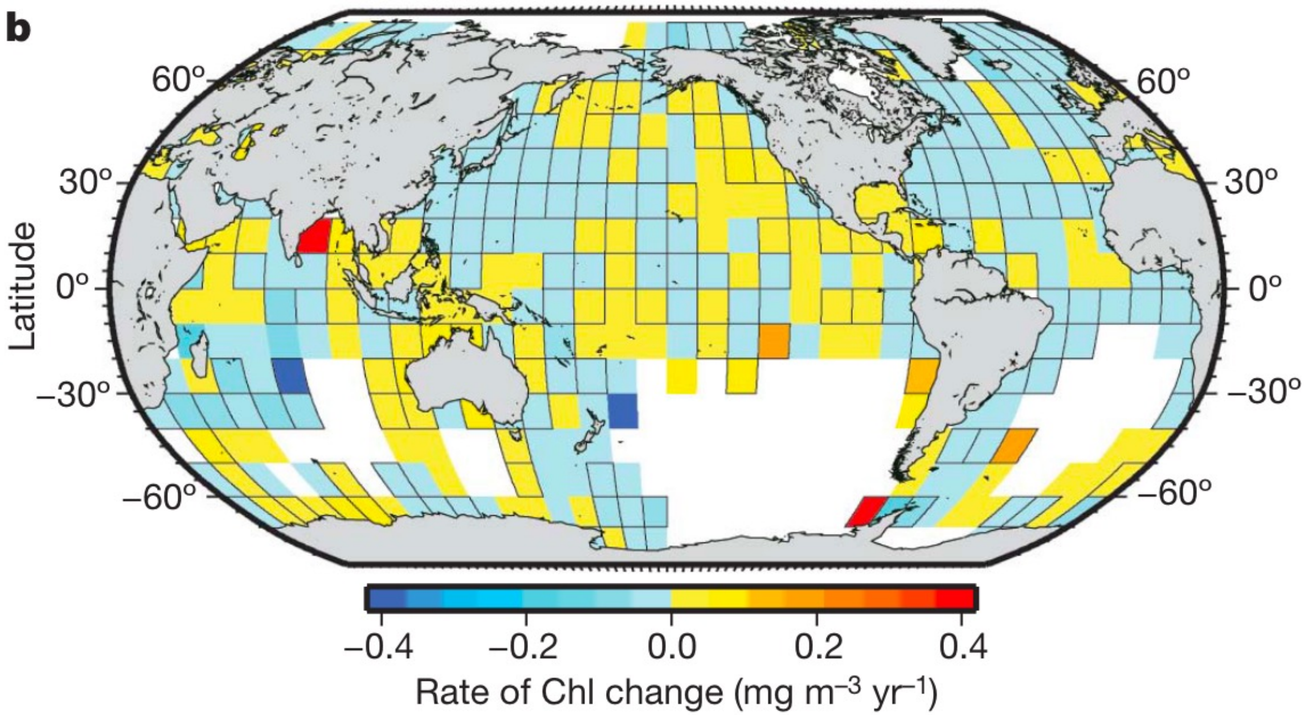
Global zooplankton trends over the past 90 years

Anthony J Richardson, Frank Coman, Claire H Davies, Ruth S Eriksen, Felicity R McEnnulty, Todd D. O'Brien, Julian Palomino-Uribe, Wayne Rochester, Anita Slotwinski, Mark L Tonks, Sarah Chisholm, Jasmine Fowler-Morrow, Kateryna Golovko, Mick Haywood, William Venables, Jason D Everett

A long-term decline in phytoplankton biomass



1899-2008
(n=445,237)
From secchi, fluorometry, HPLC, spectrophotometry

"we estimate a global decline of 1% of global median per year"

Boyce et al. (2010) *Nature*

Does blending of chlorophyll data bias temporal trend?

ARISING FROM D. G. Boyce, M. R. Lewis & B. Worm *Nature* **466,** 591–596 (2010)

David L. Mackas[1]

A measured look at ocean chlorophyll trends

ARISING FROM D. G. Boyce, M. R. Lewis & B. Worm *Nature* **466,** 591–596 (2010)

Ryan R. Rykaczewski[1,2] **& John P. Dunne**[2]

Is there a decline in marine phytoplankton?

ARISING FROM D. G. Boyce, M. R. Lewis & B. Worm *Nature* **466,** 591–596 (2010)

Abigail McQuatters-Gollop[1]**, Philip C. Reid**[1]**, Martin Edwards**[1]**,**
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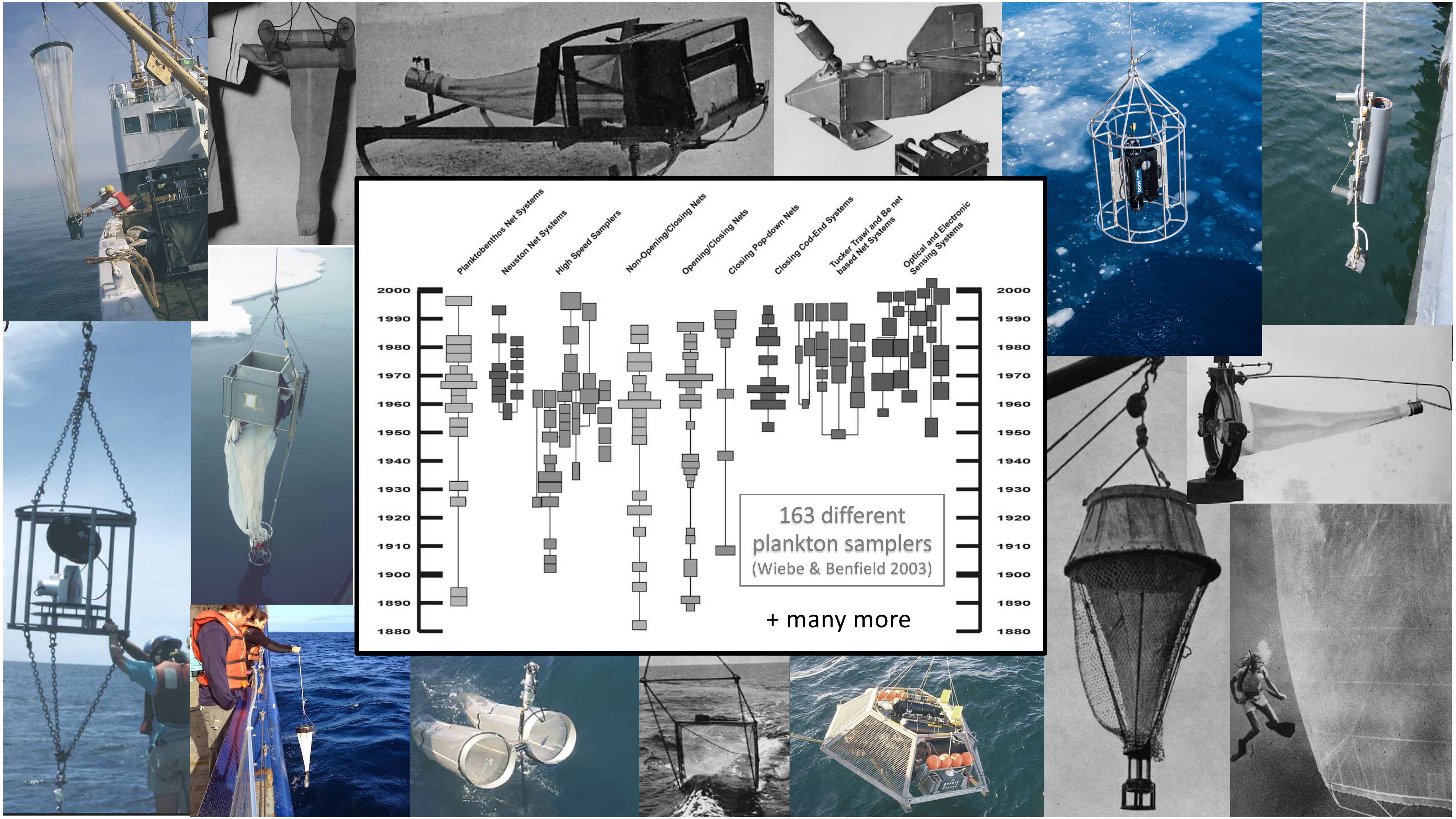
Boyce *et al.* reply

REPLYING TO A. McQuatters-Gollop *et al. Nature* **472,** doi:10.1038/nature09950 (2011); D. L. Mackas *Nature* **472,** doi:10.1038/nature09951 (2011); R. R. Rykaczewski & J. P. Dunne *Nature* **472,** doi:10.1038/nature09952 (2011)

Daniel G. Boyce[1]**, Marlon R. Lewis**[2] **& Boris Worm**[1]

What is the long-term trend in zooplankton?



Planktobenthos Net Systems
Neuston Net Systems
High Speed Samplers
Non-Opening/Closing Nets
Opening/Closing Nets
Closing Pop-down Nets
Closing Cod-End Systems
Tucker Trawl and Be net based Net Systems
Optical and Electronic Sensing Systems
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
1880
163 different plankton samplers
(Wiebe & Benfield 2003)
+ many more

Challenges measuring and comparing plankton biomass data

Attributes	Phytoplankton biomass	Zooplankton biomass
Measurable from space	Yes	No
Measureme		
Standard m		placed
Collection		tically
Carbon con		ns (12%)
Where four		
Diel patterr		
Seasonal patterns	Considerable	Considerable
Availability of biomass	More than abundance data	More than abundance data
Time series data	Mainly coastal	Mainly coastal

1. Little method standardisation because different questions require different sampling
2. The HOW, WHERE and WHEN you sample zooplankton biomass is important

Analysing biomass data: 1. Conversions and subsetting

TABLE B2 | Equations to convert different biomass methods to carbon mass, Rearranged from Postel et al. (2000).

Conversion	Equation	References
SV to DM	$\log_{10}(DM) = 1.15 * \log_{10}(SV) - 2.292$	Postel, 1990
DV to CM	$\log_{10}(CM) = (\log_{10}(DV) + 1.434)/0.820$	Wiebe, 1988
WM to CM	$\log_{10}(CM) = (\log_{10}(WM) + 1.537)/0.852$	Wiebe, 1988
DM to CM	$\log_{10}(CM) = (\log_{10}(DM) + 0.499)/0.991$	Wiebe, 1988
AFDM to CM	$\log_{10}(CM) = (\log_{10}(AFDM) - 0.410)/0.963$	Bode et al., 1998

BOX 2 | DATA WRANGLING: CONVERTING ZOOPLANKTON BIOMASS BETWEEN DIFFERENT MESH SIZES AND USING PROXY ESTIMATES

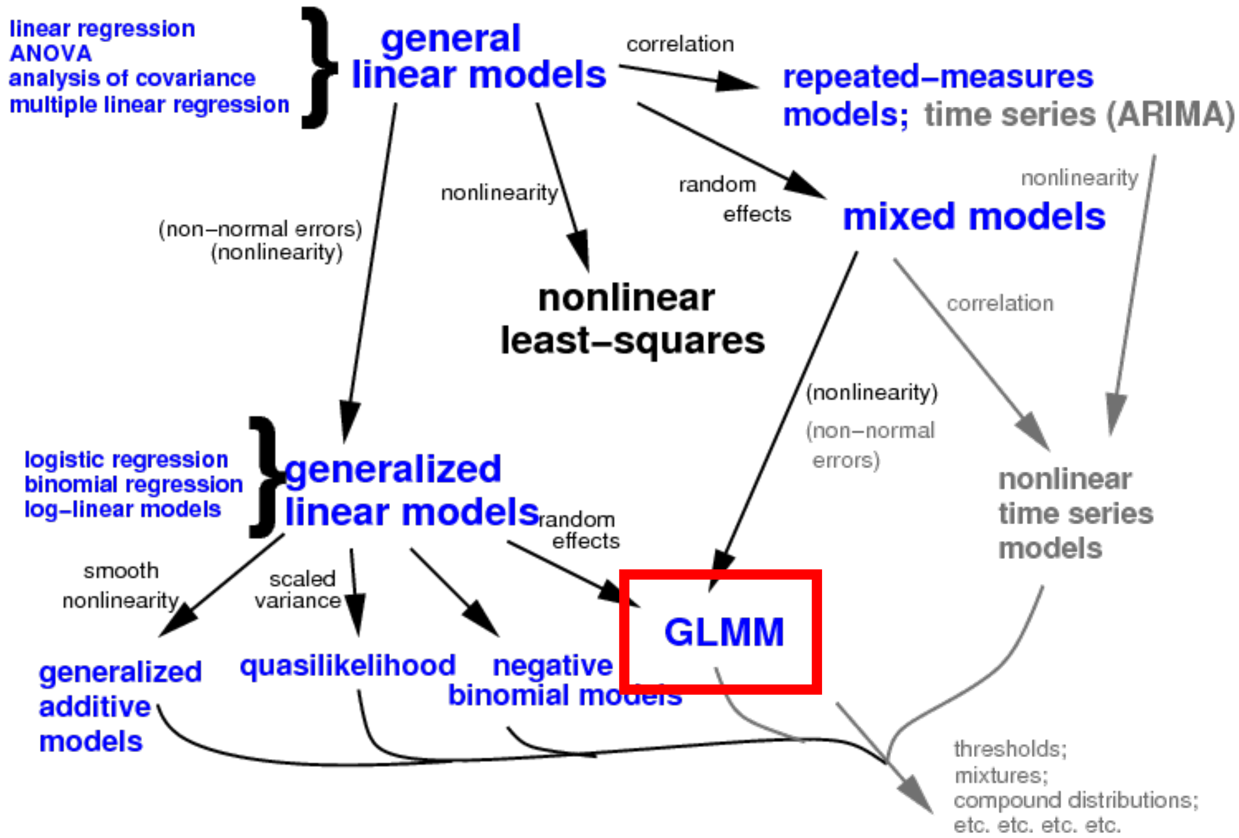
Different mesh sizes: Different mesh sizes of nets provide very different biomass values, with higher zooplankton biomass estimates from finer mesh nets. To convert biomass data collected with different mesh sizes to an equivalent mesh size, common conversions can be applied (**Table B3**; Moriarty and O'Brien, 2013), although it must be acknowledged that the best conversion is dependent upon the zooplankton assemblage present. Fortunately, different net systems produce similar estimates of zooplankton when operated with similar mesh sizes (Skjoldal et al., 2013).

TABLE B3 | Equivalent mesh size conversions (modified from Moriarty and O'Brien, 2013).

Conversion	Equation	References
333 µm to 200 µm mesh	$\log_{10}(CM_{200}) = 1.4461 * \log_{10}(CM_{333})$	O'Brien, 2005
505 µm to 330 µm mesh	$\log_{10}(CM_{333}) = 1.2107 * \log_{10}(CM_{505})$	O'Brien, 2005

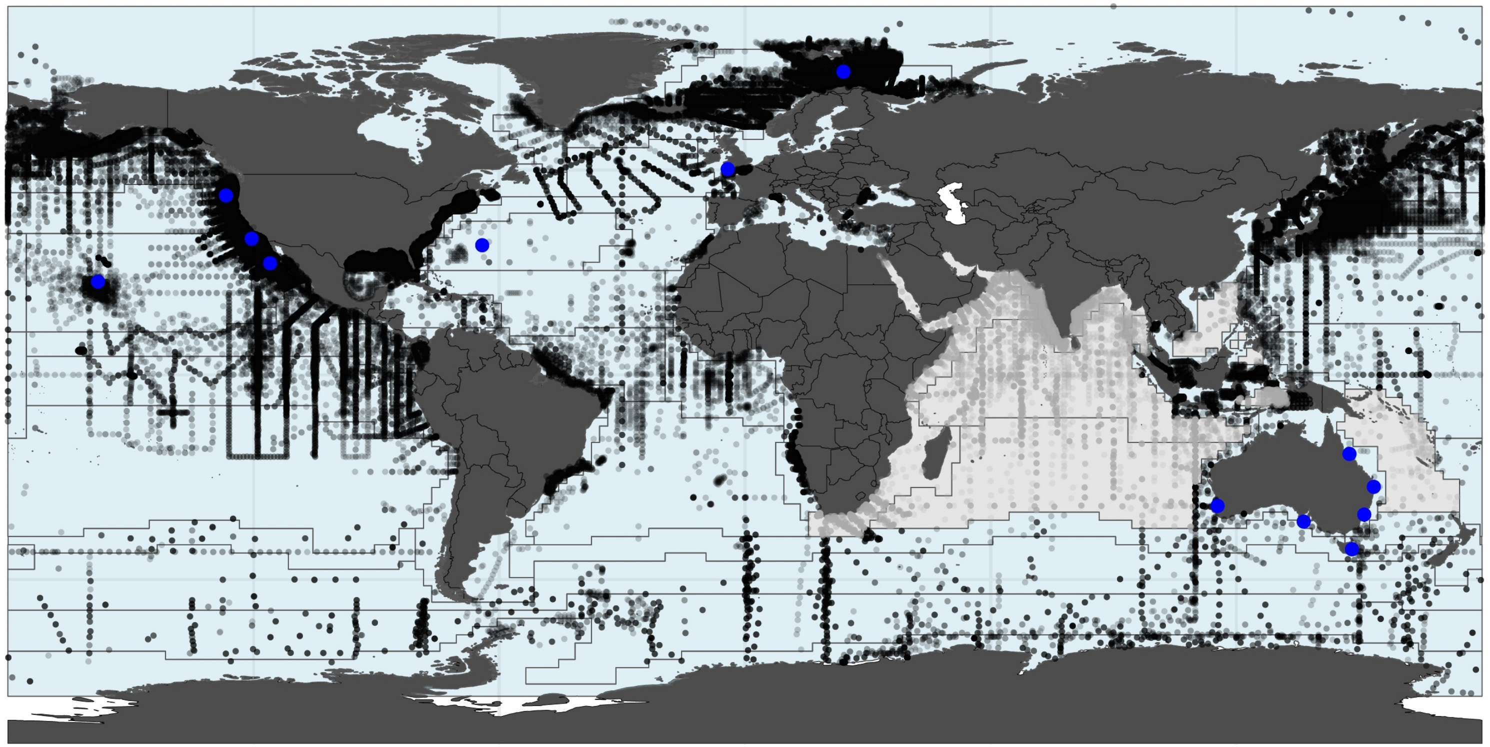
Everett et al. (2017)

2. Analysing biomass data: Generalised mixed modelling



Ben Bolker

Compiled global zooplankton biomass data



Samples included (n = 196,941)

Samples excluded (no data in Longhurst province >1995)

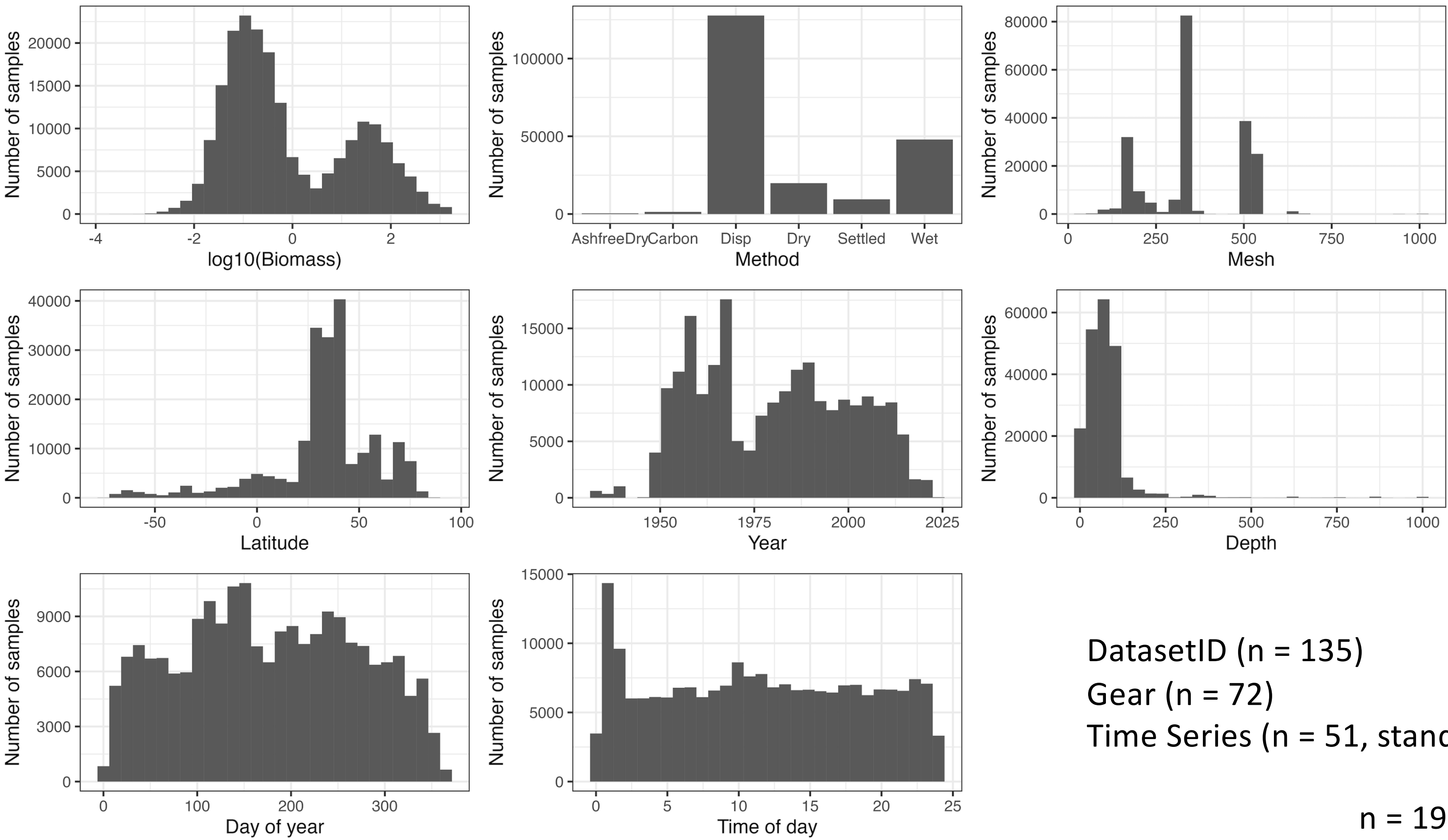
Time series (standard)

Longhurst province boundaries

NOTE: Created "pseudo" time series from survey data within Longhurst provinces

Data from: **COPEPOD (NOAA, Todd O'Brien);** IMOS (Integrated Marine Observing System); Pangaea; data paper by McEnnulty et al. (2020); public websites.

Distribution of variables



DatasetID (n = 135)
Gear (n = 72)
Time Series (n = 51, standard + “pseudo”)

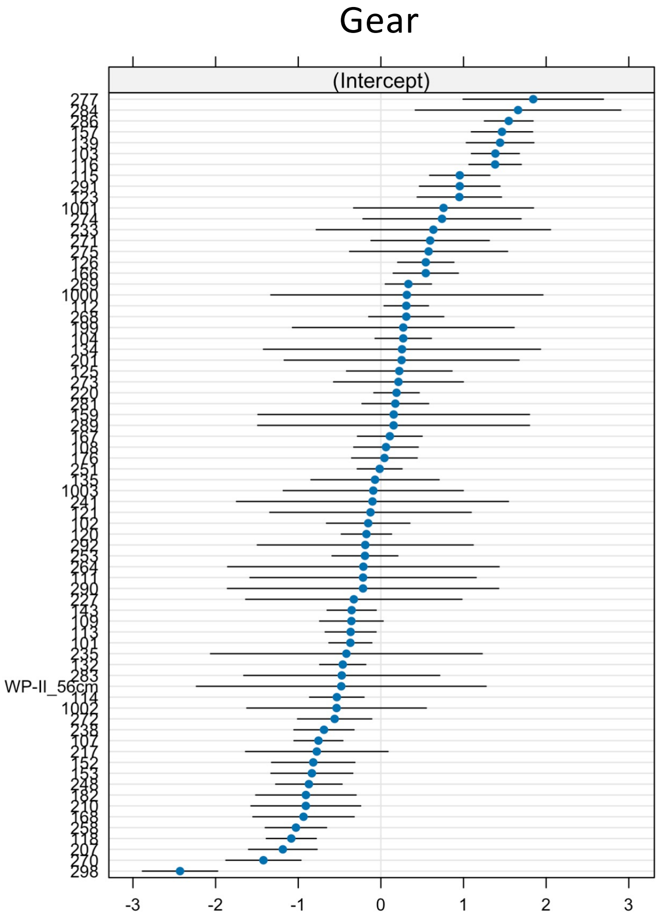
n = 196,941 samples

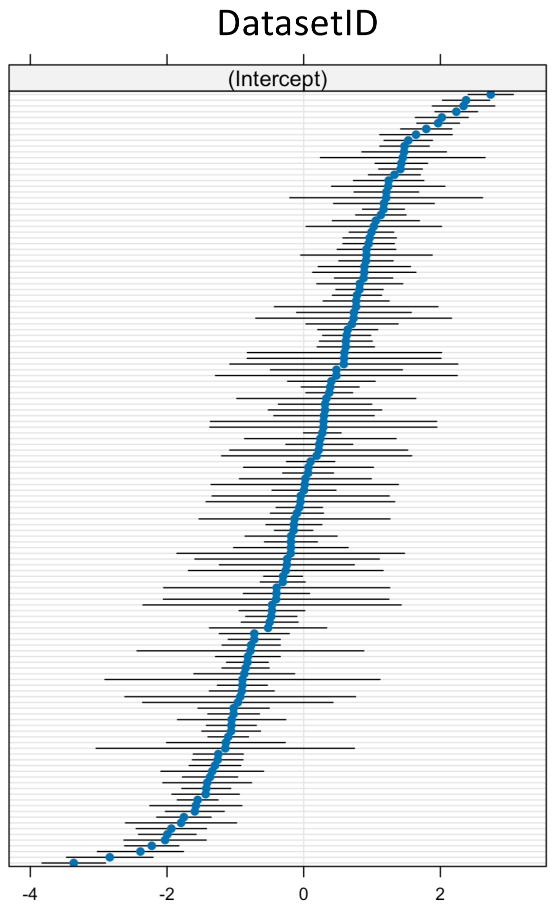
Generalised linear mixed model (GLMM)

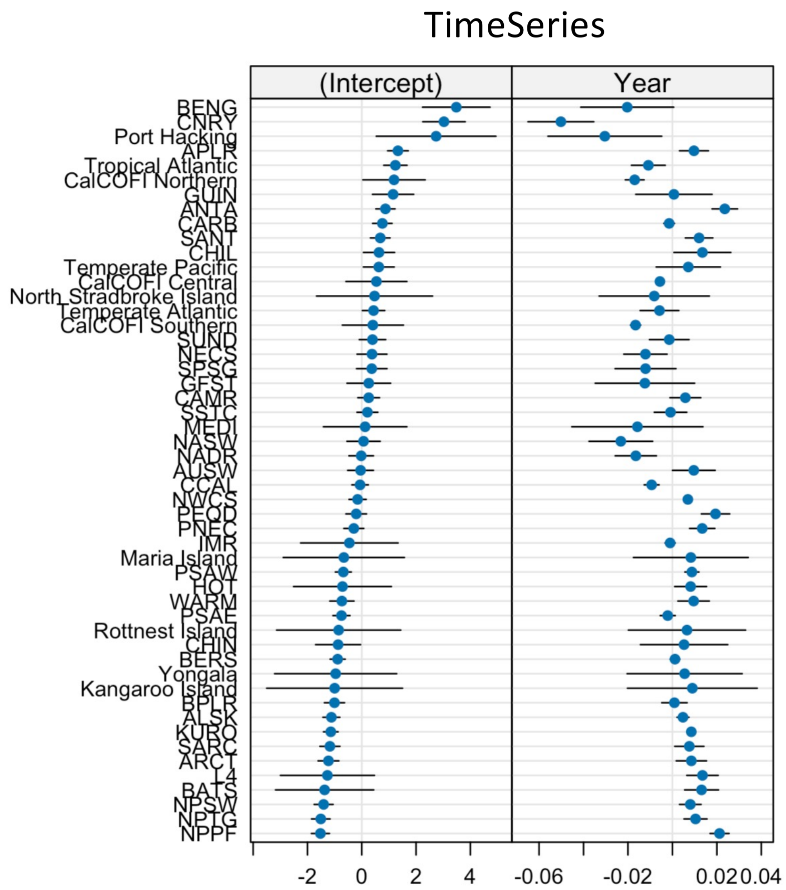
```
Biomass ~ Year +
          Method +
          Mesh +
          Tow +
           ns(Depth, df = 3) +
           harmonic(Time of day, k = 2) +
          ns(Latitude, 2) * harmonic(Day of Year, k = 2) +
          TimeSeries*SST +
          (1 | DatasetID) +
          (1 | Gear) +
          (1 + Year | TimeSeries)
```

```
Error structure: Gamma(link = "log")
```

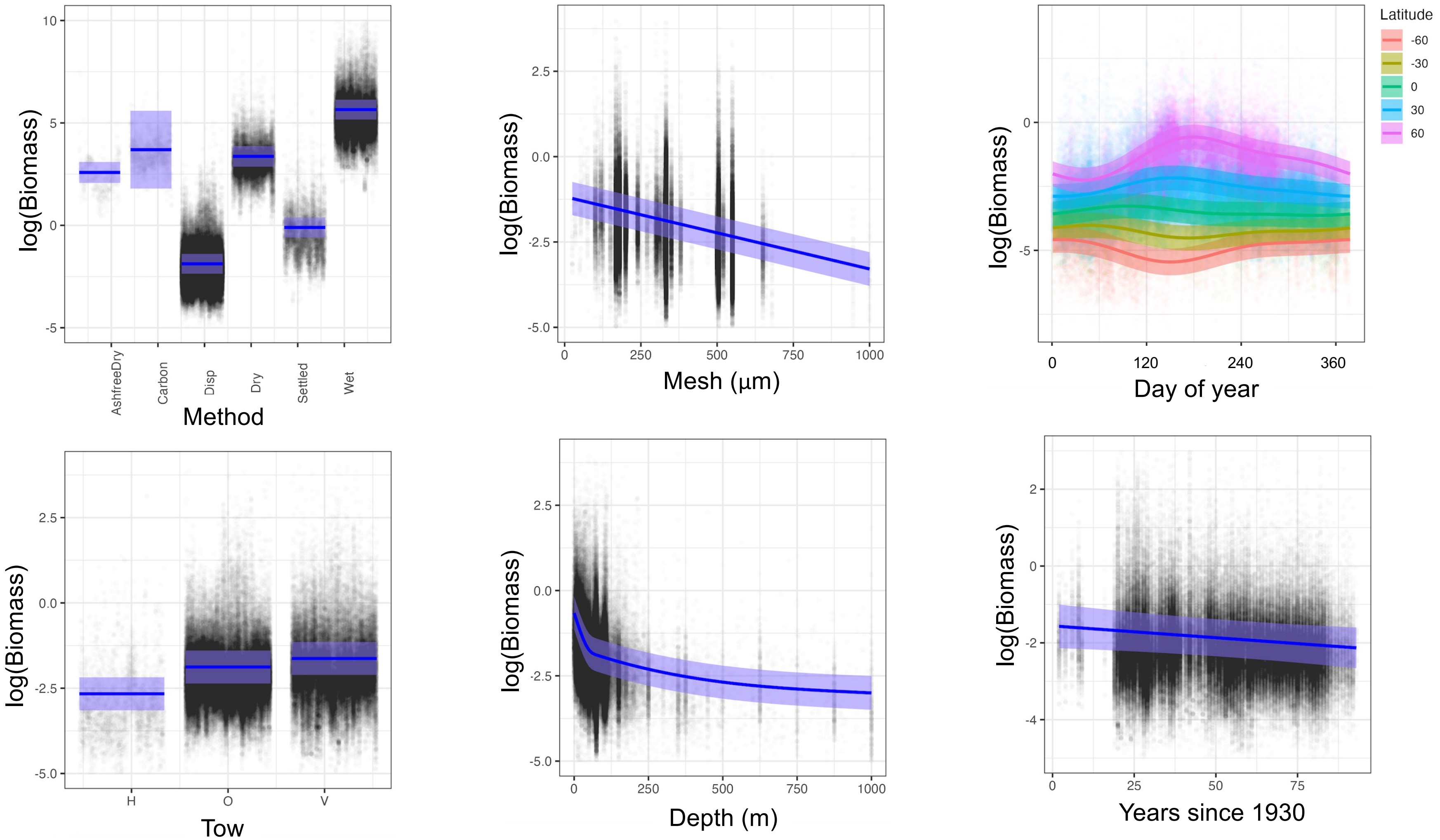
Random effects



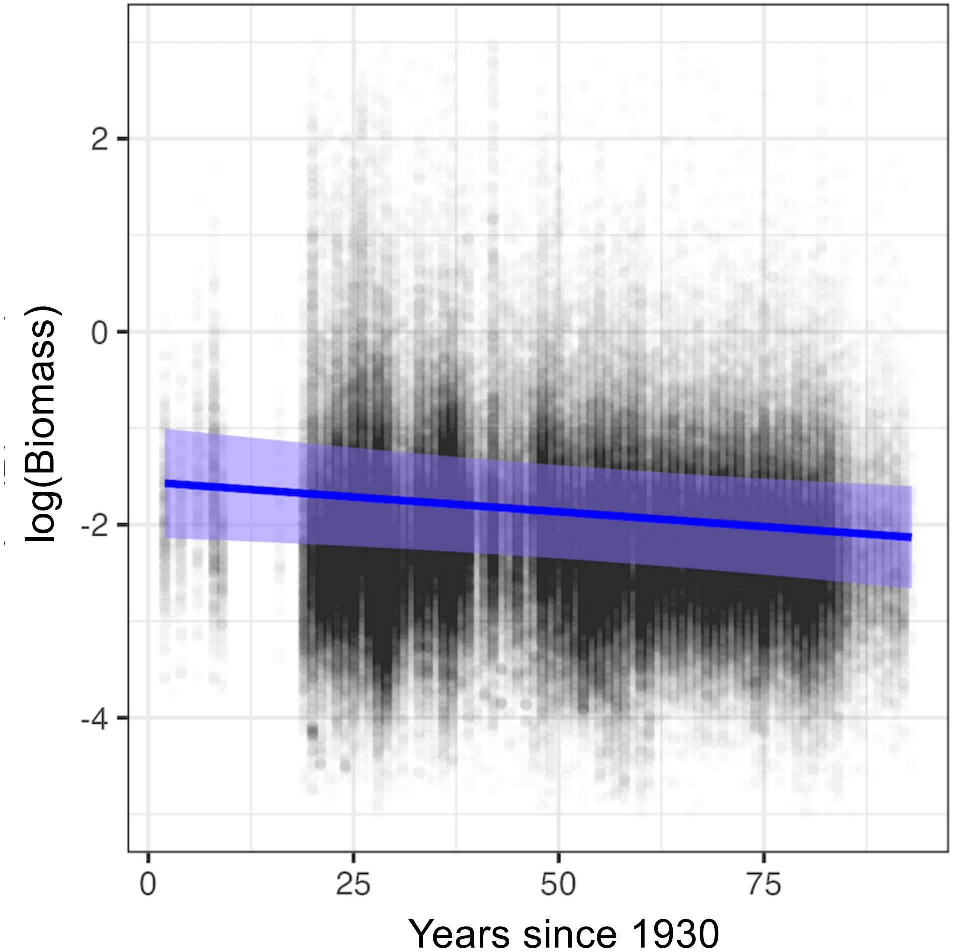




A global model of zooplankton biomass



A global decline in zooplankton biomass



Year slope = -0.004505 (p=0.036)

Equates to a decline of:

exp(-0.004505) = 0.9955
= 0.45% yr^{-1}

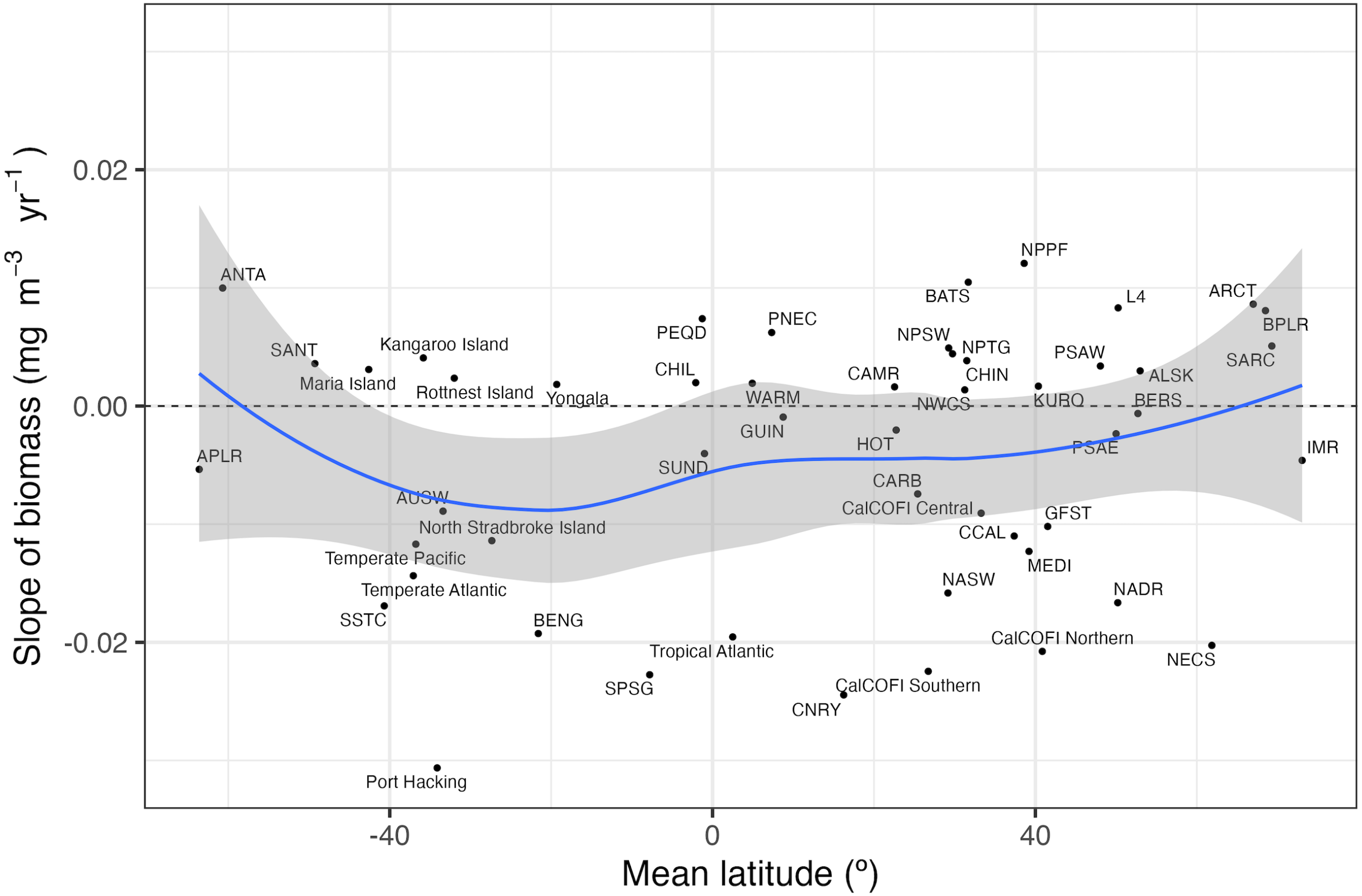
cf. Phytoplankton decline 1% yr^{-1}

How do zooplankton trends vary by latitude?

Term = Fixed effect slope for Year + Random effect of slope for Year for each Time Series

Biomass increases

Biomass declines

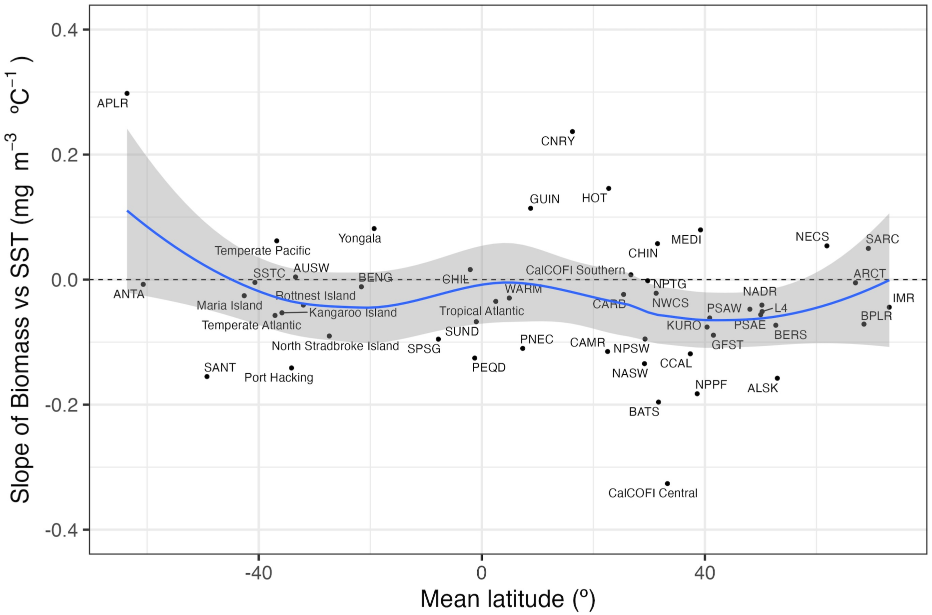


Is climate change driving the trends?

```
Term = TimeSeries*SST
```

Zooplankton increases with temperature

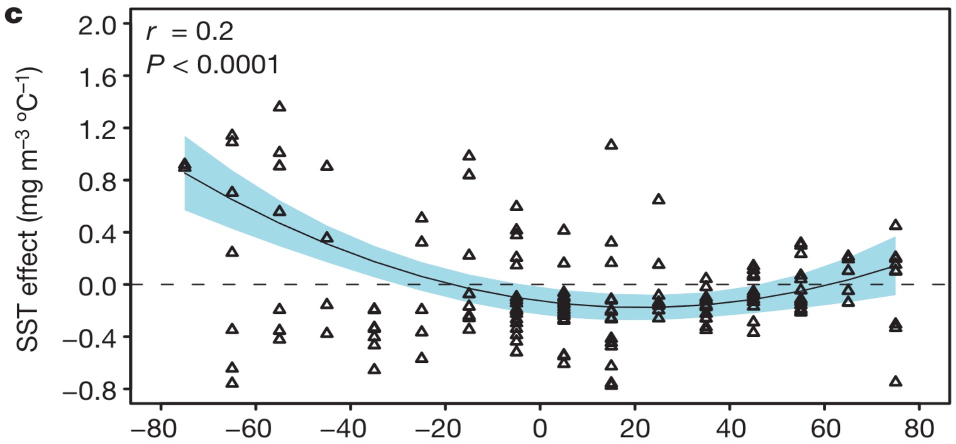
Zooplankton declines with temperature



Our study

Phytoplankton increases with temperature

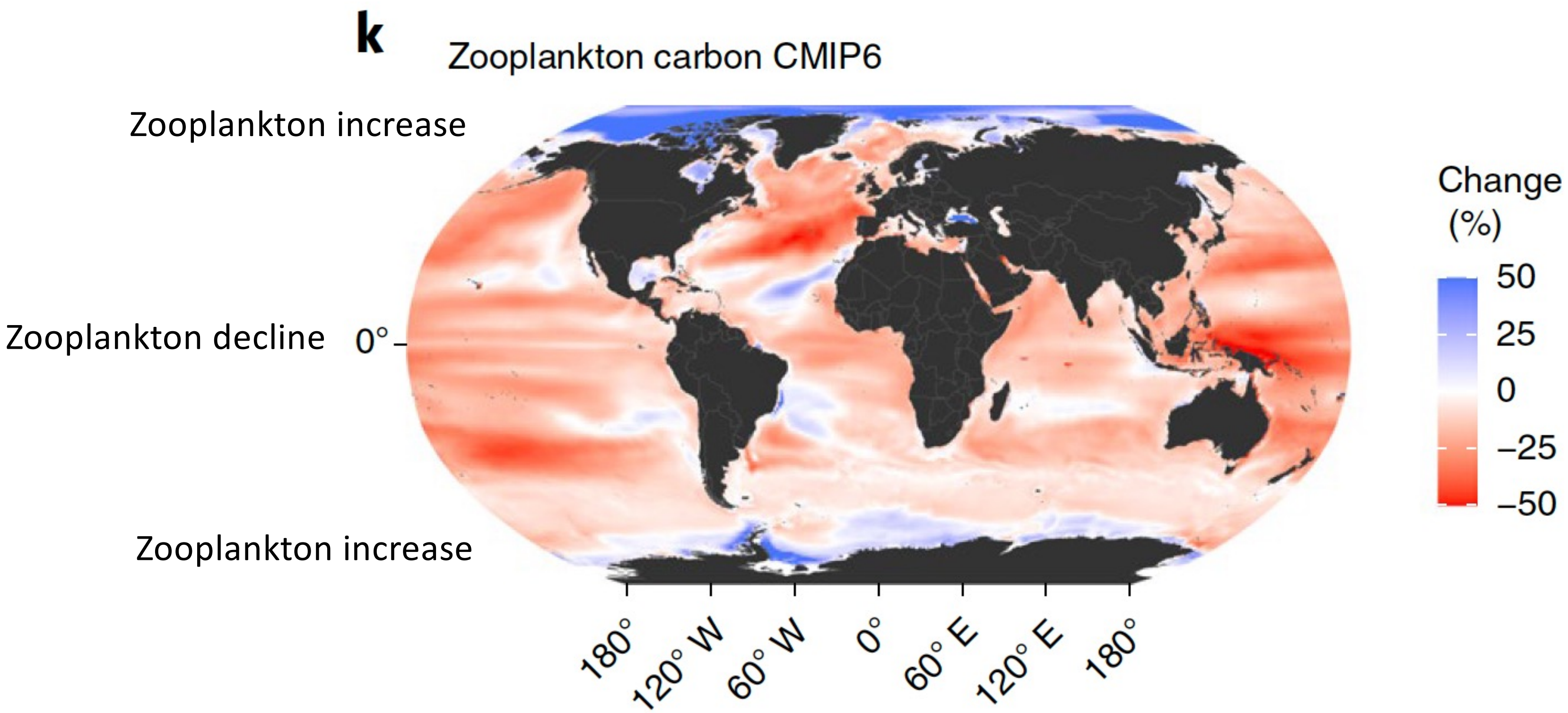
Phytoplankton declines with temperature



Increased stratification increases phytoplankton production in polar areas but decreases it in the tropics

Boyce et al. (2010)

Zooplankton and climate change with CMIP6 Earth System Models



Tittensor et al. (2021)

Caveats

1. Biases in zooplankton biomass (e.g., includes phytoplankton, detritus, interstitial space for settled volume, hides changes in functional groups, …).
2. Data gaps (e.g., most of Indian Ocean, Southern Hemisphere, tropical ocean, time of day poorly recorded, relatively few recent data,…).
3. Ignores non-linear changes.

Take-home messages

1. First observational evidence for a global decline in zooplankton biomass, but extensive regional variation.
2. Provides some independent corroboration of the decline observed in phytoplankton over last century and decline with climate change of zooplankton in Earth System Models.
3. Estimated global decline in zooplankton (0.45% yr^{-1}) slower than phytoplankton (1% yr^{-1}), suggesting no trophic amplification. Could be because in increasingly oligotrophic ocean, a greater role for gelatinous filter-feeders (Jaspers, Everett), rhizaria, and inverse pyramids (Lombard)???
4. Potential implications for fisheries and carbon sequestration.
5. Generalised mixed modelling can be a useful approach to adjust for biases in zooplankton sampling and synthesise zooplankton data.

Thanks to everyone who has made their zooplankton biomass data freely available! If you have biomass data you would like to include, please contact me: anthony.richardson@csiro.au

Long after our papers will stop being cited, our data – that is collected and made freely available – will continue to increase in value.