Velocity and seasonal shift in climate: Ecologically relevant indices for predicting changes in species distributions and phenology

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SAMS

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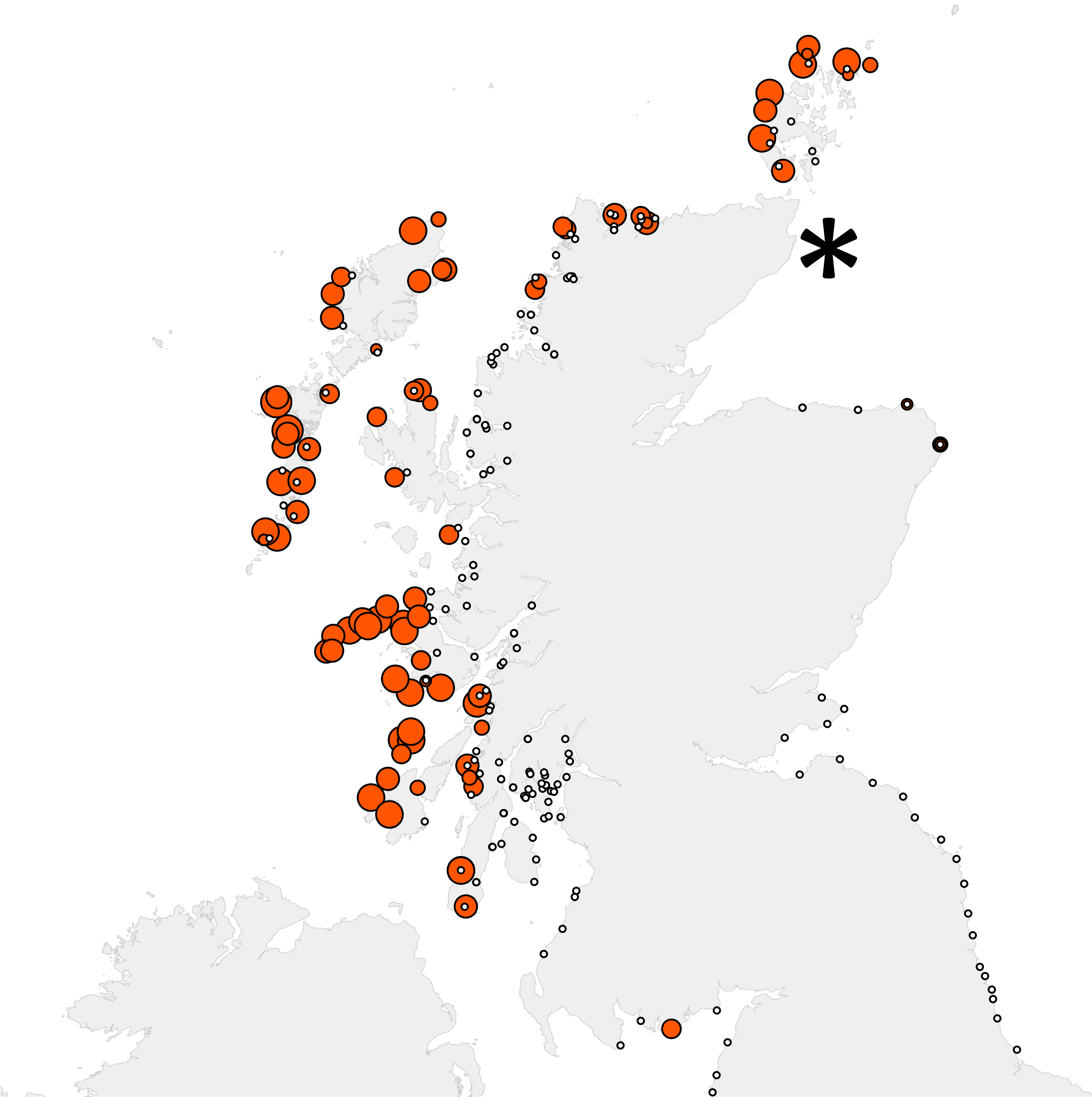
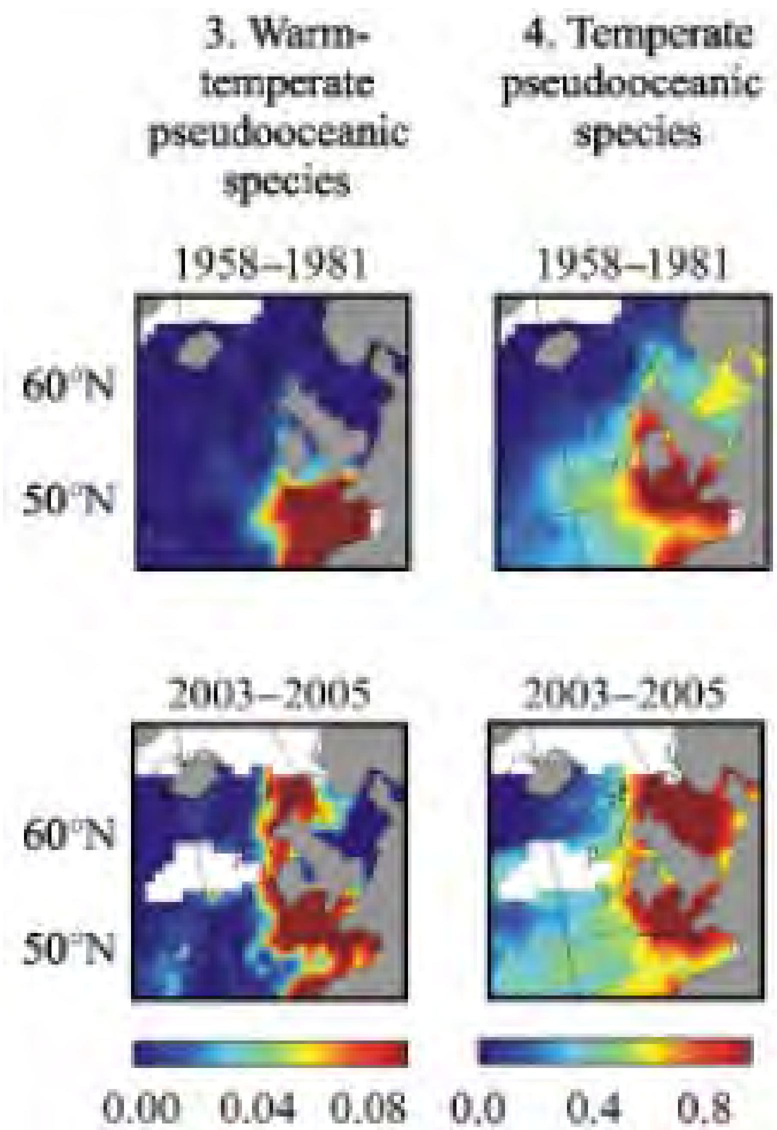
TWENTY
PENCE
20
1982



Rapid shifts in distributions of marine species

- NE Atlantic plankton
  - 1958-2005
- 1000km poleward over 40 years

230 km/decade 220 km/decade

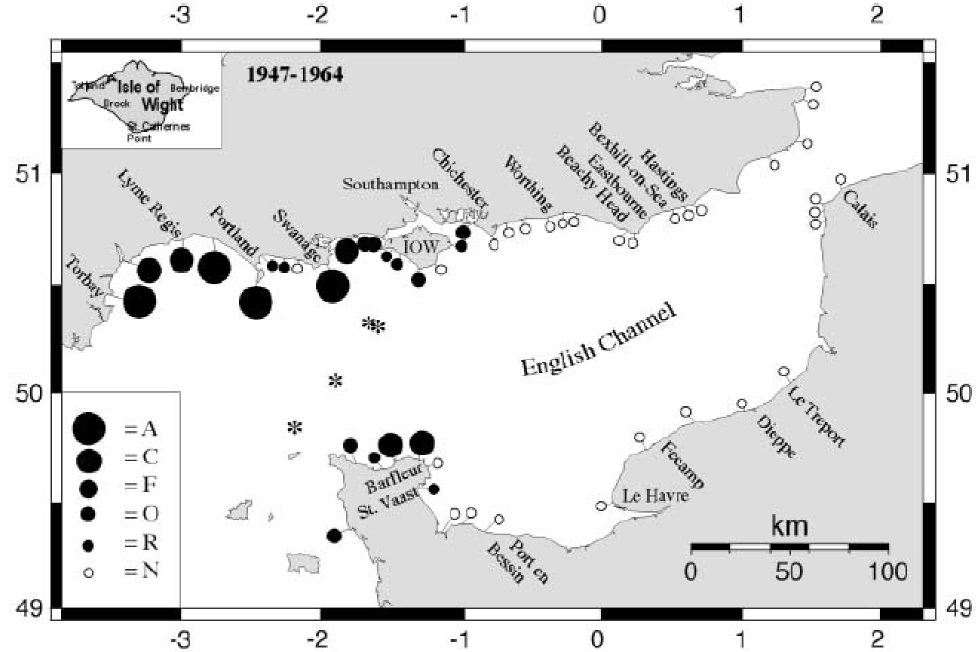


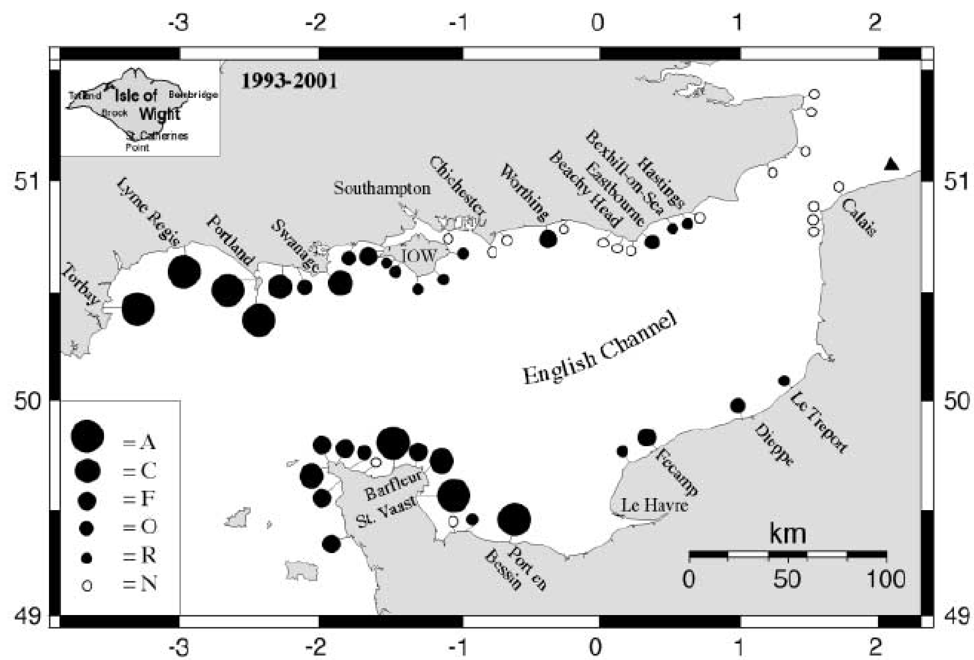
Beaugrand, G., Luczak, Christophe, and Edwards, Martin. 2009. Rapid biogeographical plankton shifts in the North Atlantic Ocean. Global Change Biology 15:1790–1803.

- Warm-water barnacles in the English Channel
  - 1964-2001
  - *Balanus perforatus*

- 120km eastwards

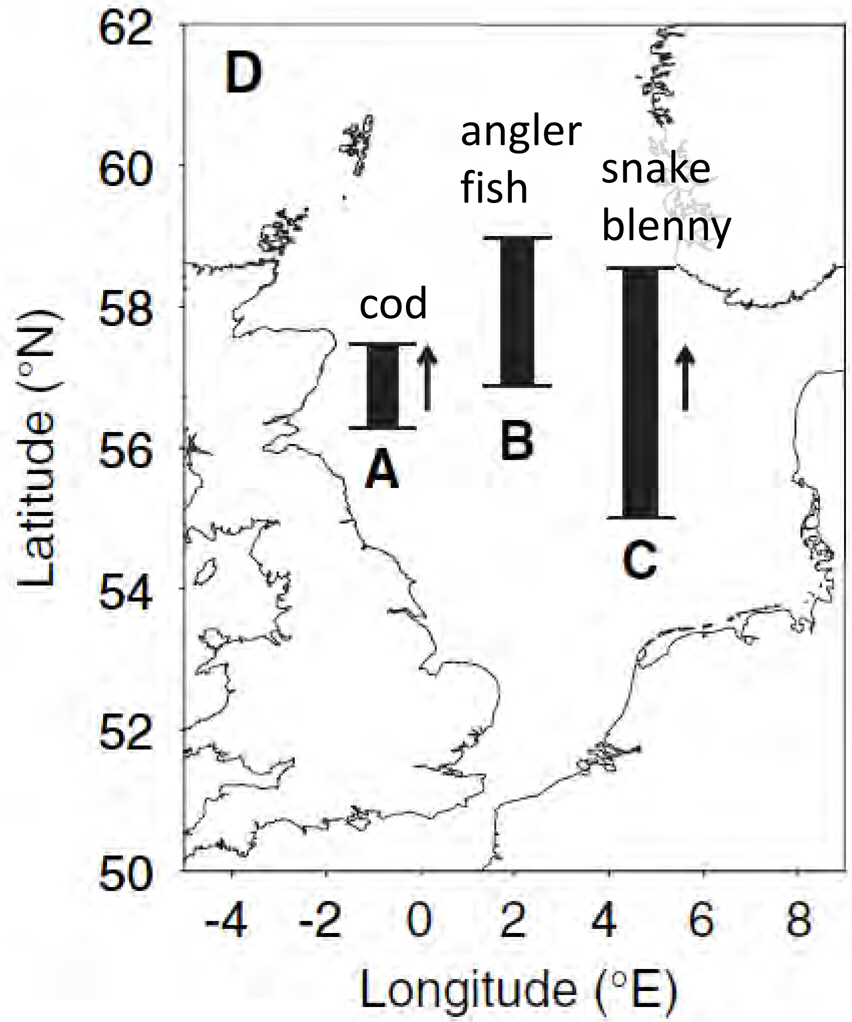
33 km/decade





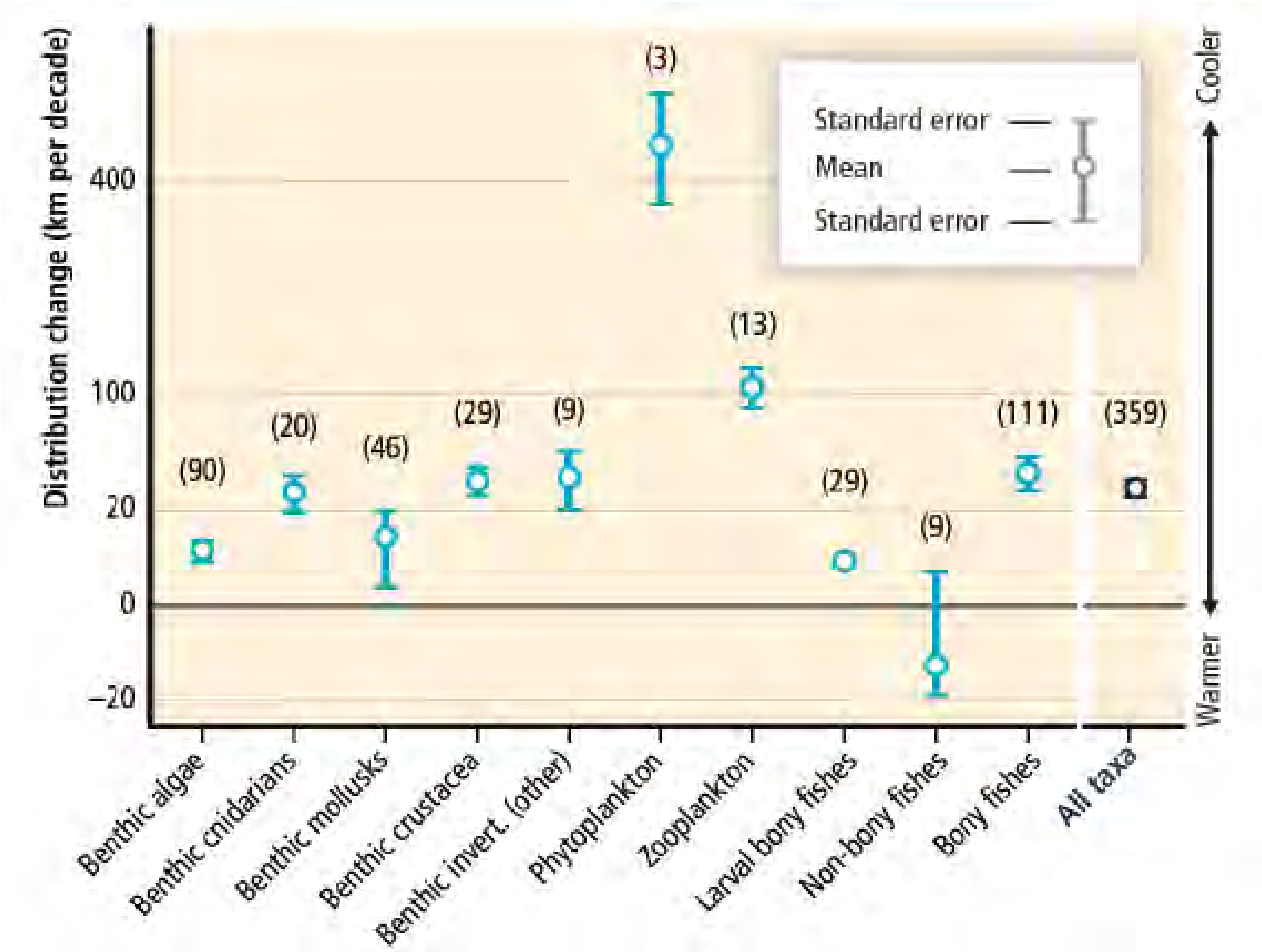
Herbert, R. J. H., S. J. Hawkins, M. Sheader, and A. J. Southward. 2003. Range extension and reproduction of the barnacle Balanus perforatus in the eastern English Channel. Journal of the Marine Biological Association of the United Kingdom 83:73–82.

- North Sea fish
  - 1962-2001
- 0 to 120km/decade



Perry, A. L., P. J. Low, J. R. Ellis, and J. D. Reynolds. 2005. Climate change and distribution shifts in marine fishes. Science 308:1912.

Marine organisms are moving to higher latitudes consistent with warming trends (*high confidence*)



Leading edge expansion

Ocean
72 km/decade

Land
6 km/decade

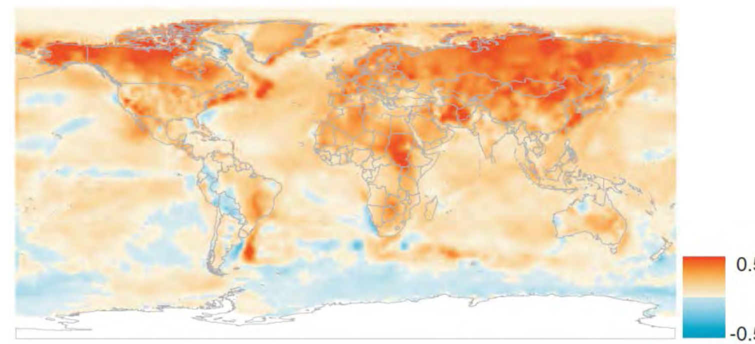
Poloczanska et al 2013 Nature Climate Change, IPCC WGII SPM

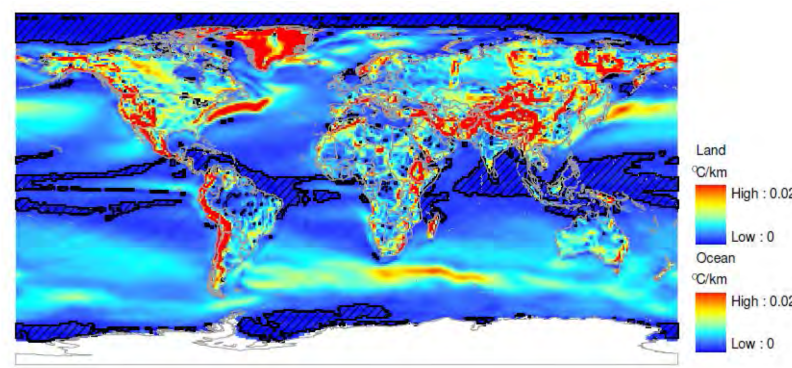
Velocity of Climate Change (VoCC)

How fast and in which direction are isotherms shifting?

1960 to 2009

$$\text{Velocity} = \frac{\text{Temperature trend}}{\text{Spatial gradient}} =$$



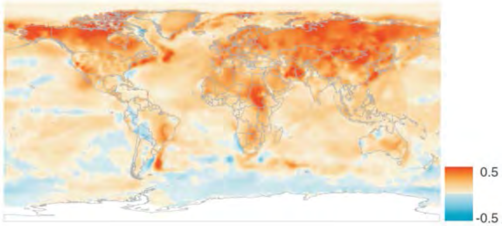


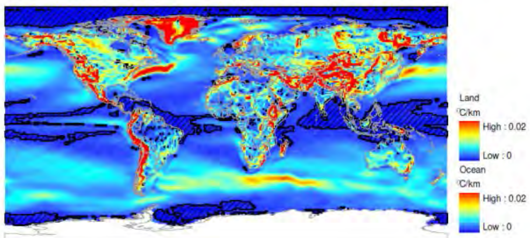
$$\text{km/yr} = \frac{°\text{C/year}}{°\text{C/km}}$$

1960-2009 surface temperatures

Loarie, S. R., et al. 2009. The velocity of climate change. Nature 462:1052–1055.

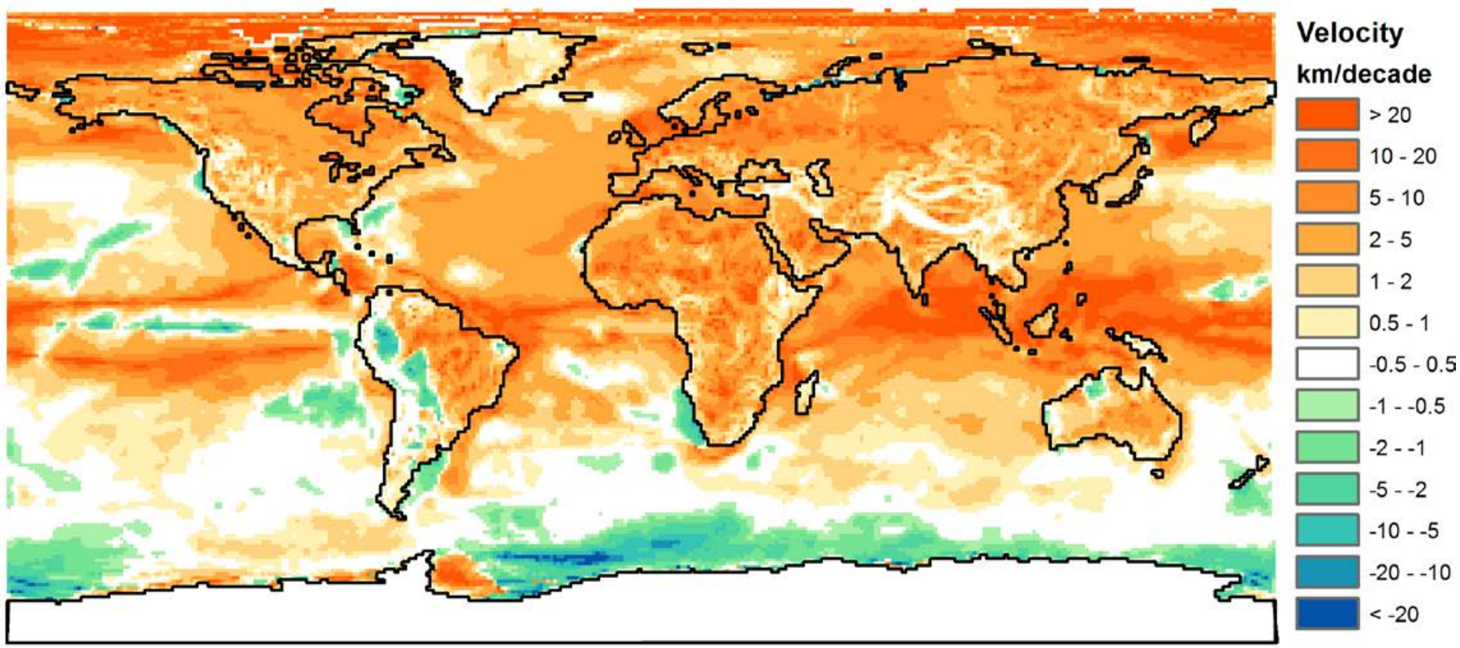
Burrows, M. T., et al. 2011. The Pace of Shifting Climate in Marine and Terrestrial Ecosystems. Science 334:652 –655. doi: 10.1126/science.1210288

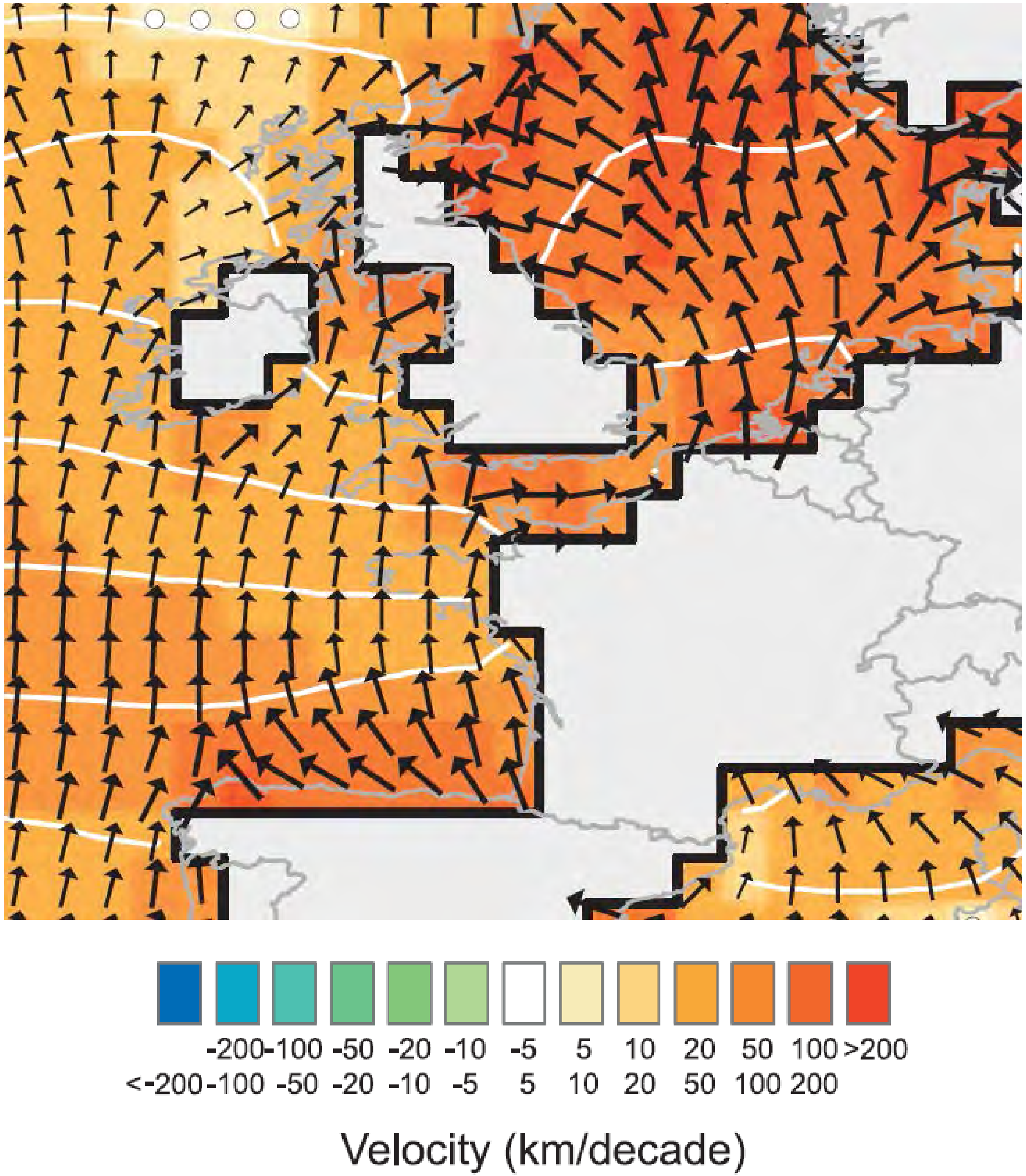




- Velocity is **fast**
  - where spatial gradients are shallow (Equator)
  - Where change in temperature is highest
- Velocity is **slow**
  - Where gradients are sharp
  - Where temperature change is
- Velocity is **negative**
  - Where the oceans have cooled (Southern Ocean)
  - Indicates movement towards warmer regions

21.7 km/decade
Ocean median

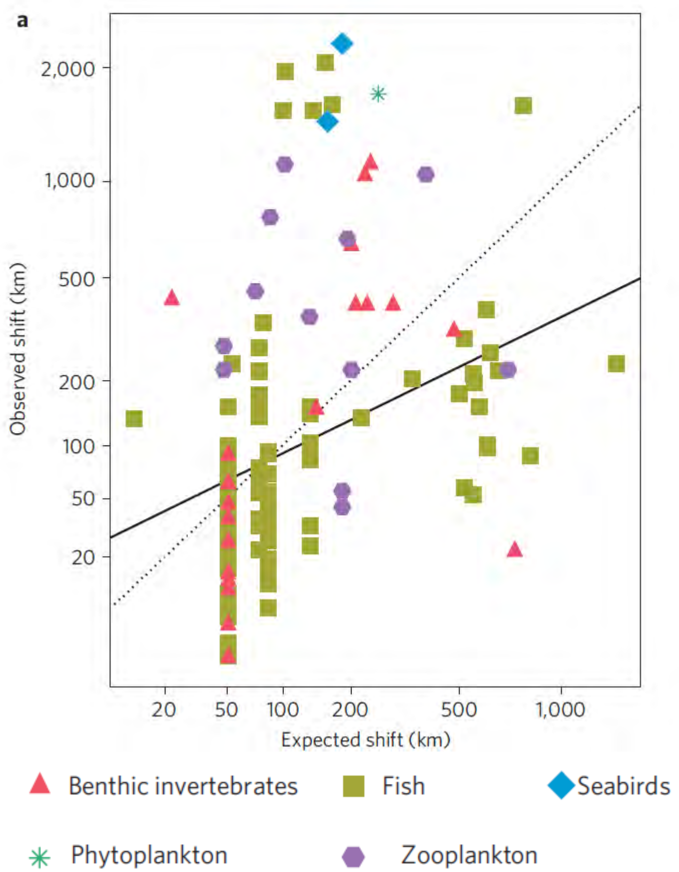




- W Scotland
  - 20-50 km/decade
- North Sea
  - 200+ km/decade

shallow gradient
+
faster warming
= greater velocity

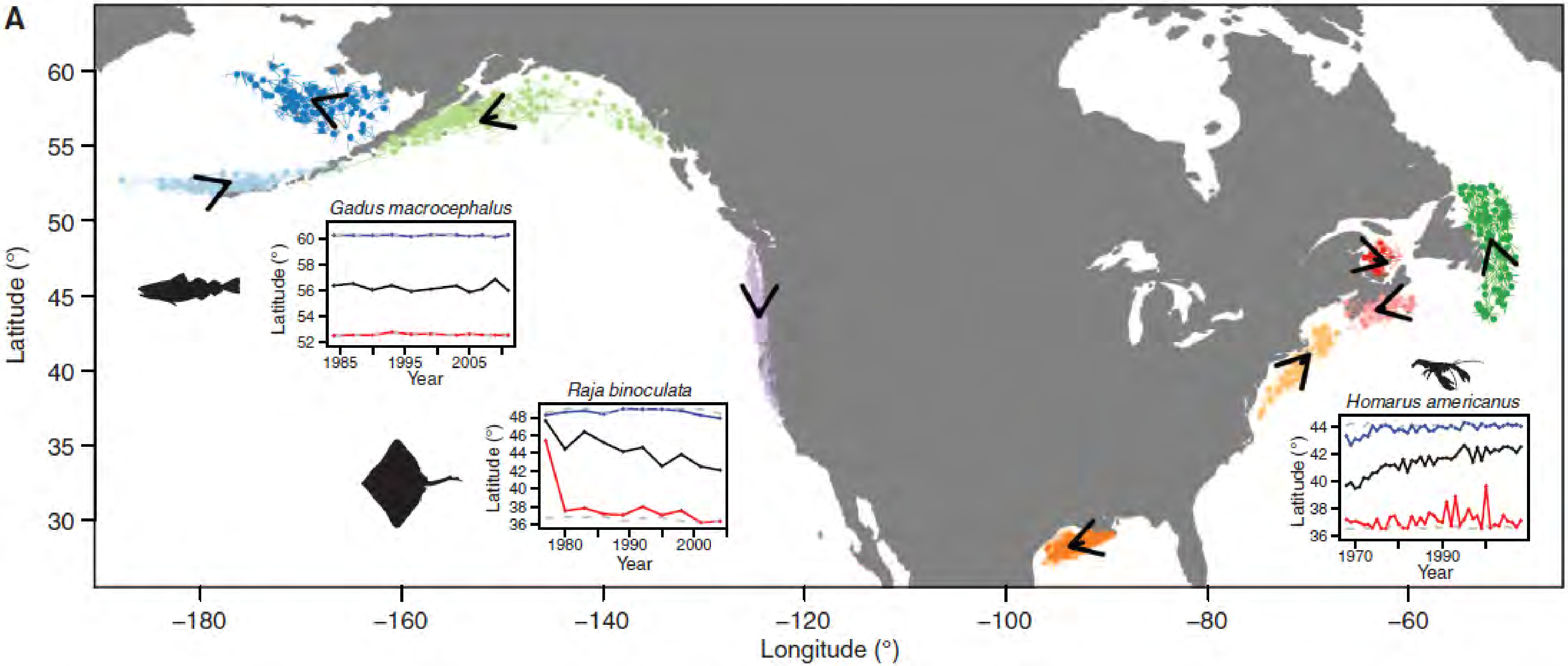
Does velocity predict observed shifts?



- **Yes,**
  for ocean observations with >10 years data
- (n=139, P<0.001)
  - some species faster, some slower

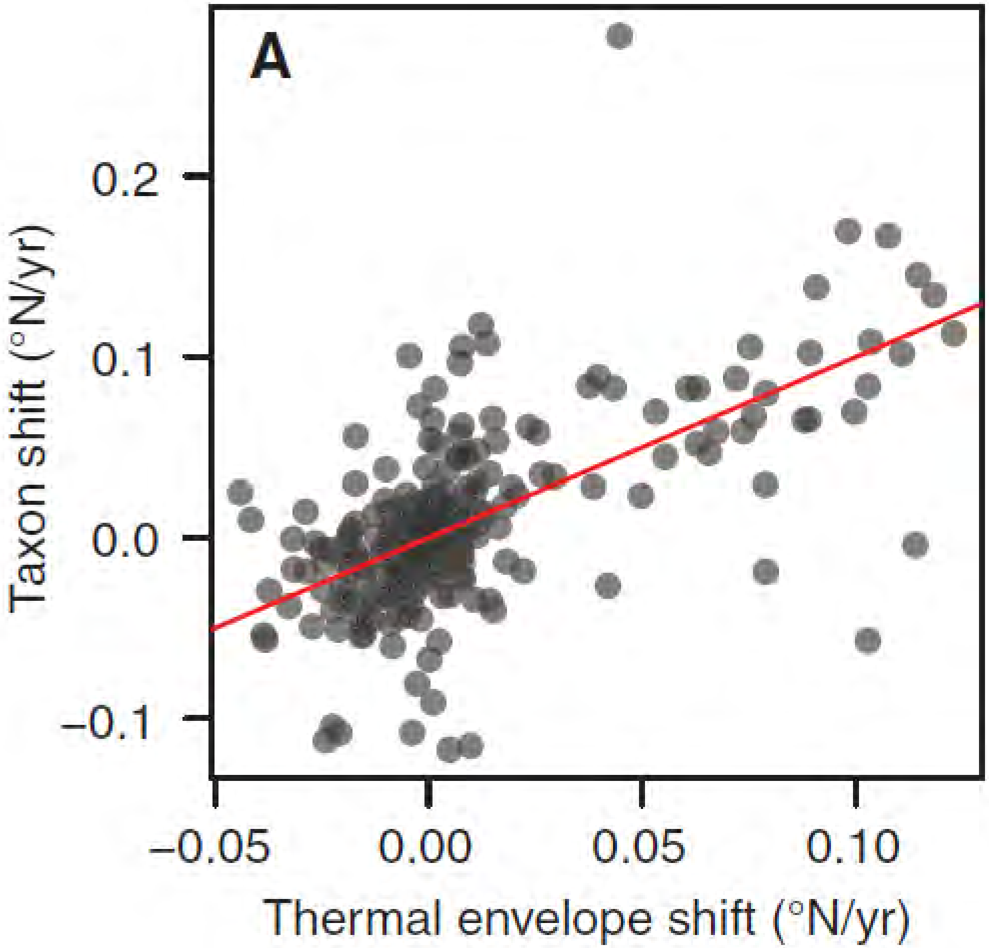
Poloczanska, E. S et al. **2013**. Global imprint of climate change on marine life. *Nature Climate Change*. doi:10.1038/nclimate1958

Marine taxa track local climate velocities



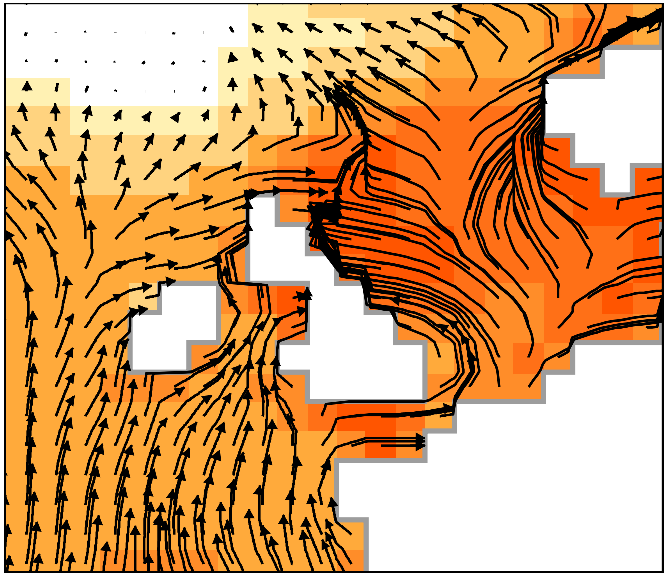
128 million individuals across 360 marine taxa sampled from 1968-2011

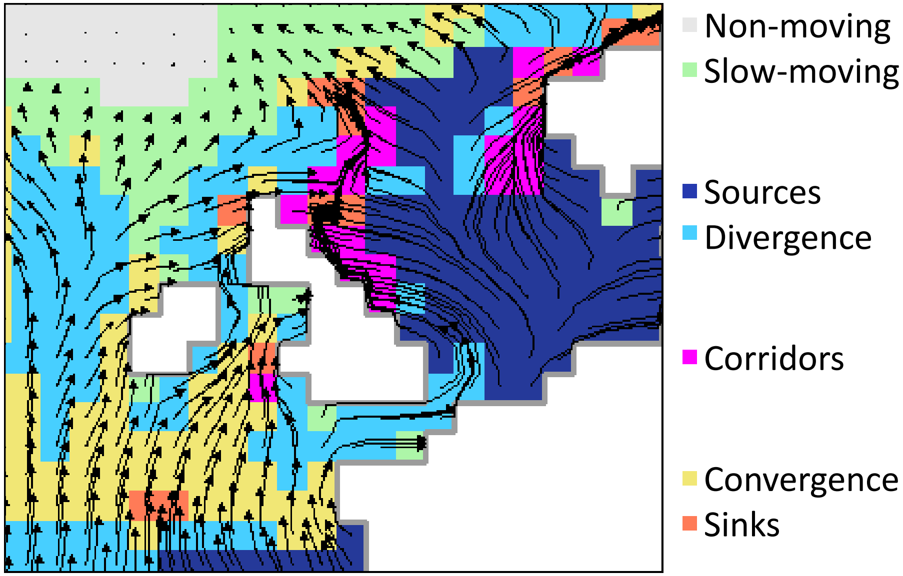
Pinsky et al. 2013 Science

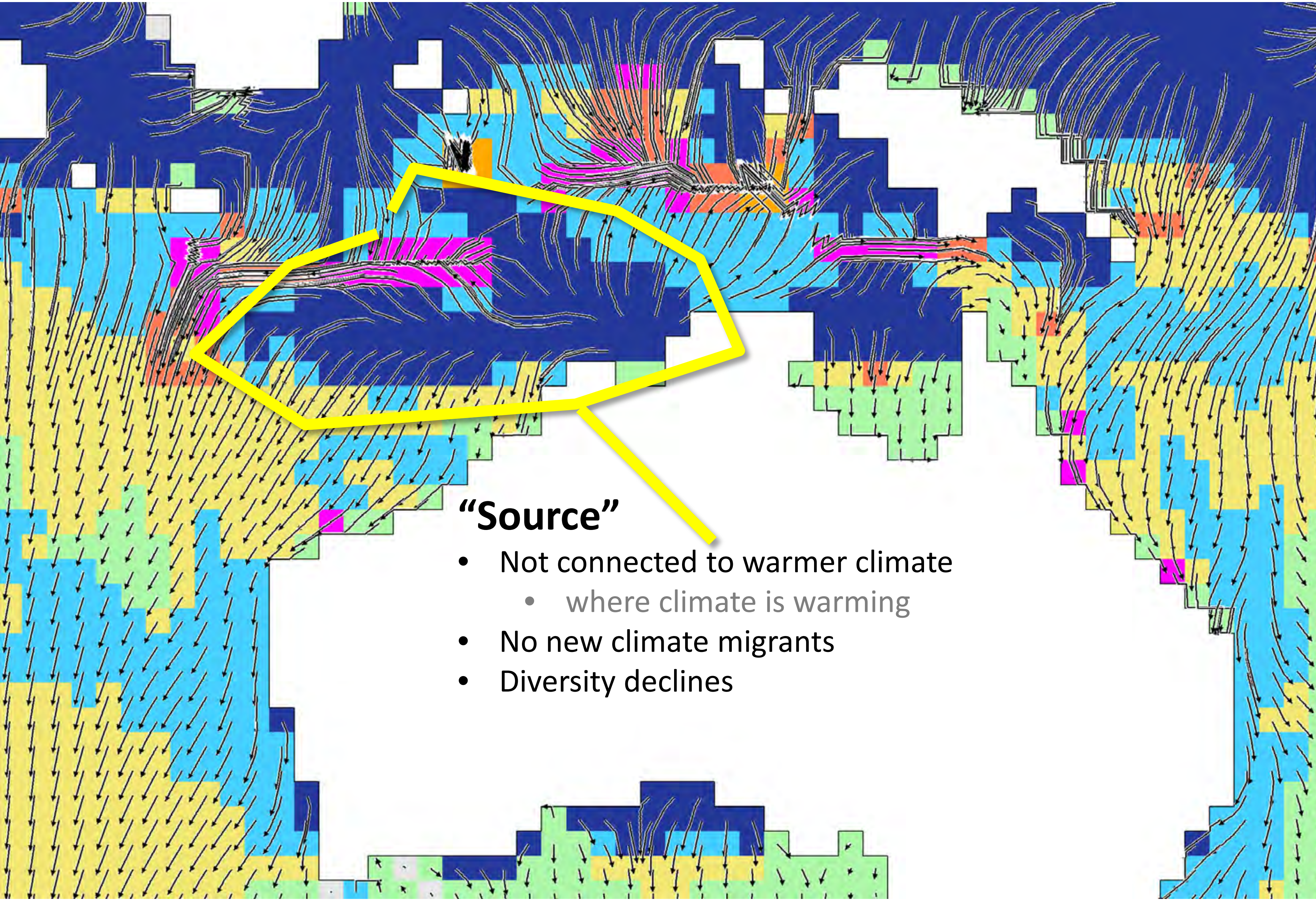


Pinsky et al. 2013 Science

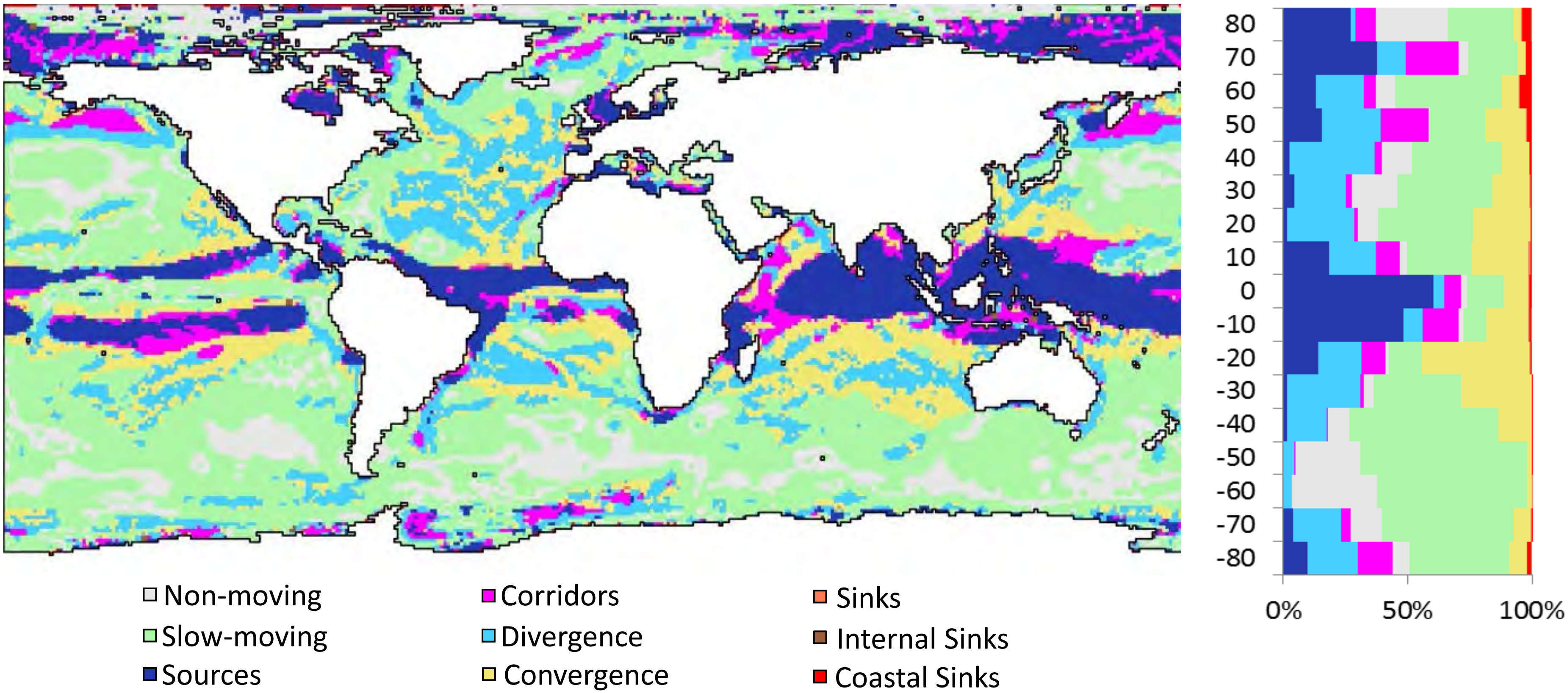
Projections from velocity of climate change





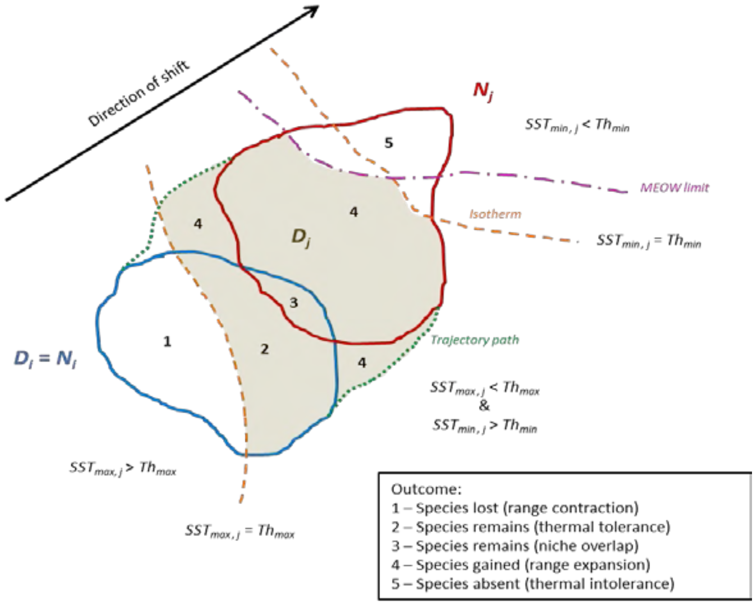

"Source"
• Not connected to warmer climate
• where climate is warming
• No new climate migrants
• Diversity declines

Global patterns: **oceans**



Sources are arranged around the equator and on poleward-facing coasts
Sinks are mostly on equatorward-facing coasts

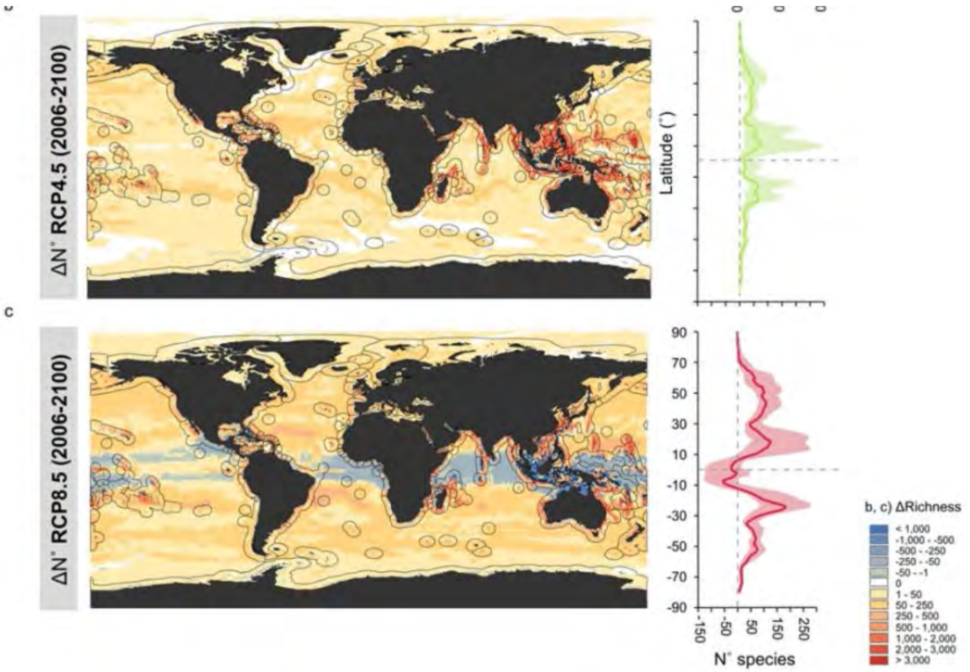
VoCC Trajectories used to shift distributions



…plus assumptions about upper thermal limits
(Tmax + 1SD over 50 years)

and many species distributions (e.g. Aquamaps)

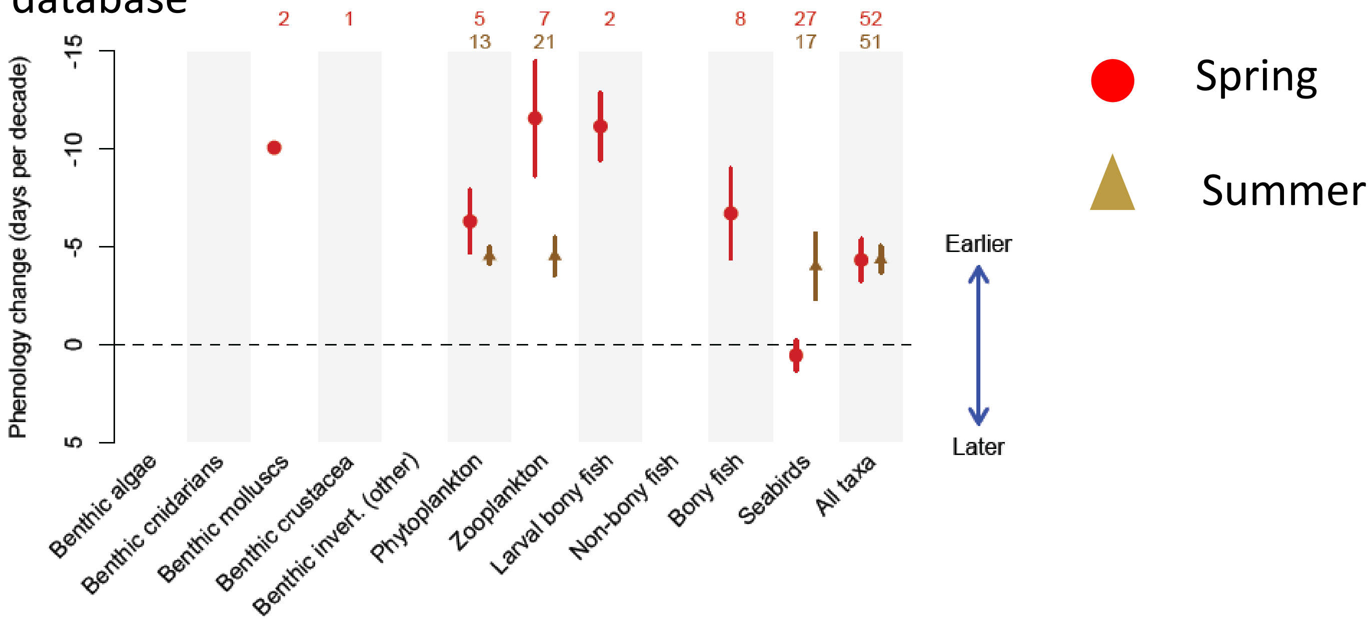
…to give projected change in species richness globally



García Molinos et al., unpublished

Metaanalysis: How fast is **phenology** shifting?

Whole database



Spring advancement ocean: 4.4 days dec^{-1}

Spring advancement coastal: 7.3 days dec^{-1}

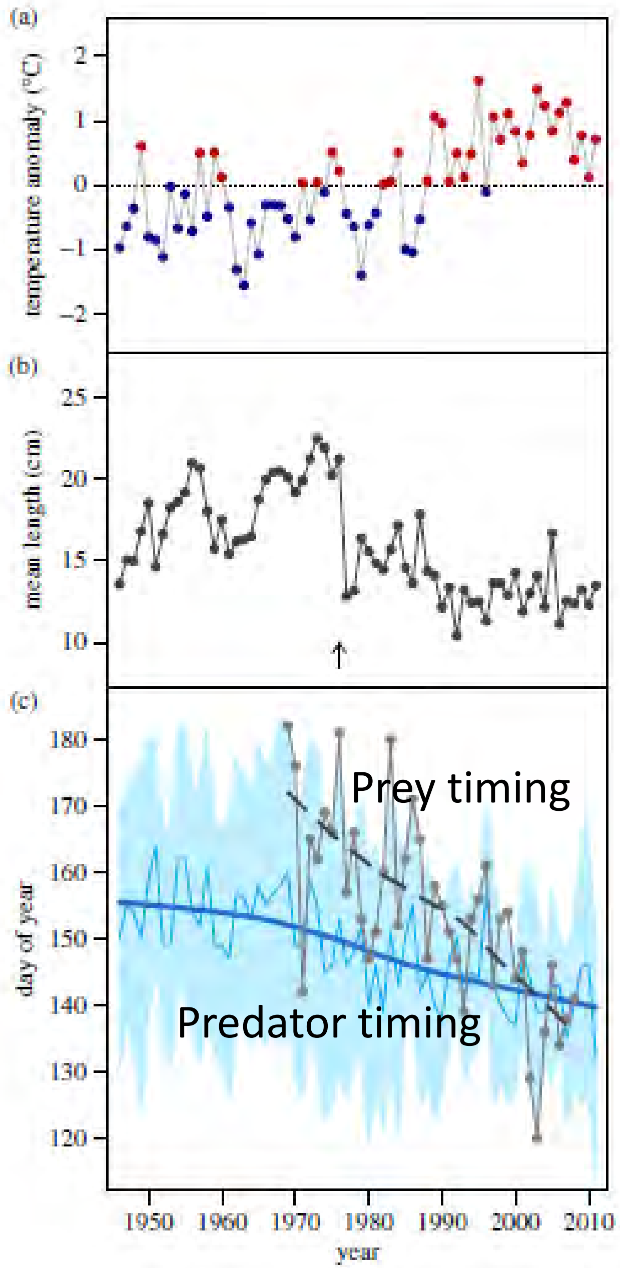
Spring advancement land: 2.3-2.8 days dec^{-1}

Parmesan and Yohe 2003 Nature
Parmesan 2007 GCB
Root et al 2003 Nature

Phenology change
– an analogous predictor to VoCC?

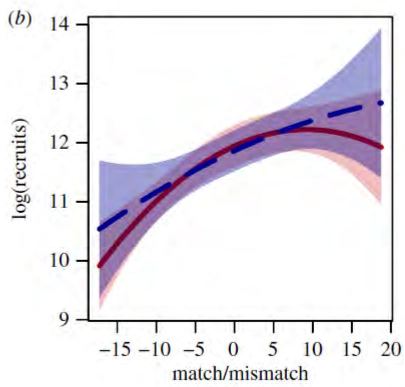
- By how much should organisms change their seasonally timed activities to track changes in temperature?

- **The change in arrival time of equal seasonal temperatures over longer periods** (decades)



Perch in a UK lake

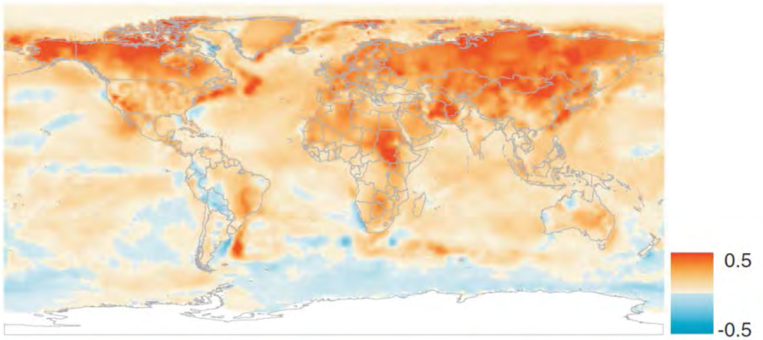
- Zooplankton prey getting earlier faster than larval perch
- Larvae get less food, reducing recruitment



Ohlberger, J., S. J. Thackeray, I. J. Winfield, S. C. Maberly, and L. A. Vollestad. 2014. When phenology matters: age-size truncation alters population response to trophic mismatch. Proceedings of the Royal Society B: Biological Sciences 281:20140938–20140938.

Seasonal climate shifts

$$\text{Seasonal shift} = \frac{\text{Long-term temperature trend by month}}{\text{Seasonal rate of change in temperature}}$$



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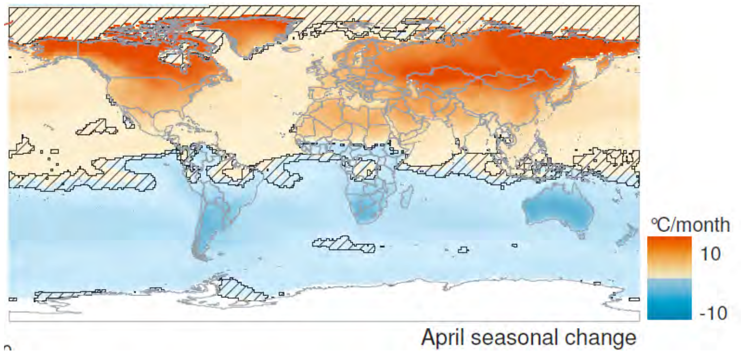


$$\text{days/yr} = \frac{°\text{C/year}}{°\text{C/day}}$$

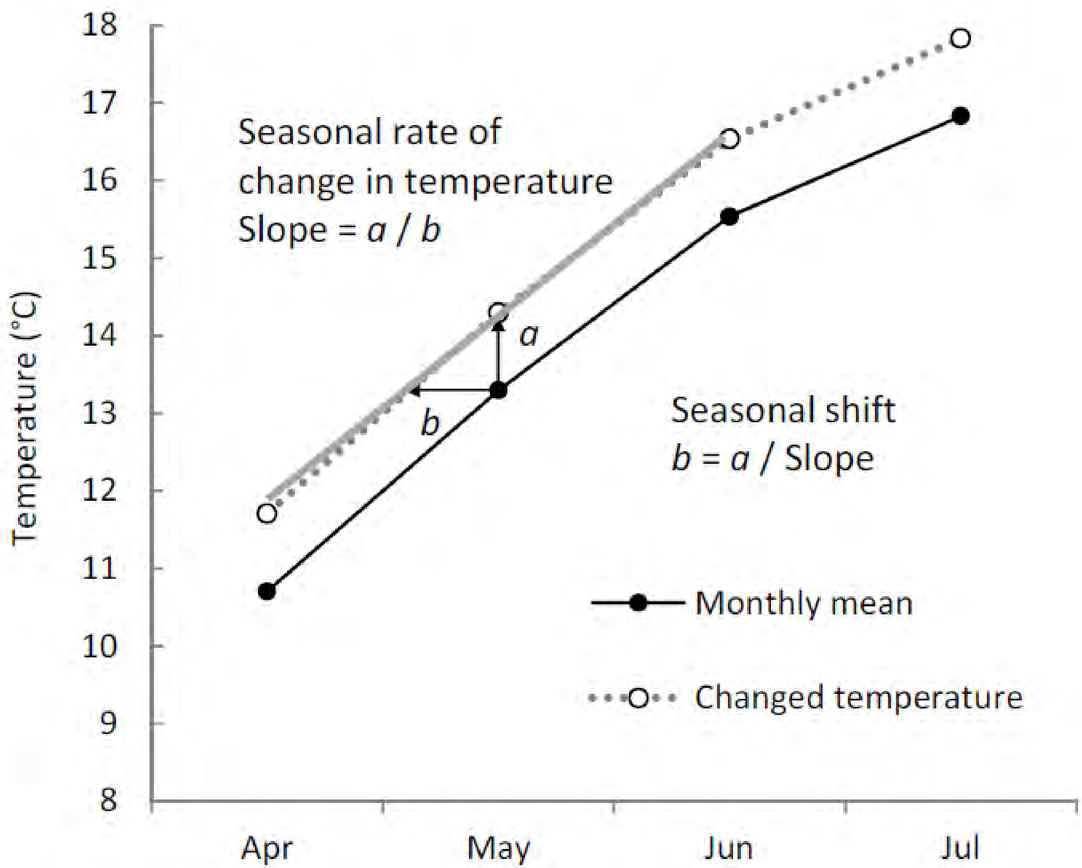
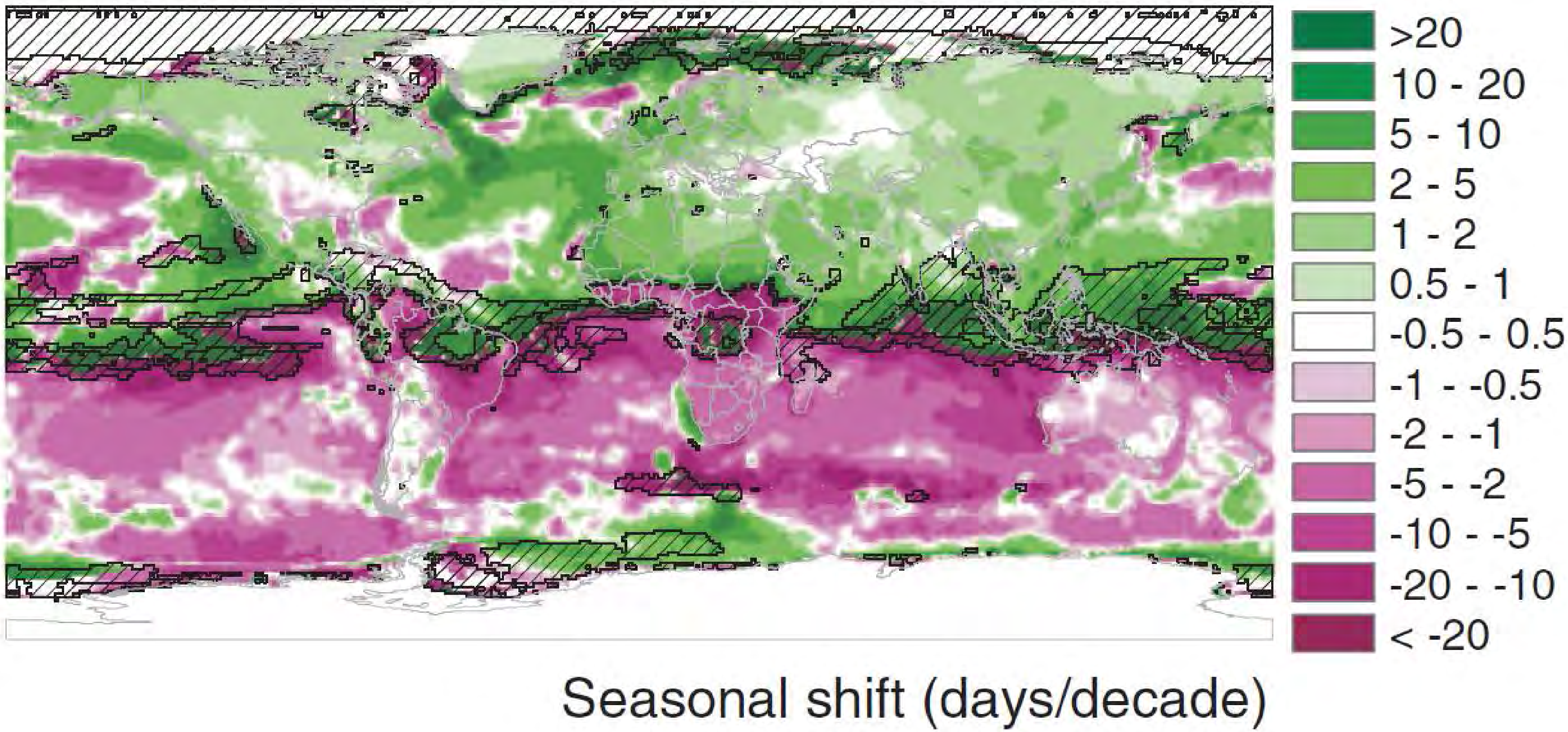
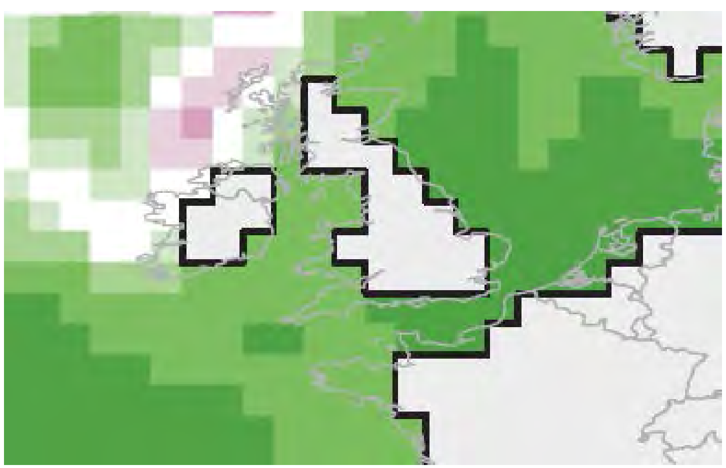


Fig. S5.

Calculation of seasonal shift. Seasonal shift is the advance or delay in timing of seasonal arrival of fixed temperatures. If the rate of seasonal change in temperature is given by the slope of the grey line, then the seasonal shift, b, is the temperature change (a, positive or negative) divided by the slope.

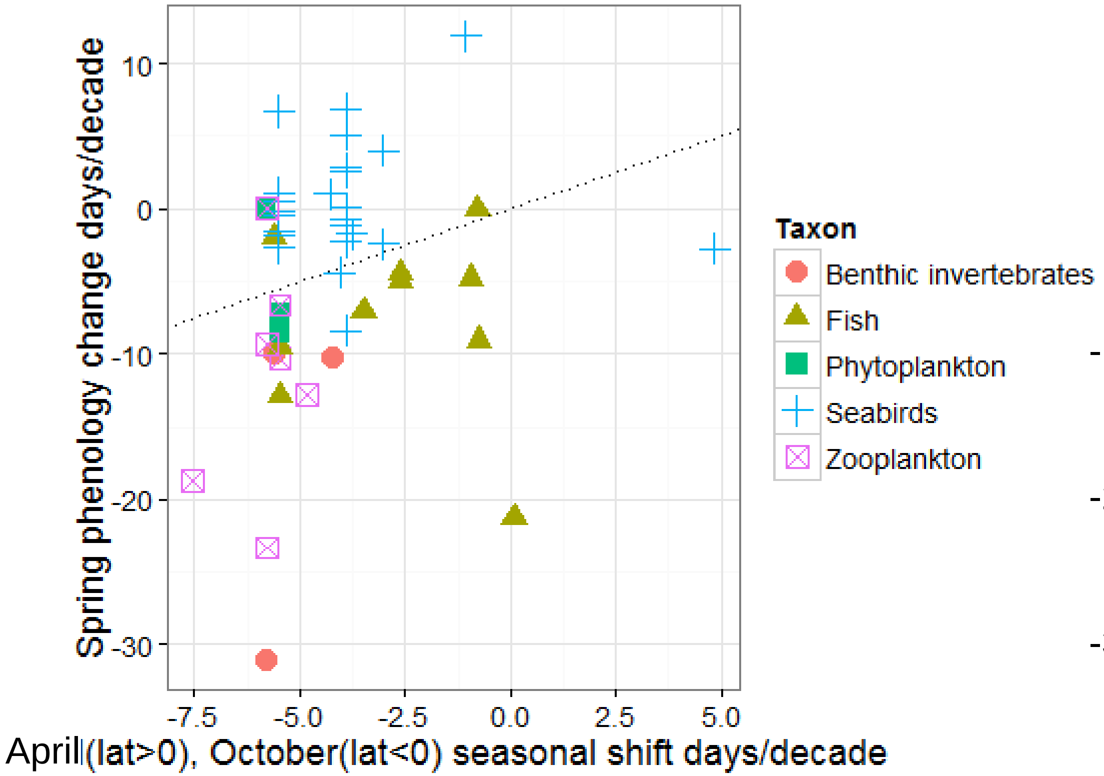


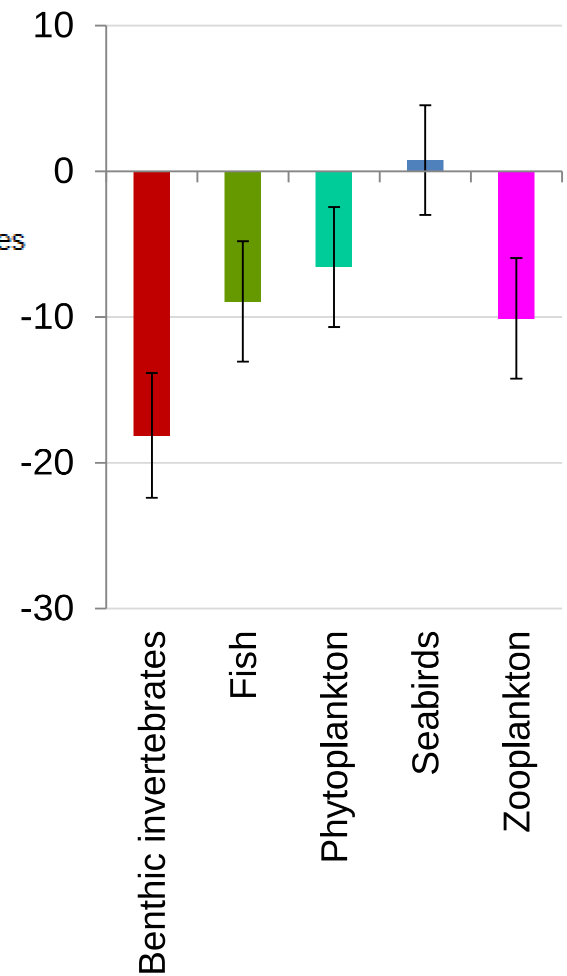


April

- W Scotland
  - 0.5-1 days/decade
- North Sea
  - 5-10 days/decade

Does Seasonal climate shift (SCS) predict spring phenology change?

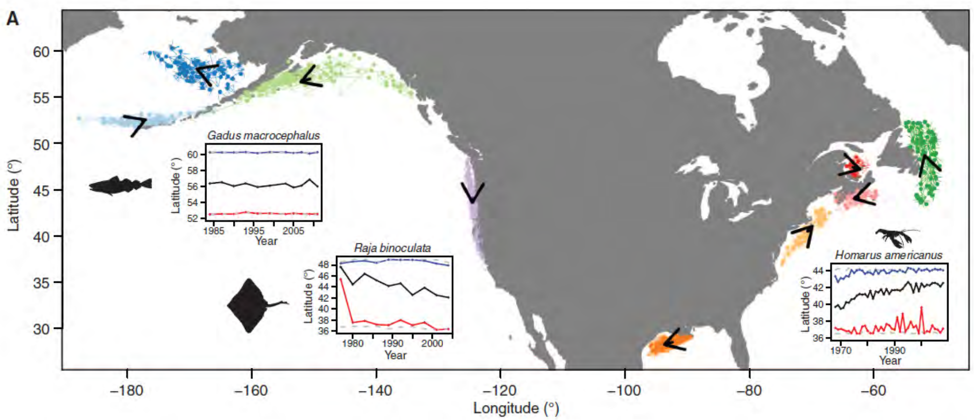




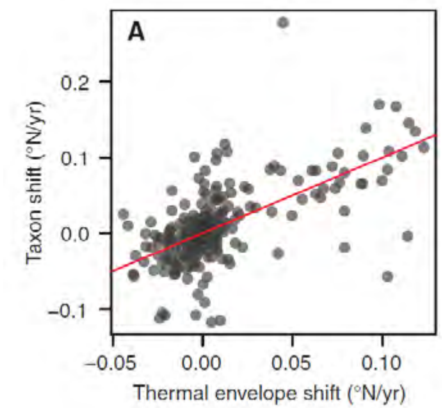
- **No, in the ocean**
- (n=57, P=>0.05)… But very significant taxon effects

Better validation data may help

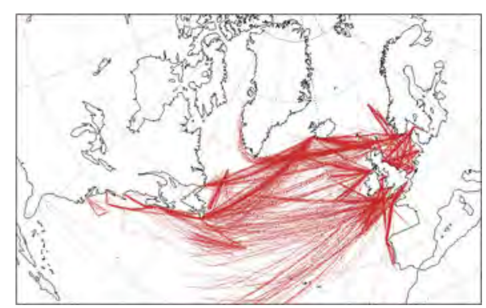
- Like…..



Pinsky et al. 2013 Science



- phenology change versus spatially variable climate change
  - ✓ e.g. continuous plankton recorder

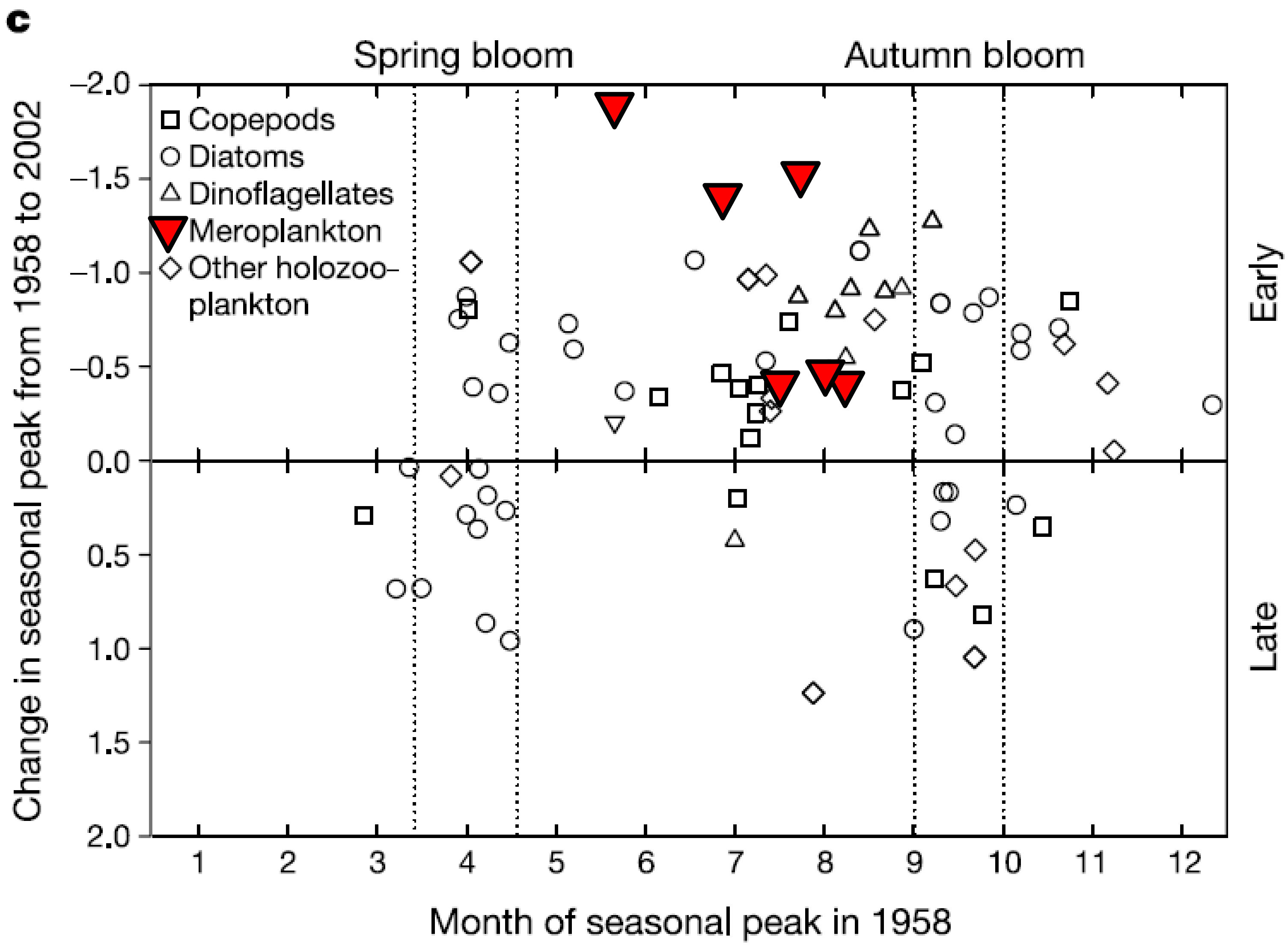


Days per decade

-10 days

0 days

+10 days



Edwards, M., and A. J. Richardson. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. Nature 430:881–884.

We need more phenology data from the ocean…

2454 T. Amano *et al.* *An index of first flowering dates*

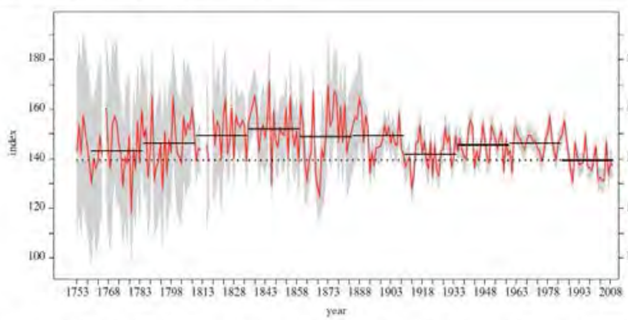


Figure 1. The median (red line) and 95% credible intervals (grey area) of the estimated community-level index (day of the year) showing a temporal change in the timing of first flowering shared by 405 plant species observed throughout the UK. The black line indicates the mean for every 25 years and the dotted line that for the most recent 25 years. The years without estimates indicate those without any observation records (1766, 1813, 1814 and 1817).

1700 2000

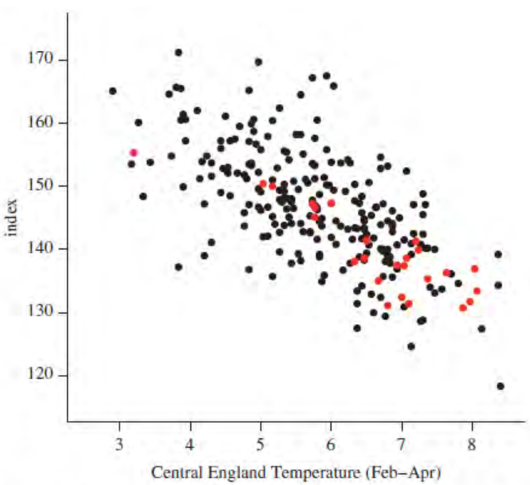


Figure 2. The significant negative correlation between the community-level index and the mean of the CET for Feb–Apr. The records for the most recent 25 years (red points) lie in the area of high temperature and early-first flowering.

- UK Phenology network
  - 2 million records back to 1700
- Poloczanska et al 2013
  - 57 studies

First flowering timing index versus Central England Temperature

Amano, T., et al 2010. Proc Roy Soc B:rspb20100291.

Thank you

NSF – for NCEAS
NERC
CSIRO

Anthony Richardson
Elvira Poloczanska