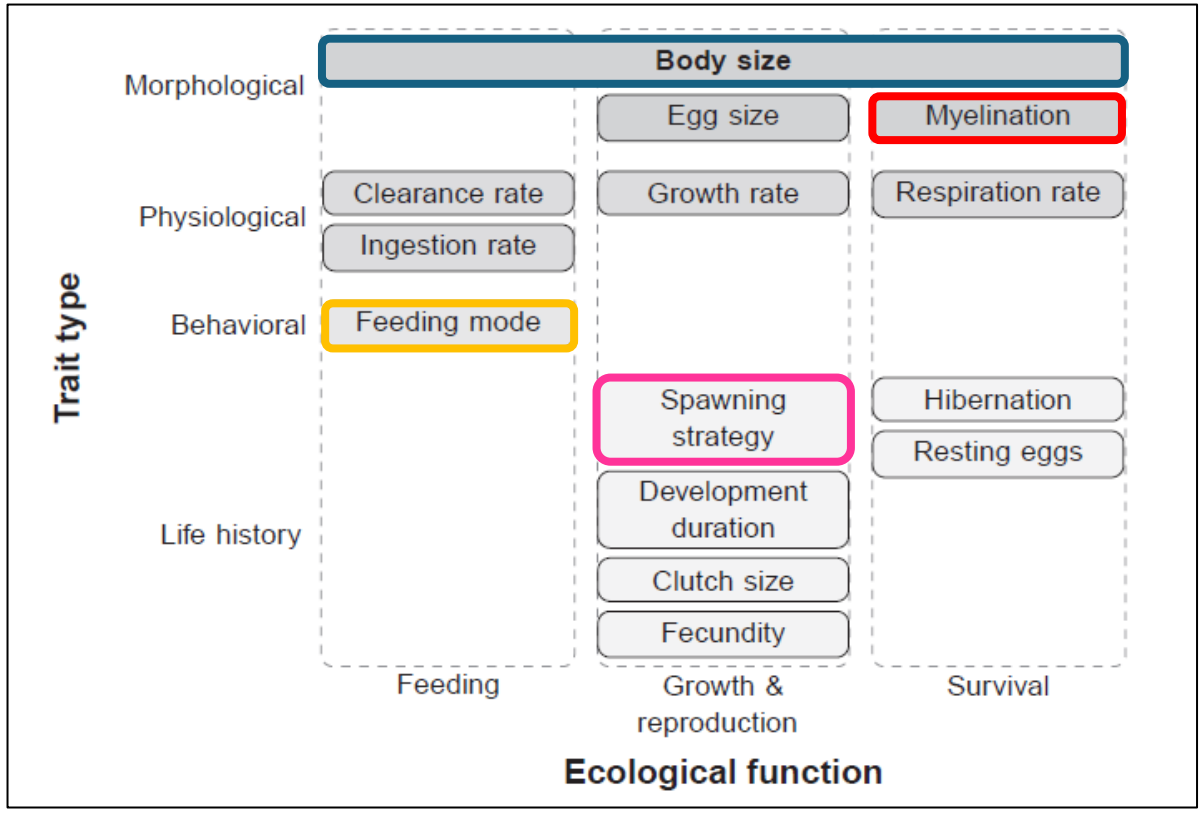
(3) **Increase in Chla & microphytoplankton in summer for AB shelf** but decreases in other seasons (**1997-2018**; Lamont et al. 2018).



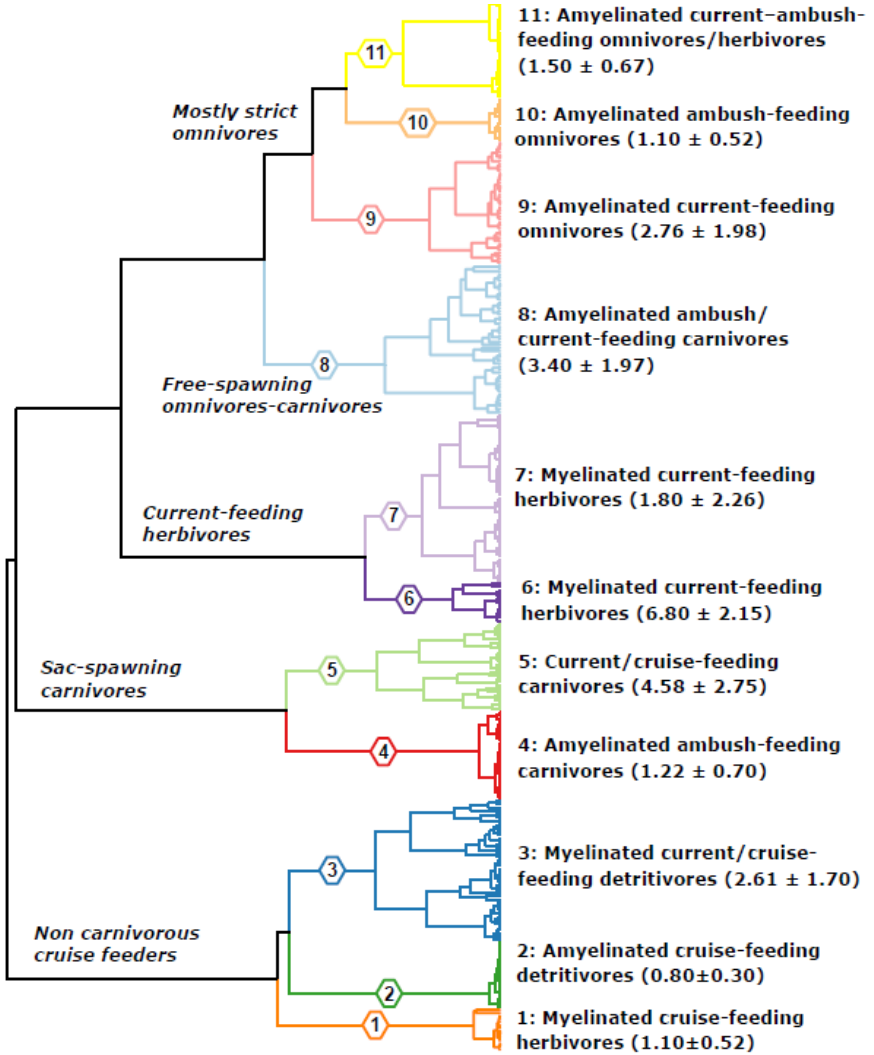
(4) Slight but significant **decline** in satellite-derived **NPP rates** on the **Agulhas Bank** (**1998–2018**; Mazwane et al. 2022)



Functional traits / groups – summarise patterns?



- Main characteristics impacting **fitness** & link to **carbon cycling**
- Classified according to ecological function
- Allocate copepods to groups with distinct ecological roles

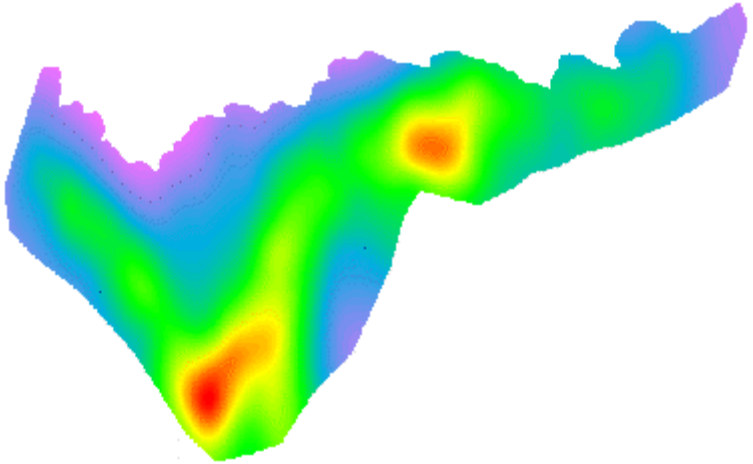


Brun et al. (2017) A trait database for marine copepods.

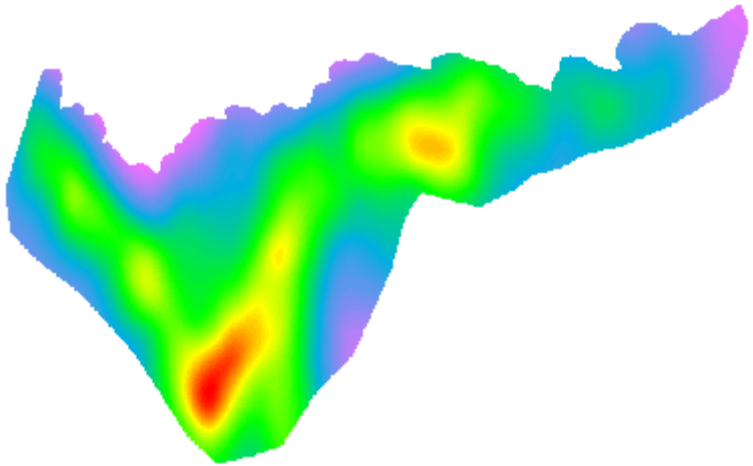
Benedetti et al. (2022) Copepod functional traits and groups show divergent biogeographies in the global ocean. J. Biogeography

EAT -> Trophic group

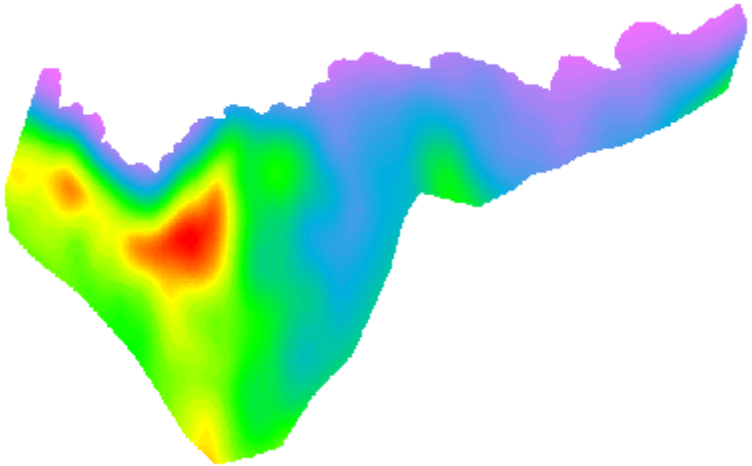
Herbivores (Biomass)



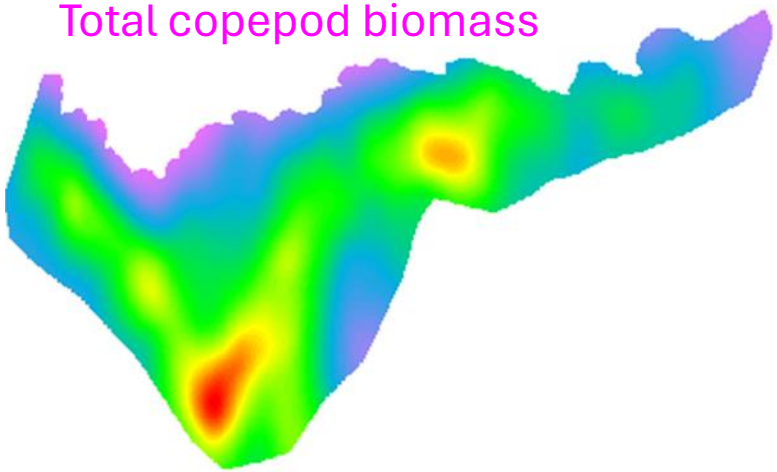
Omnivores (Biomass)



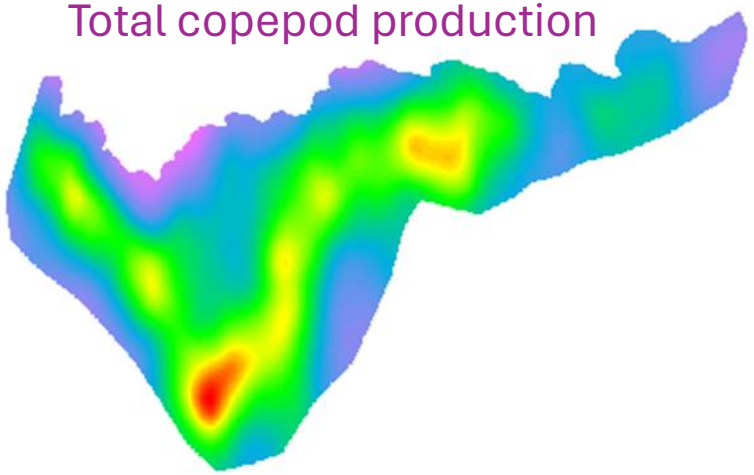
Detritivores (Biomass)



Total copepod biomass

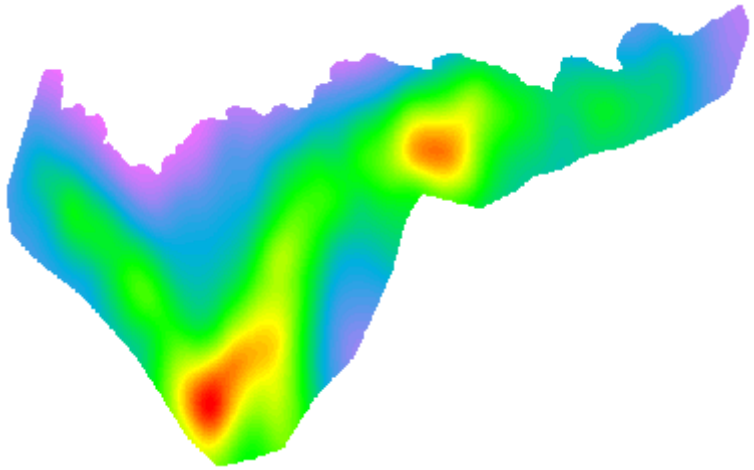


Total copepod production

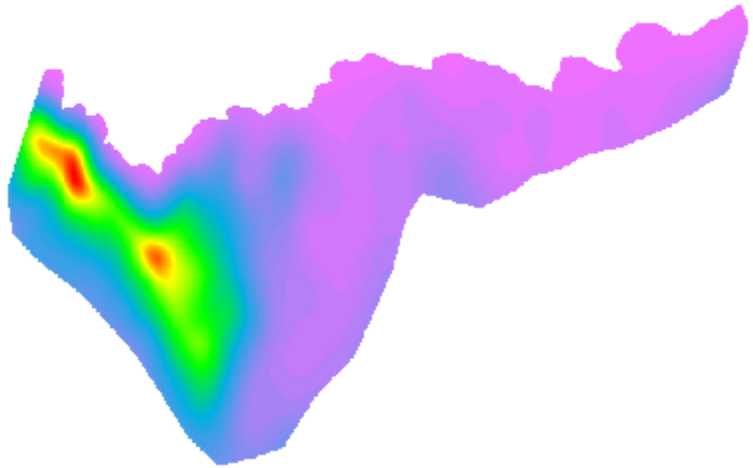


EAT -> Feeding type

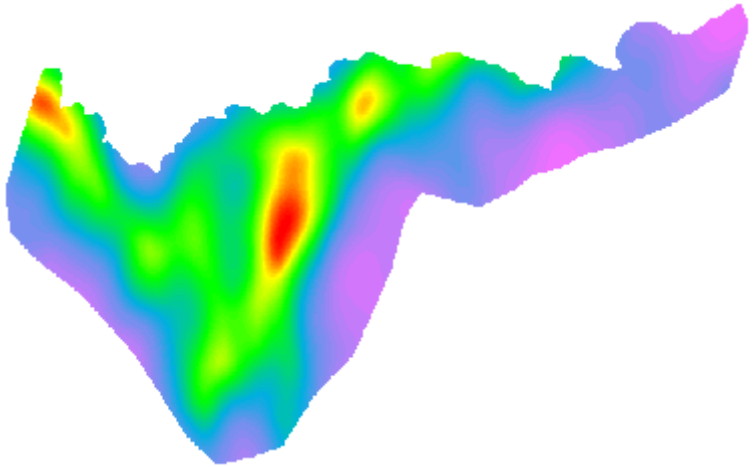
Current feeders



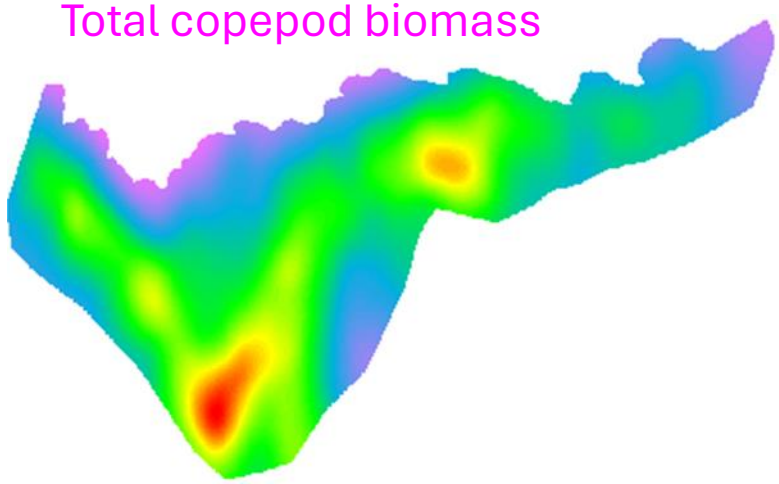
Cruise feeders



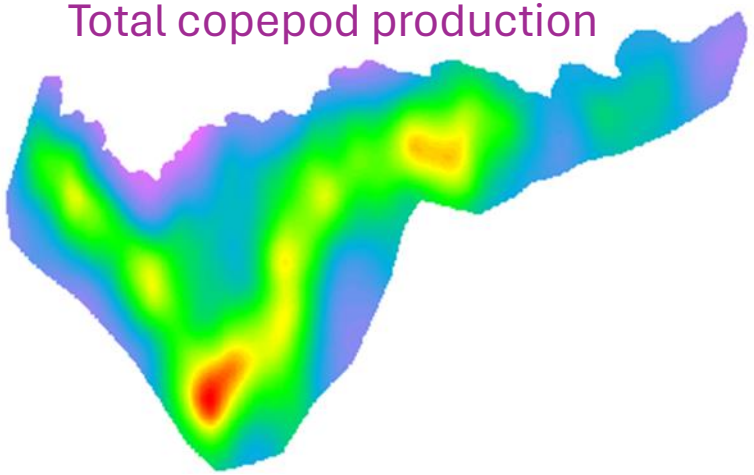
Ambush feeders



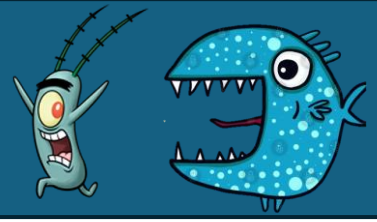
Total copepod biomass



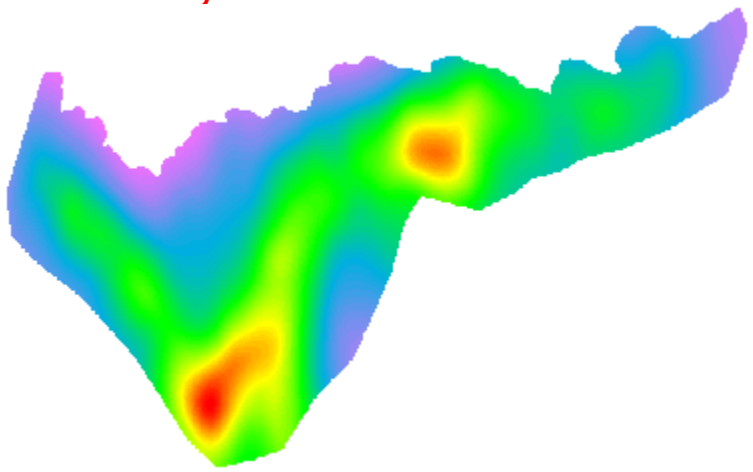
Total copepod production



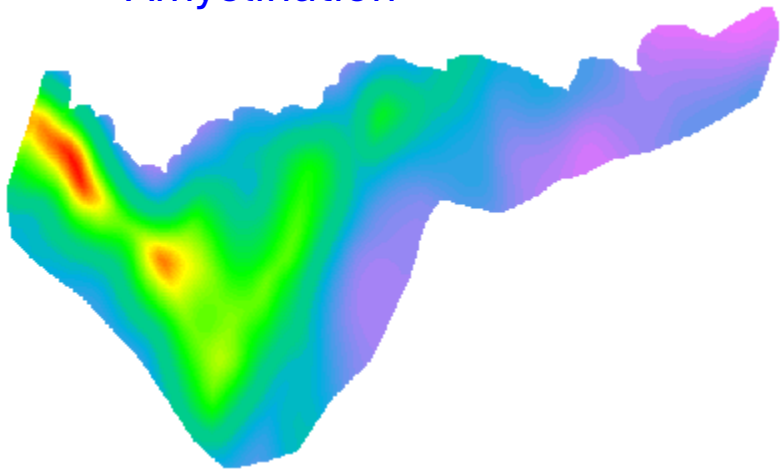
PREY -> Myelination



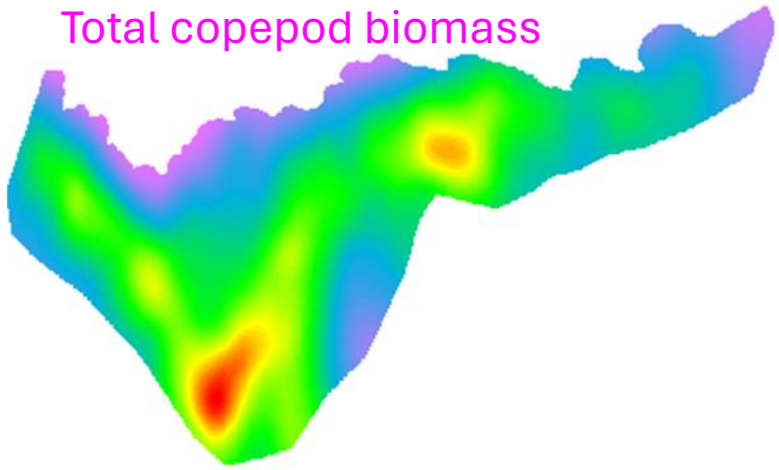
Myelination



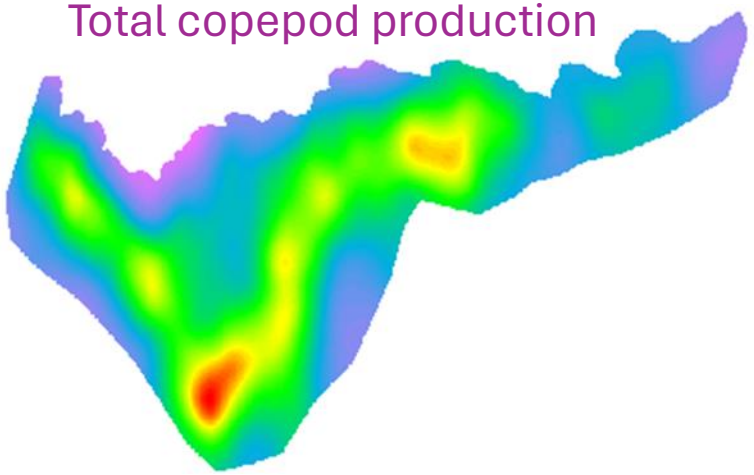
Amyelination



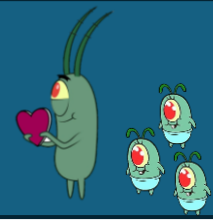
Total copepod biomass



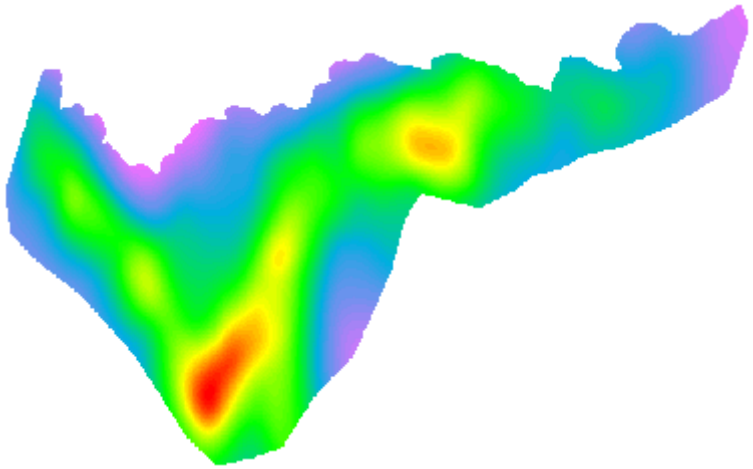
Total copepod production



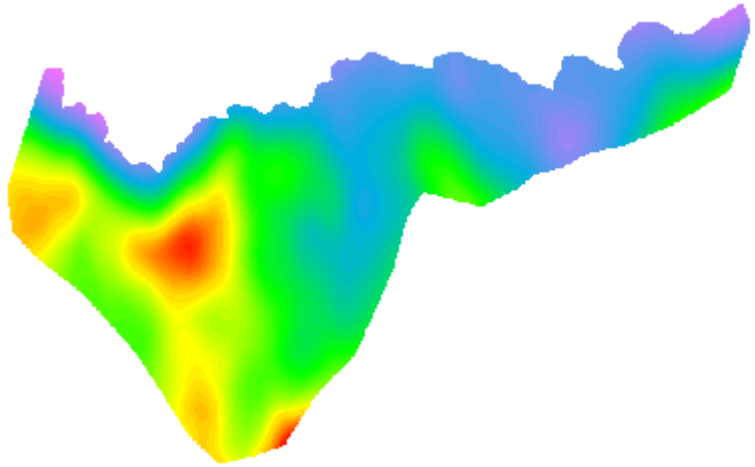
LOVE -> Reproductive mode



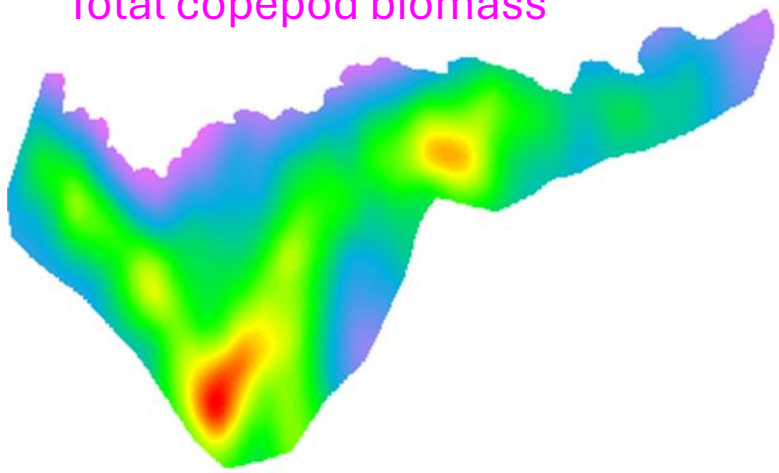
Broadcast spawners



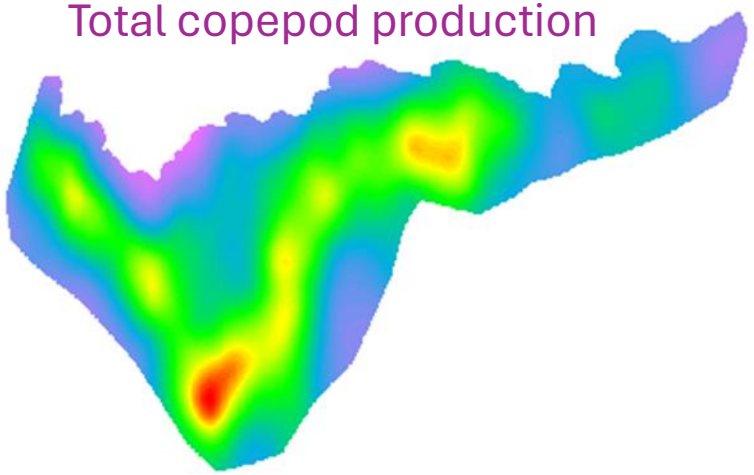
Sac spawners



Total copepod biomass

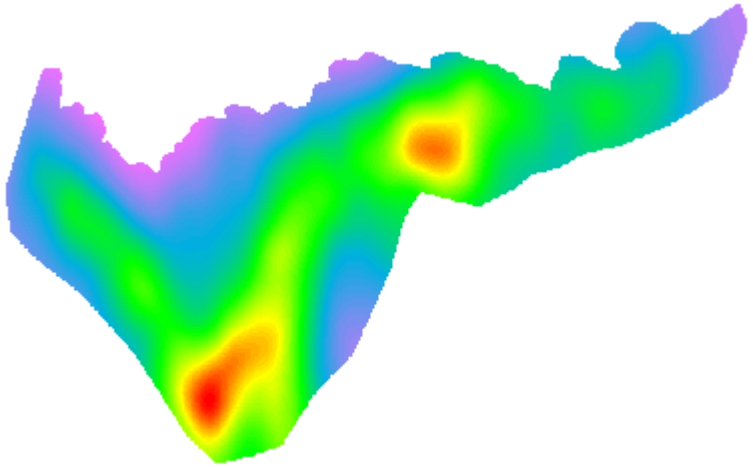


Total copepod production

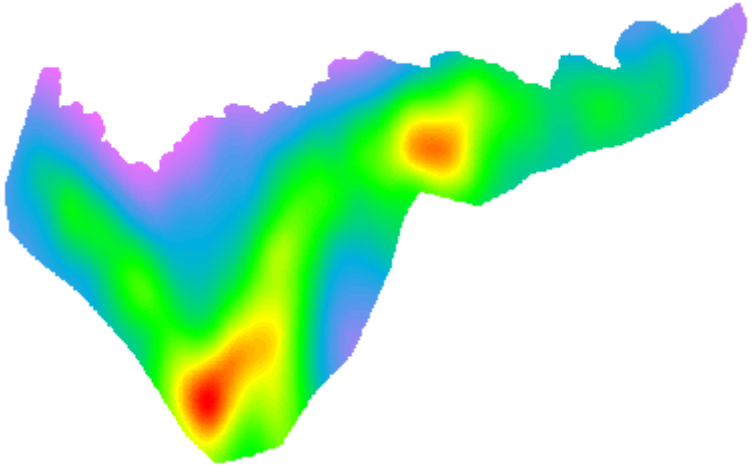


1. Myelinated, current-feeding herbivores

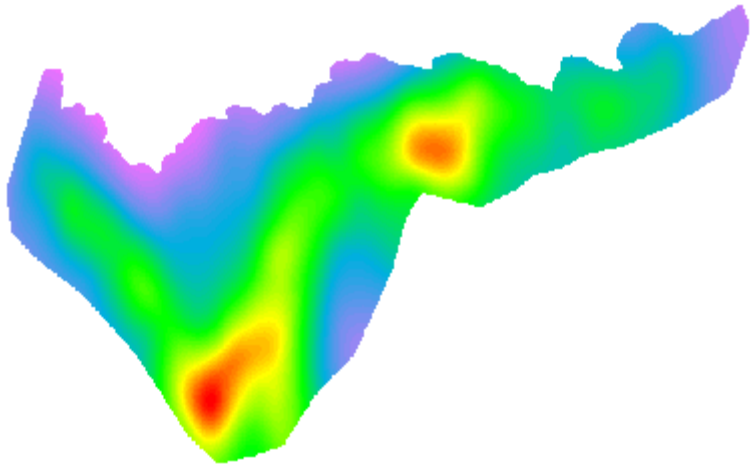
Myelinated (all)



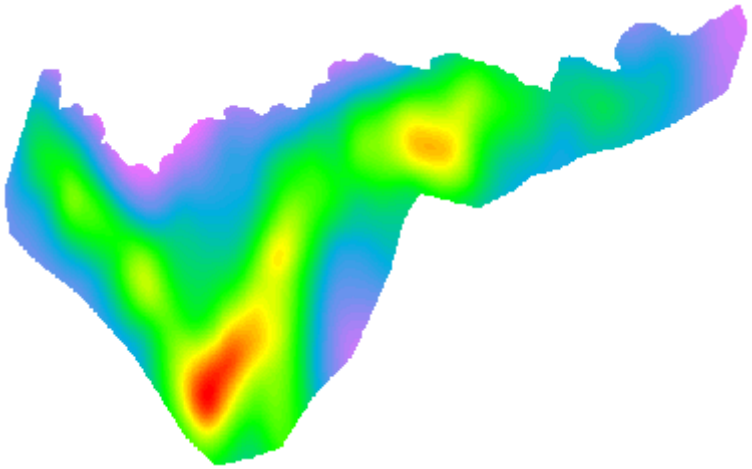
Current feeders (all)

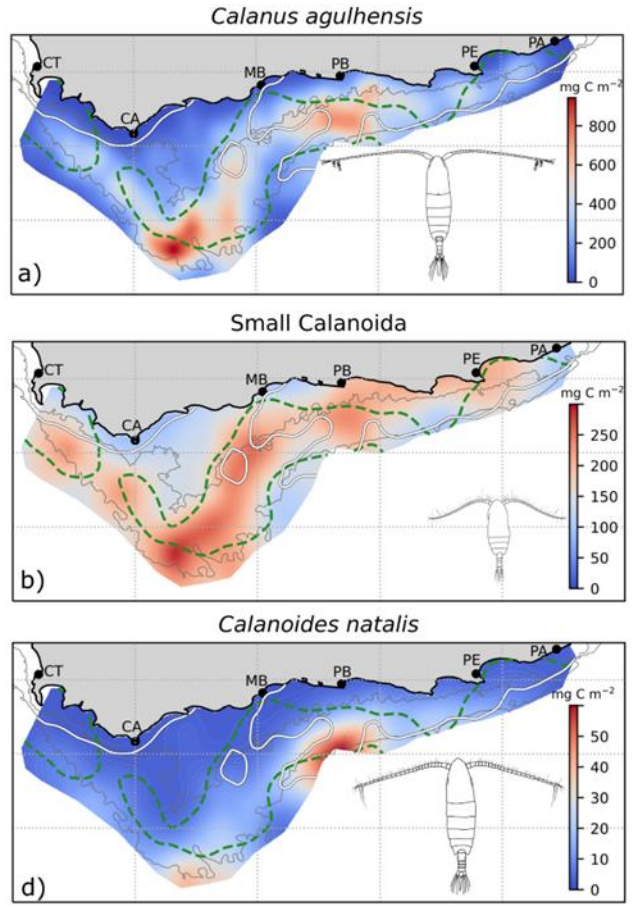


Herbivores (all - primarily)



Broadcast spawners – all



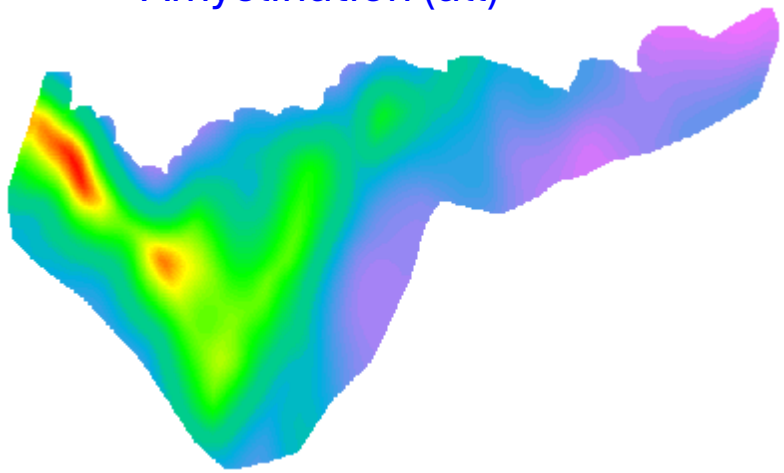


FG 6 & 7

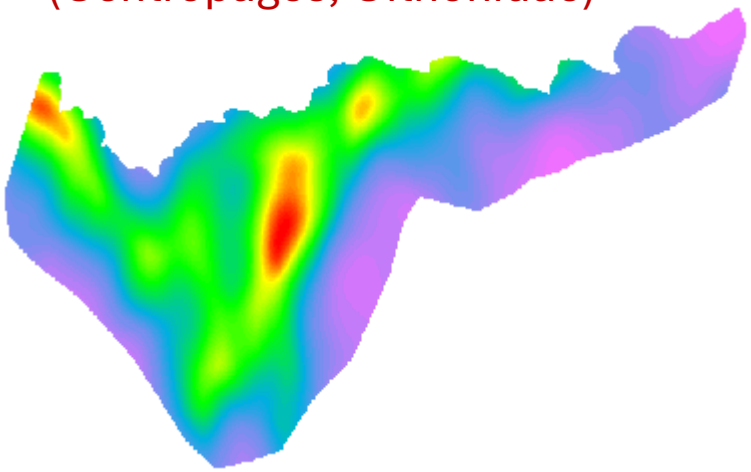
Benedetti et al. (2022)

2. Amyelinated, current / ambush-feeding omnivores

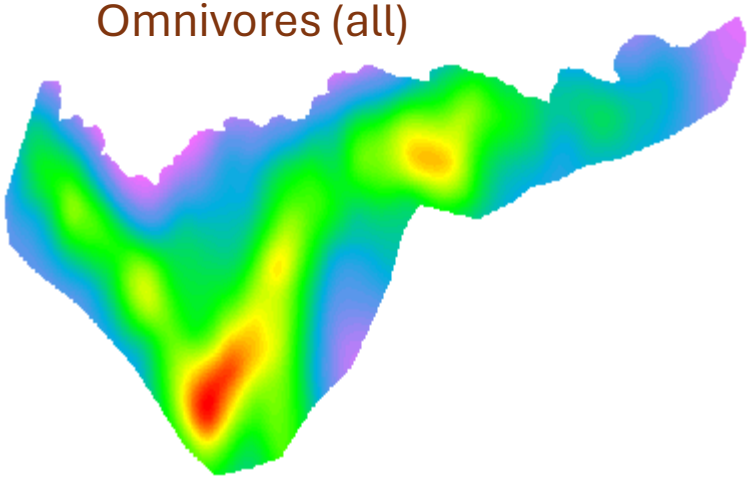
Amyelination (all)



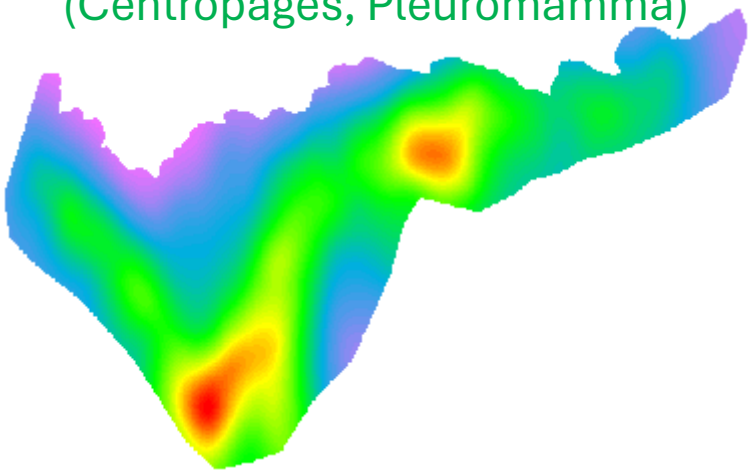
Ambush feeders
(Centropages, Oithonidae)



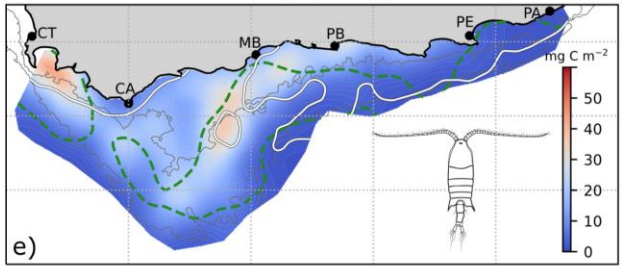
Omnivores (all)



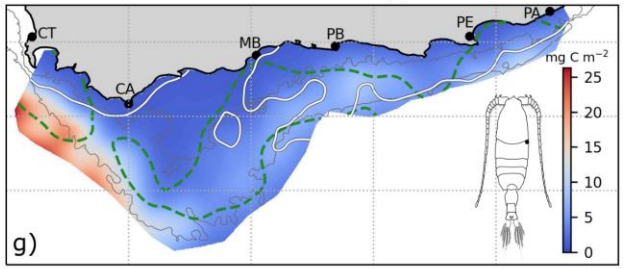
Current feeders
(Centropages, Pleuromamma)



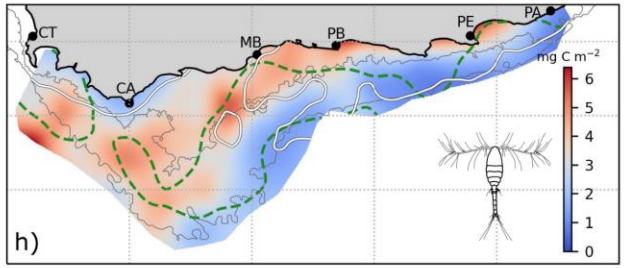
Centropages spp.



Pleuromamma spp.



Oithonidae

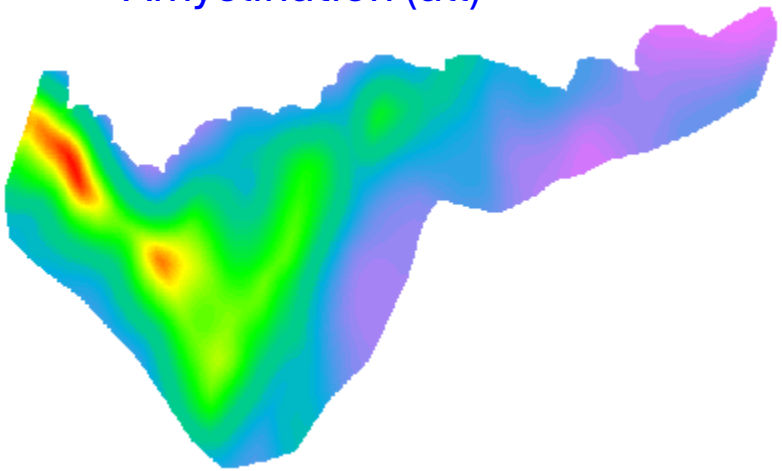


FG 9,10,11

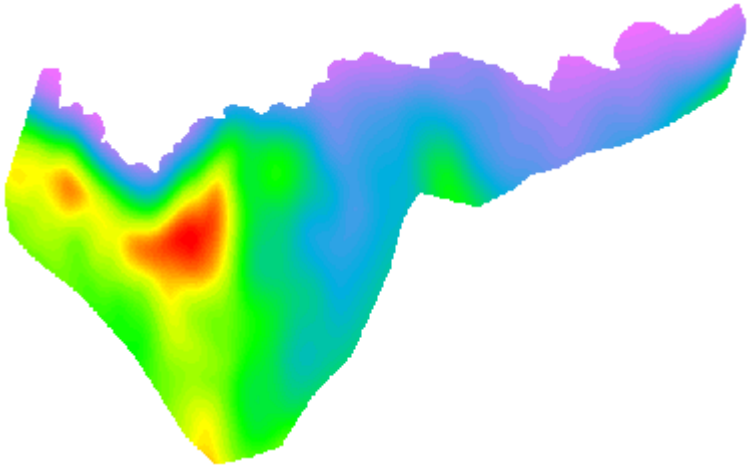
Benedetti et al. (2022)

3. Amyelinated, current / cruise-feeding detritivores

Amyelination (all)

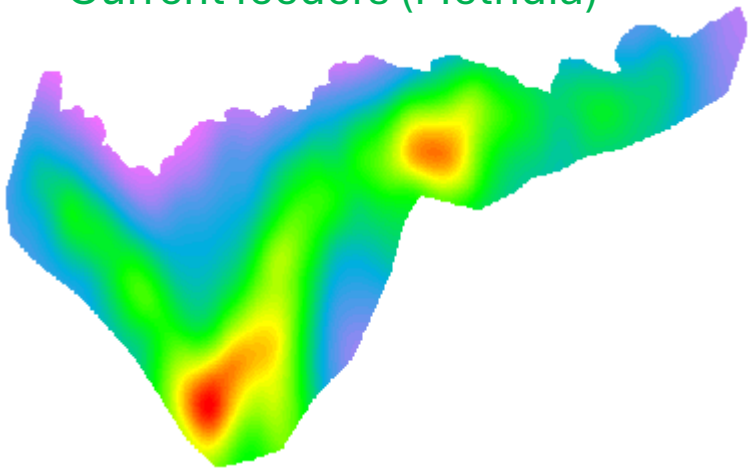


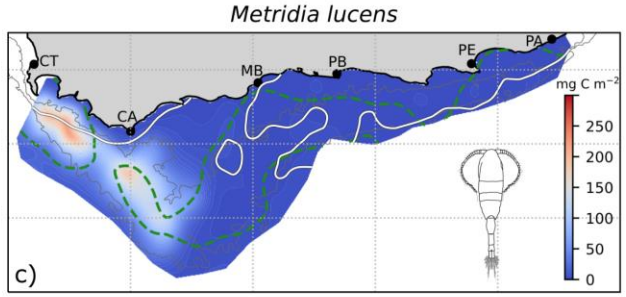
Detritivores (all)

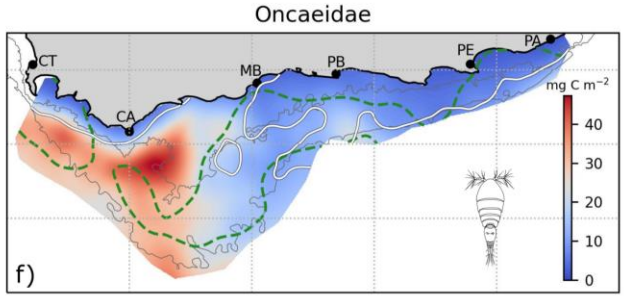


Cruise feeders (all)

Current feeders (Metridia)







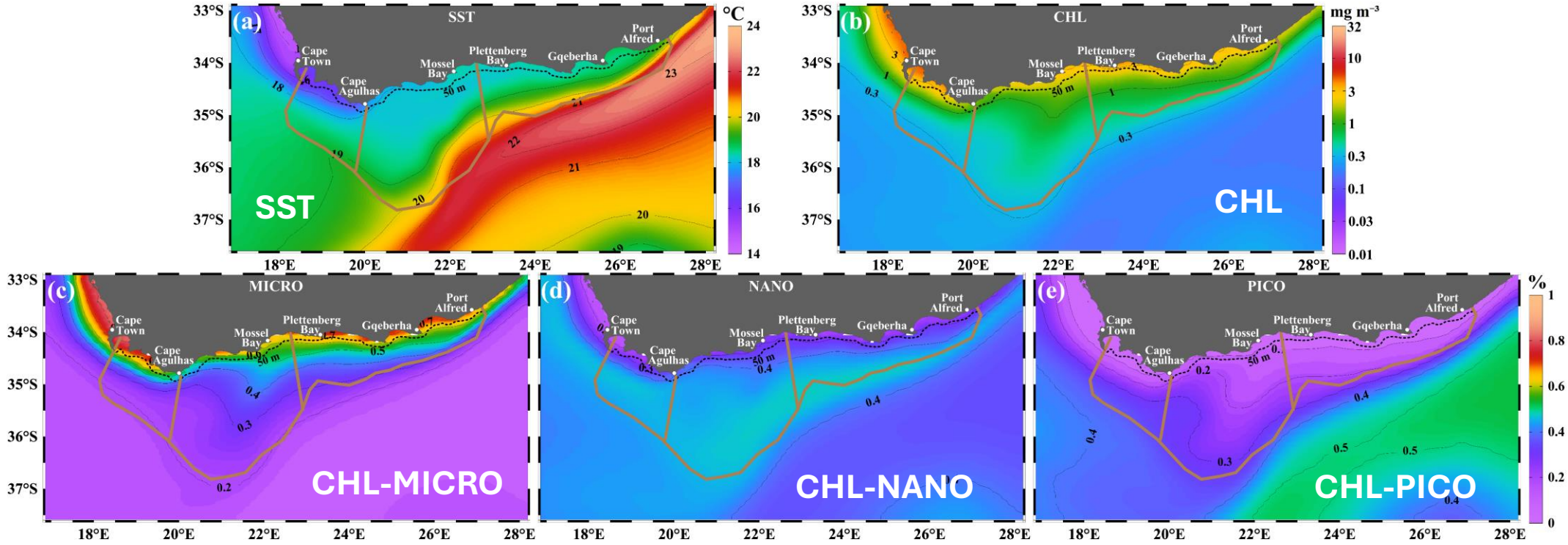
FG 2 & 3

Benedetti et al. (2022)

To be continued… new analysis using functional trait approach

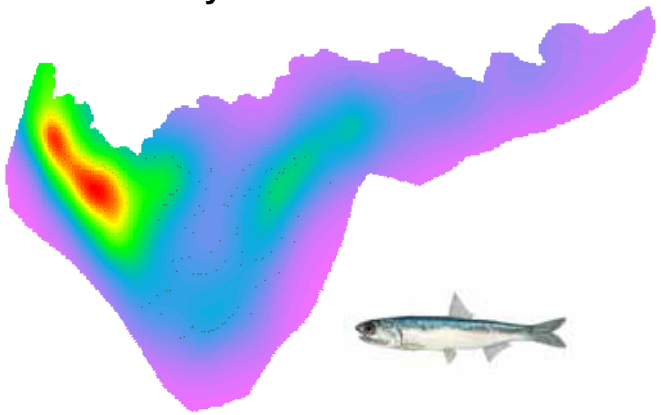
- Spatial (WAB, CAB, EAB) & temporal (1988-2011)
  - **Environment**: remotely-sensed SST, Chl*a*, Chl size
  - **Copepod FTs**: Feeding mode, Myelination, Reproductive strategy
  - **Predation**: Anchovy, Sardine, Redeye biomass

eat
prey
love

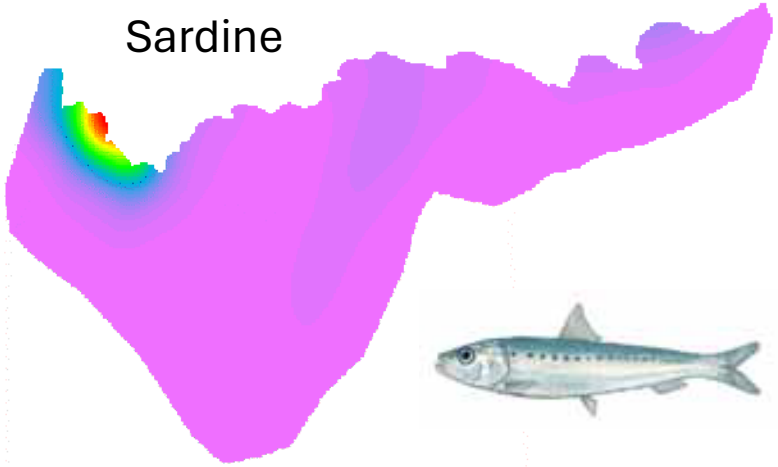


Predation: pelagic fish biomass

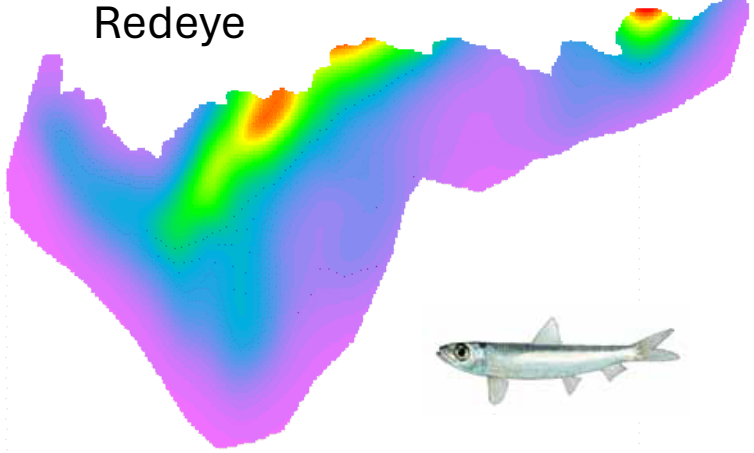
Anchovy



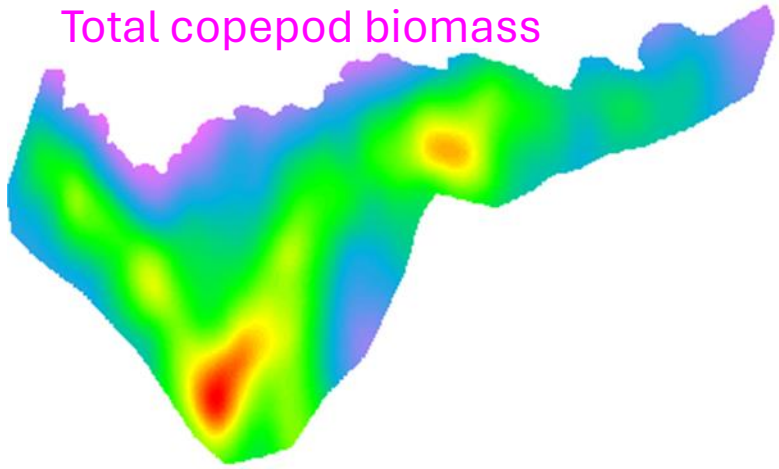
Sardine



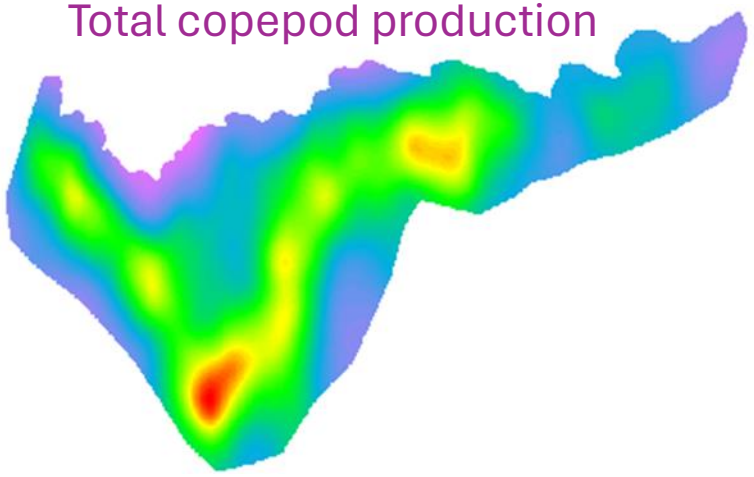
Redeye



Total copepod biomass

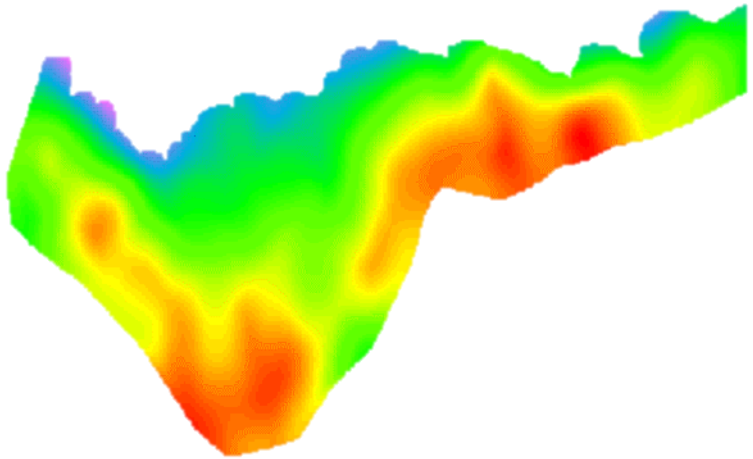


Total copepod production

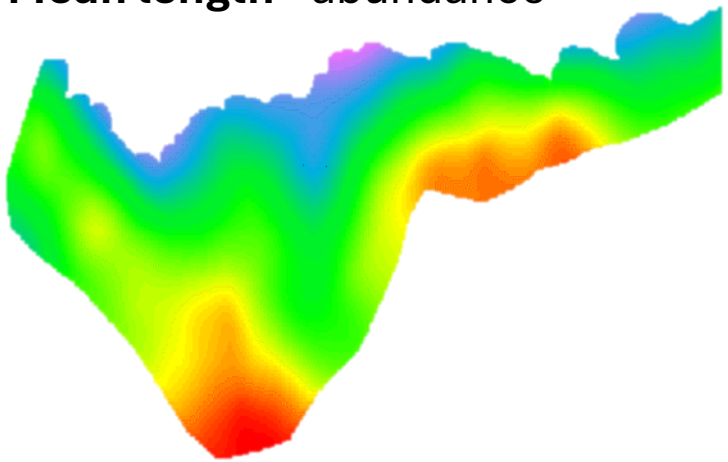


SIZE -> Total length

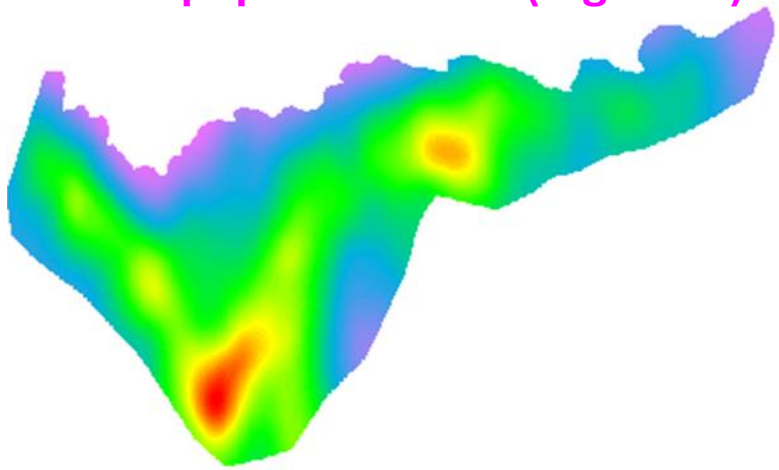
Mean length - biomass



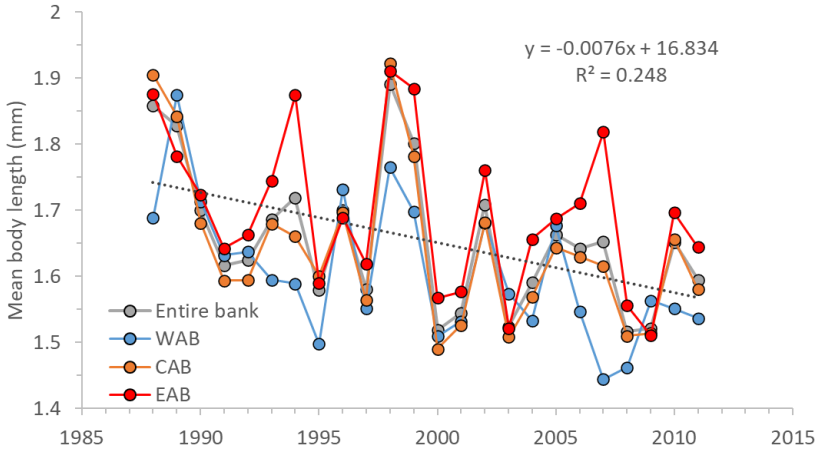
Mean length - abundance



Total copepod biomass (mg C m^{-2})

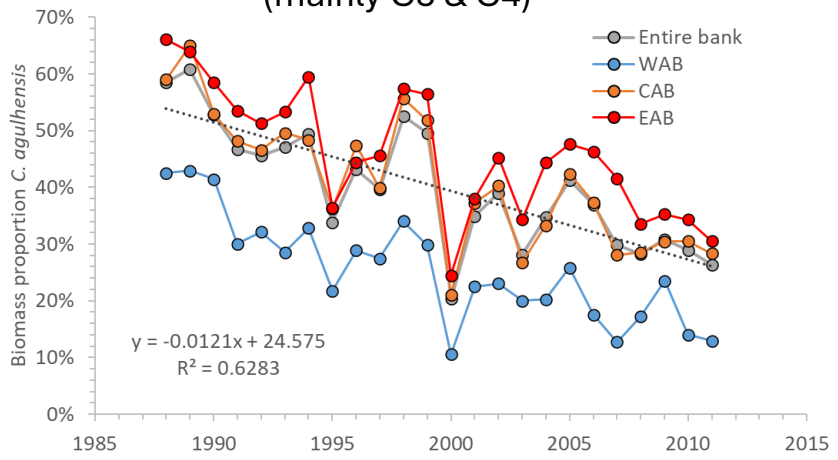


Decline in mean copepod body length



Decline in *C. agulhensis* (prop. biomass)

(mainly C5 & C4)



Conclusions (so far – work in progress…)

- Significant decline in total copepod biomass (*C. agulhensis* + small calanoids)
- Signicant decline in mean copepod length
- No long-term trends observed for other taxa
- No clear / consistent environmental links
- Decline - mainly a consequence of top-down control by pelagic fish
- A shift towards smaller zooplankton is likely to be reinforced by ocean warming, with negative consequences for fisheries production as well as carbon sequestration.

☺ 

Acknowledgements

- **ICES/PICES** & symposium organisers
- **SCOR**
- Past collaborators:
  Margaux Noyon, Jacob Carstensen, David Walker →

Ministry of Higher Education and Science Denmark

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