Analyses of observed and projected shifts in marine life

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OCEAN AND ATMOSPHERE FLAGSHIP
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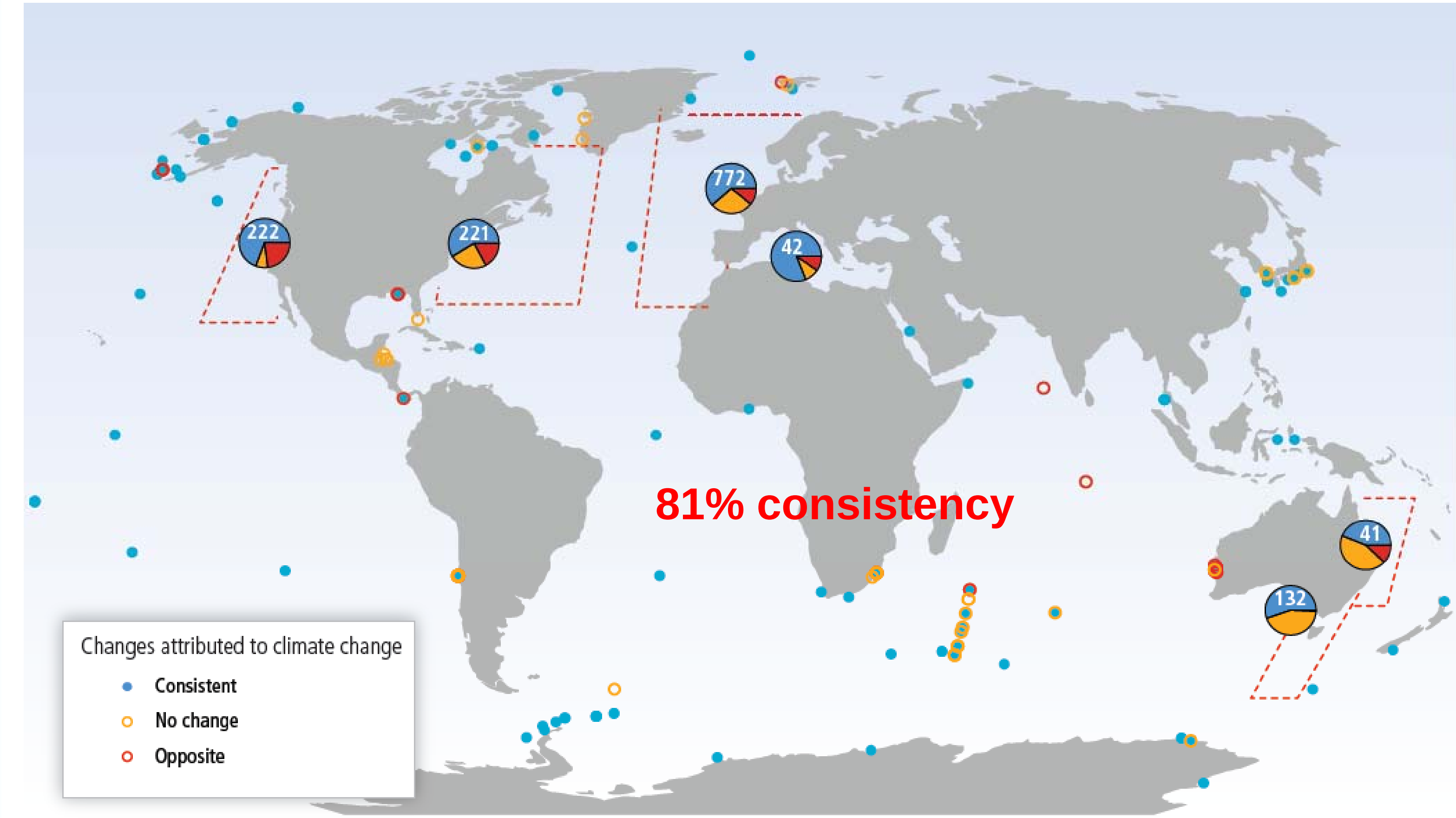
Responses of species and ecosystems to climate change have been observed from every ocean sub-region (*high confidence*).



1735 observations of 857 species from 208 studies

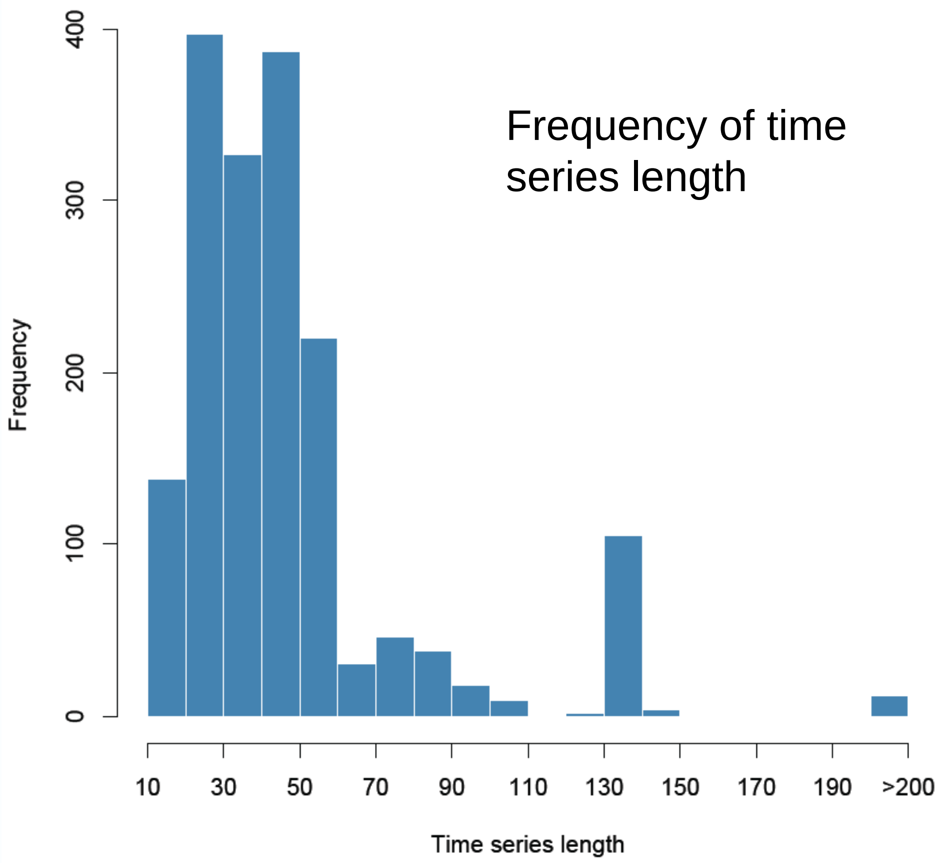
Meta-analysis of impacts literature

Responses: Distribution, Phenology, Abundance, Demography, Community structure, Calcification

Three criteria for inclusion:

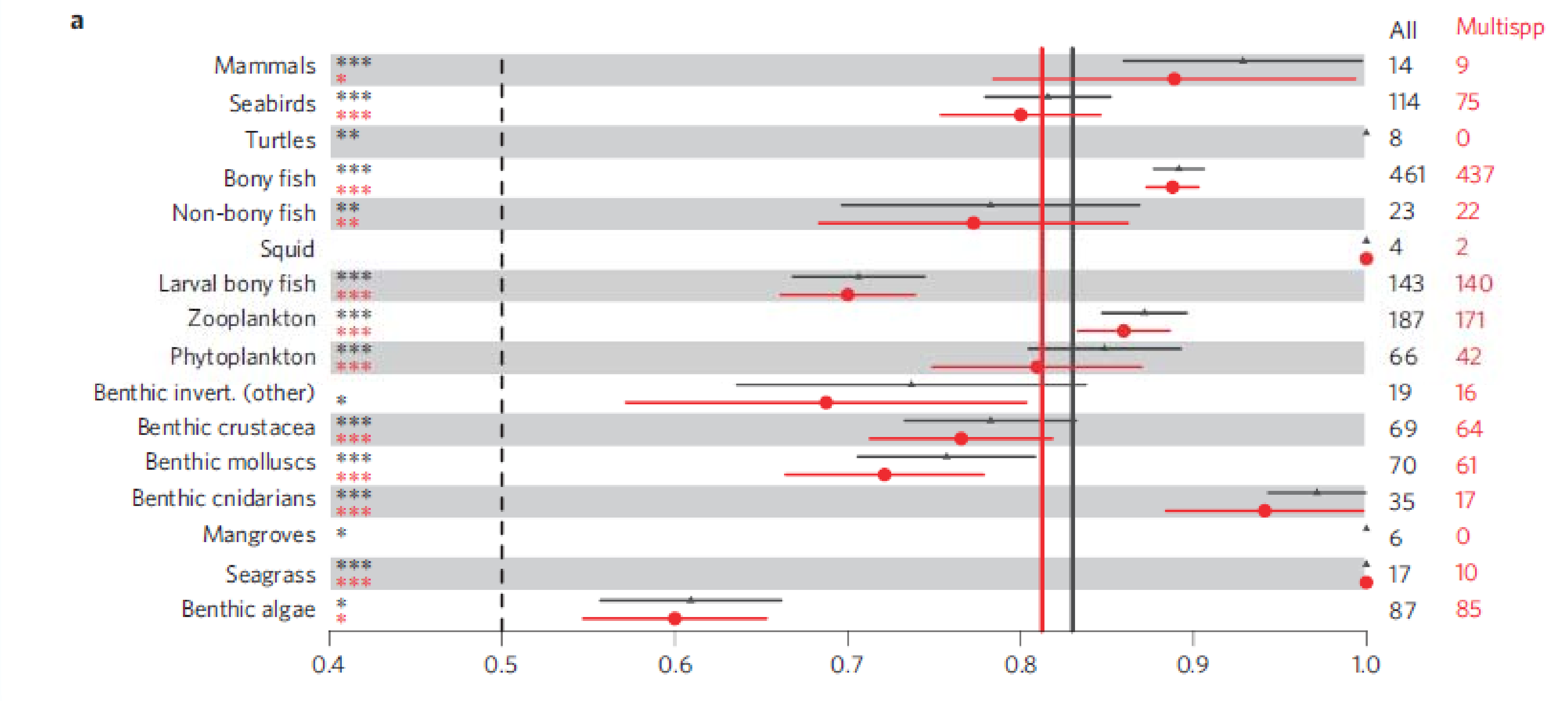
1. Inferred or test for trends in biological and climate variables
2. Include data after 1990
3. Spanned at least 19 years

Included consistent, inconsistent and no change observations



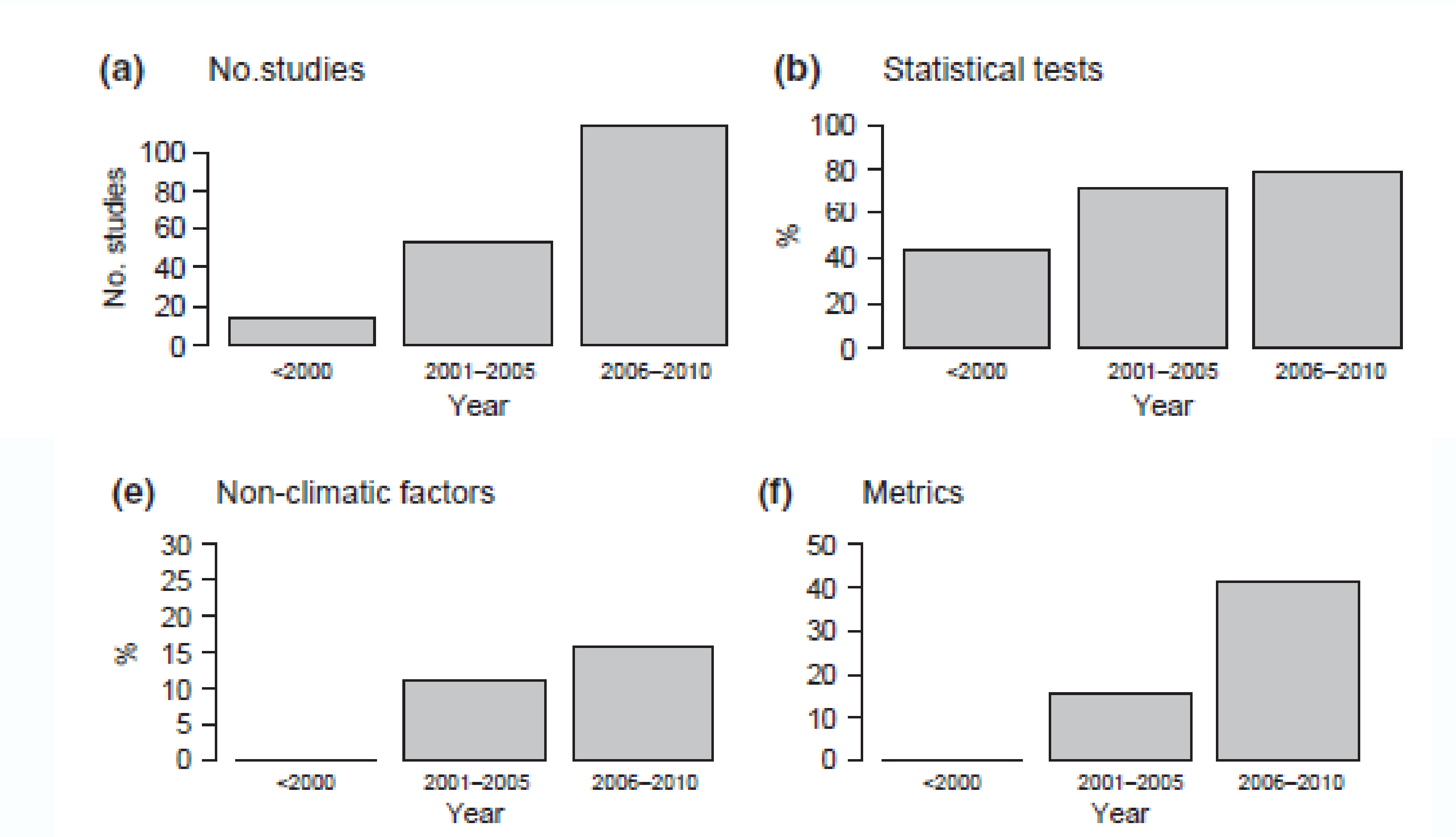
Analyses: Consistency, metrics for phenology and distribution

Consistency using all data (black) and multi-species only (red)



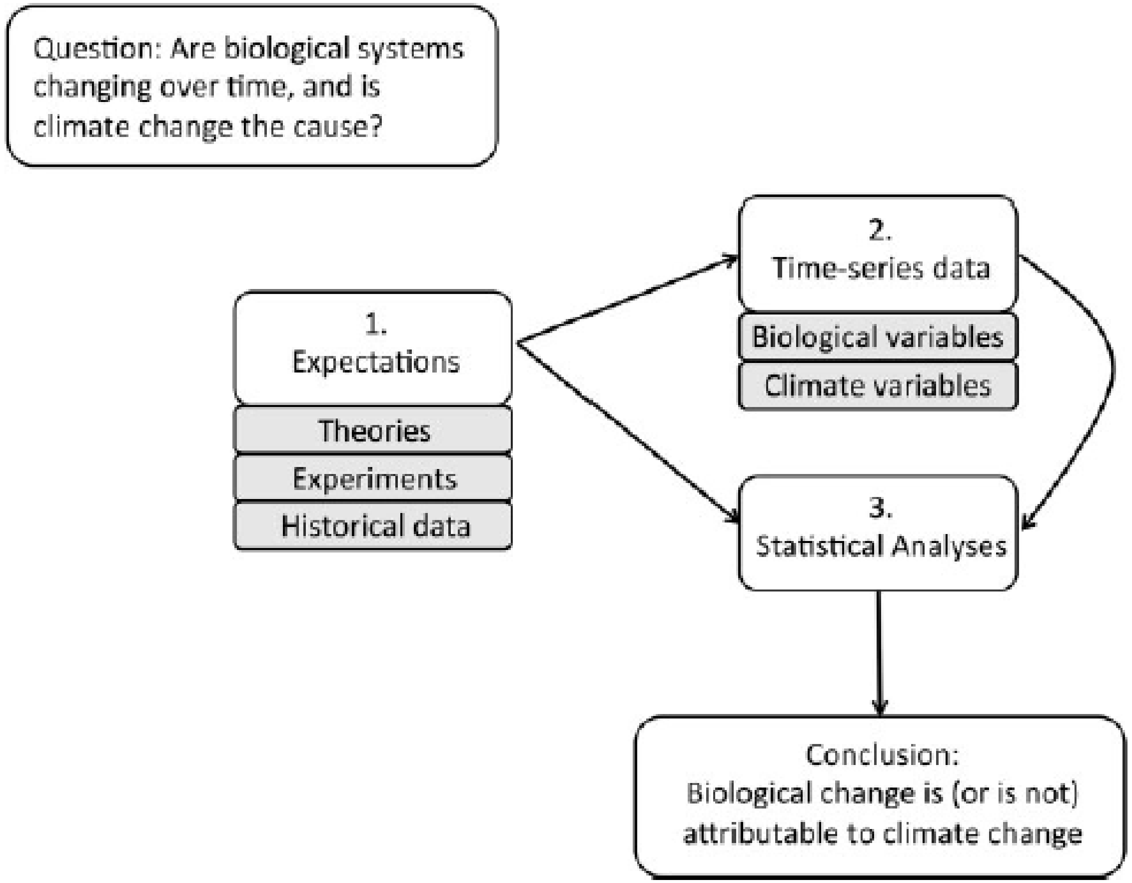
<11% were single-species studies

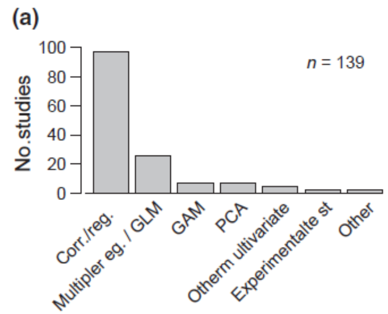
Attributes through time of marine studies in climate change ecology



Brown et al 2011 GCB

A framework for attribution of biological change to climate change

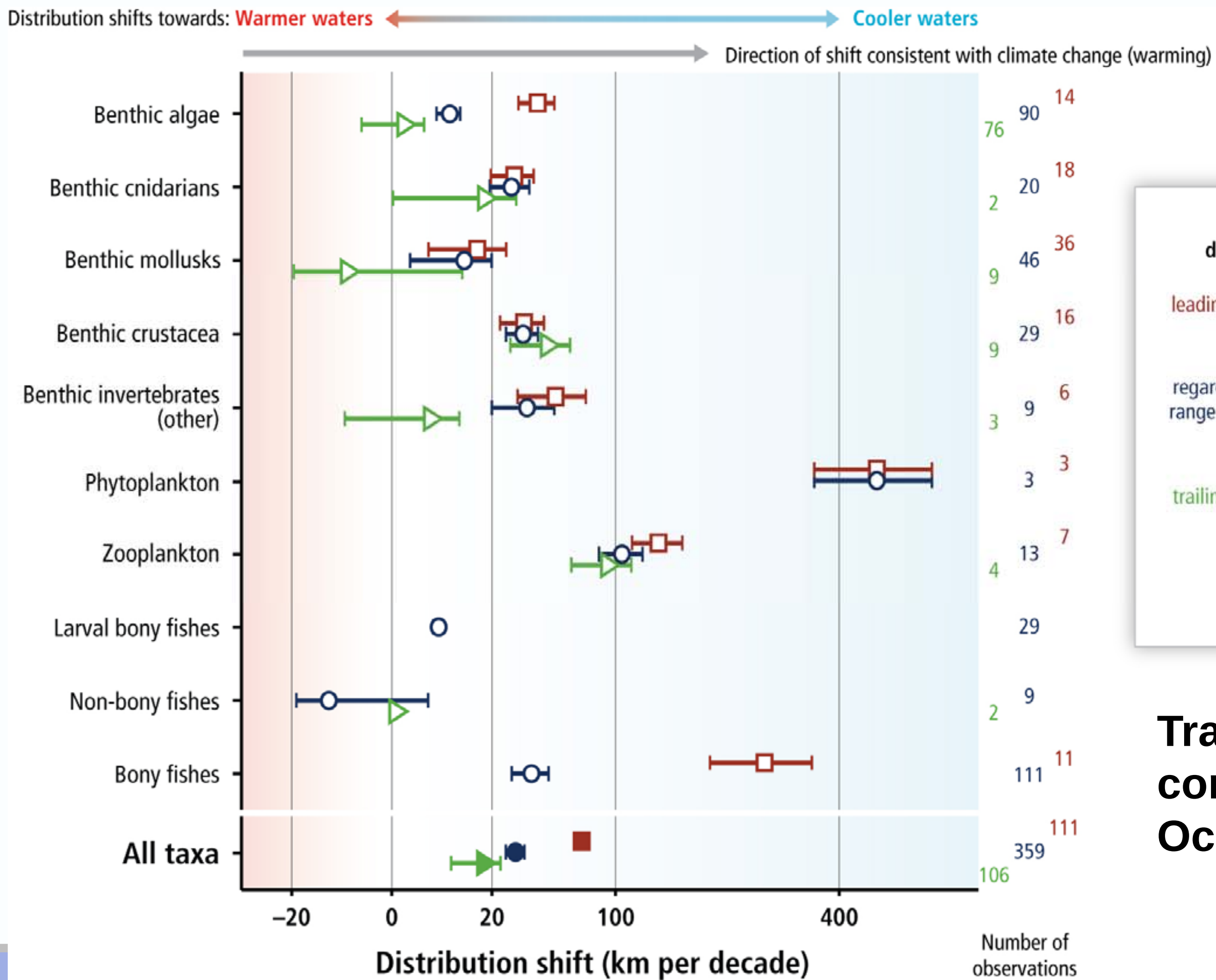




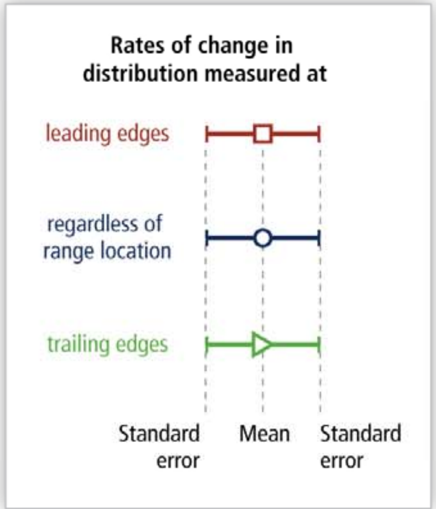
Best practices for ecological attribution

Lines of evidence	Tropical coral reefs
Paleo data: document associations between historical climate change and ecological responses	Over the past 490 My, coral reef die-off coincided with increases in CO_2, methane, and/or warm temperatures[1]
Experiments: document a significant role of climate in species' biology	Laboratory experiments show corals bleach under stresses such as warm temperatures, extreme salinities and high rates of sedimentation[2]
Long-term observations: significant and consistent associations between a climate variable and a species' response	Coral bleaching events consistently follow warm sea surface temperature events (e.g. El Niño)[4]
Fingerprints: responses that uniquely implicate climate change as causal factor	First observations of mass tropical coral bleaching in 1979, concurrent with accelerating SST warming[7]
Change in climate variable at relevant scale has been linked to GHG forcing	Ocean warming has been linked to GHG forcing with some GHG projections indicating the Pacific will move towards a more 'El Niño-like' state[10]
Meta-analyses: global coherence of responses across taxa and regions	16% of tropical coral reefs lost globally in 1997/98 El Niño event[12]

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



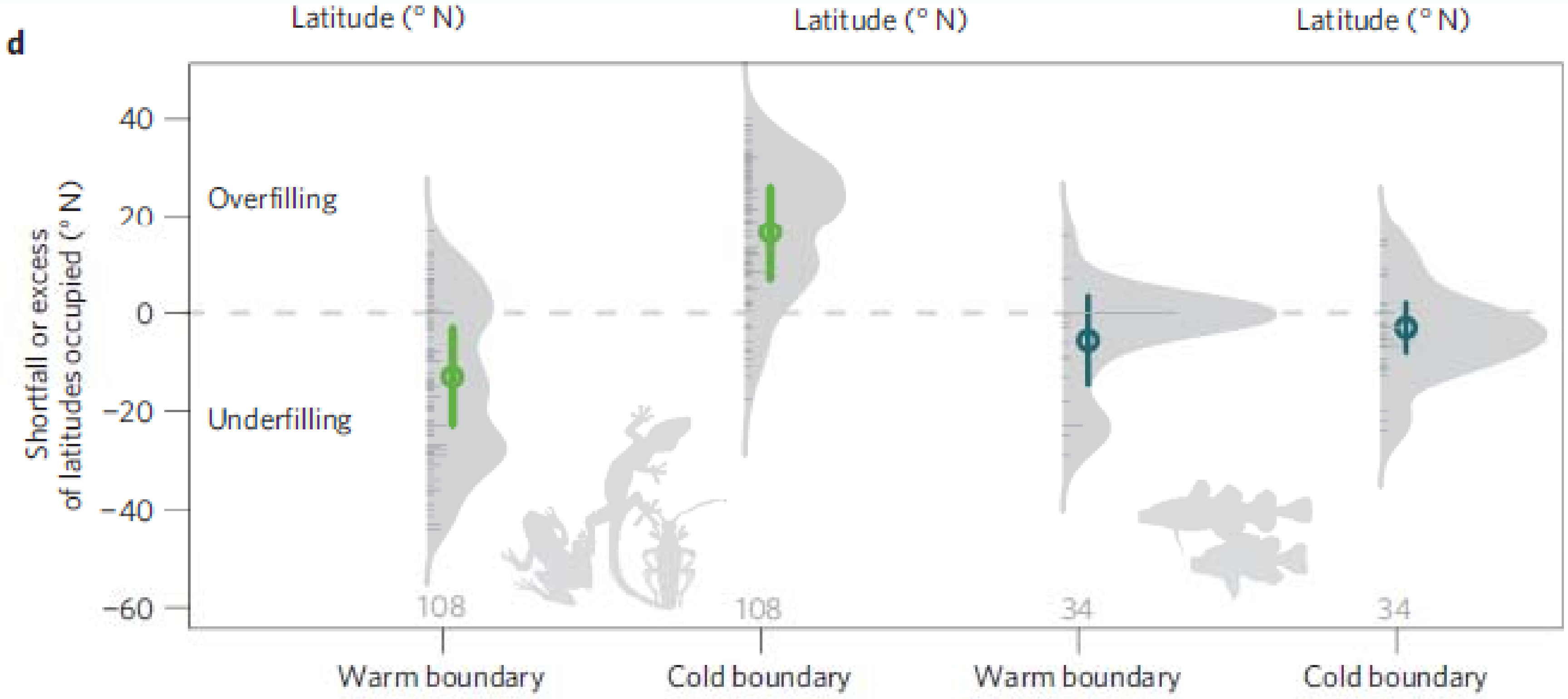
Leading edge expansion:
Ocean 72 km dec^{-1}
Land 6 km dec^{-1}



Trailing edge contraction:
Ocean 15 km dec^{-1}

Poloczanska et al 2013 Nature Climate Change, IPCC WGII SPM

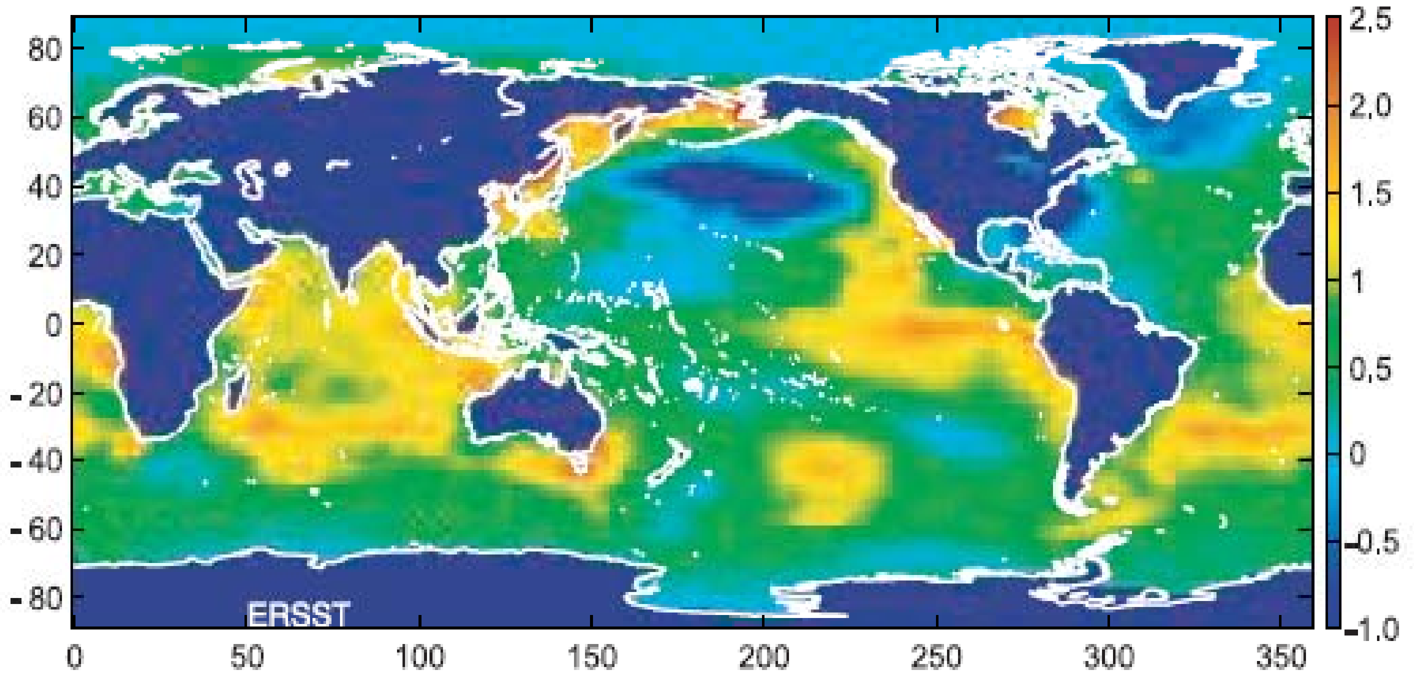
Marine ectotherms are thermal conformers at leading and trailing range edges



Can we produce expectations for range shifts?

- ❖Warming patterns are uneven
- ❖How fast should organisms move to track changes in temperature over time, in which direction?
- ❖Are shifting marine organisms keeping pace with climate change?

Observed warming



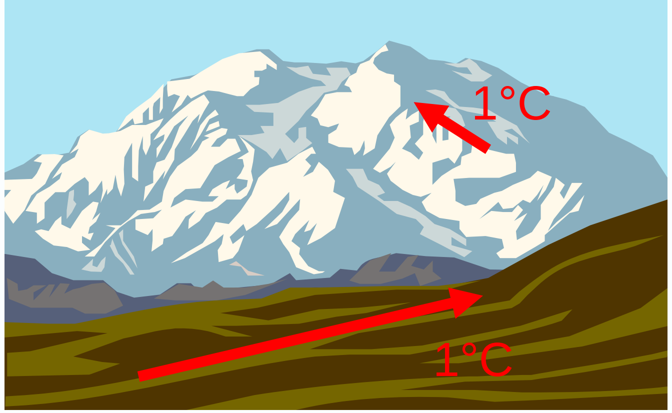
Ridgway 2007

The velocity of climate change

Velocity describes the SPEED and the DIRECTION that an organism would have to move to keep its current thermal environment

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

Consider velocities for an animal on the side of a mountain vs in the middle of a desert?

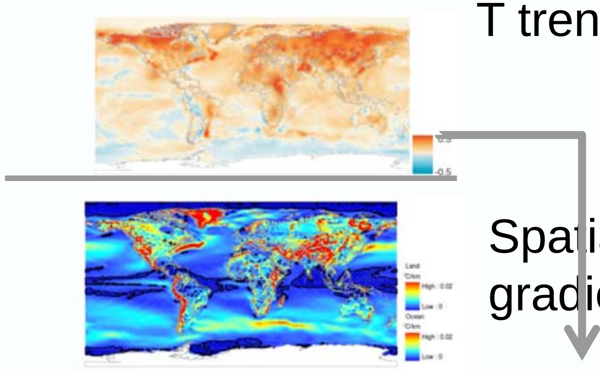


Velocity is **fast**

- where spatial gradients are shallow (Equator)
- Where change in temperature is highest

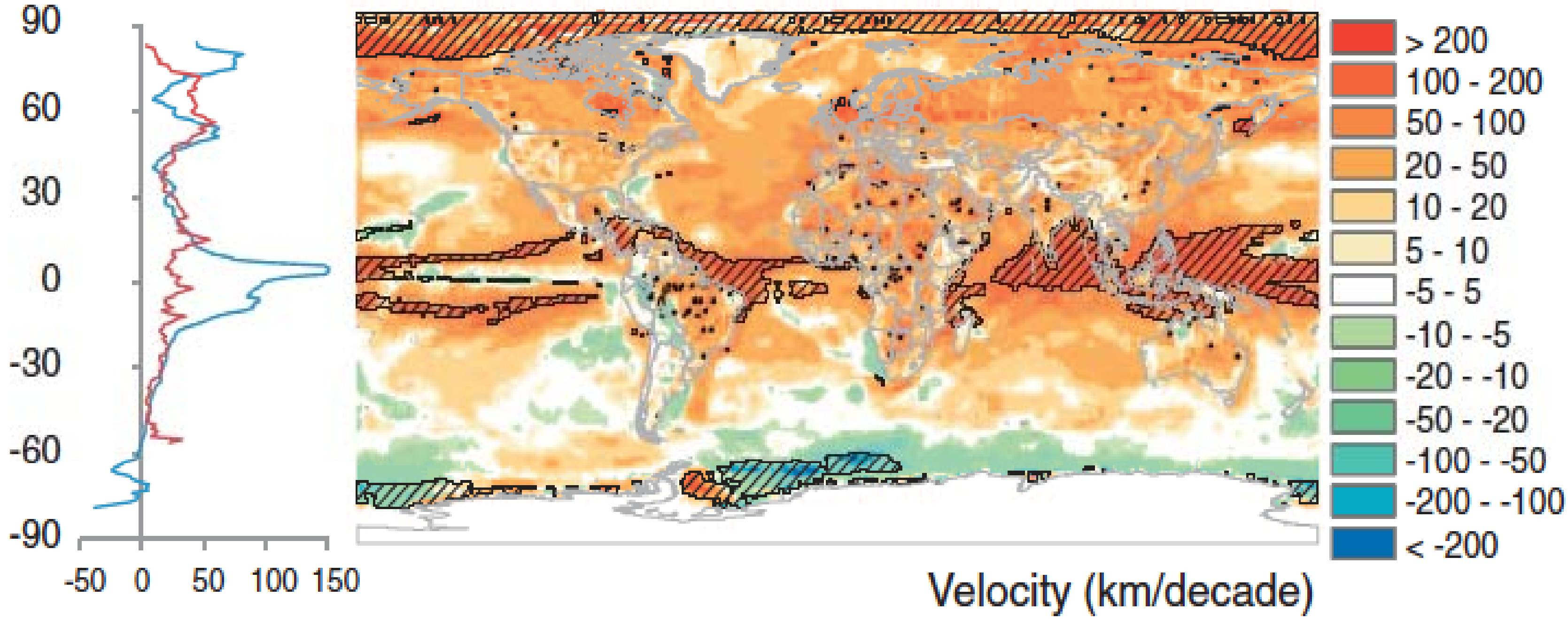
Velocity is **slow**

- Where gradients are sharp
- Where temperature change is least



Velocity is **negative**

- Where the oceans have cooled (Southern Ocean)
- Indicates movement towards warmer regions

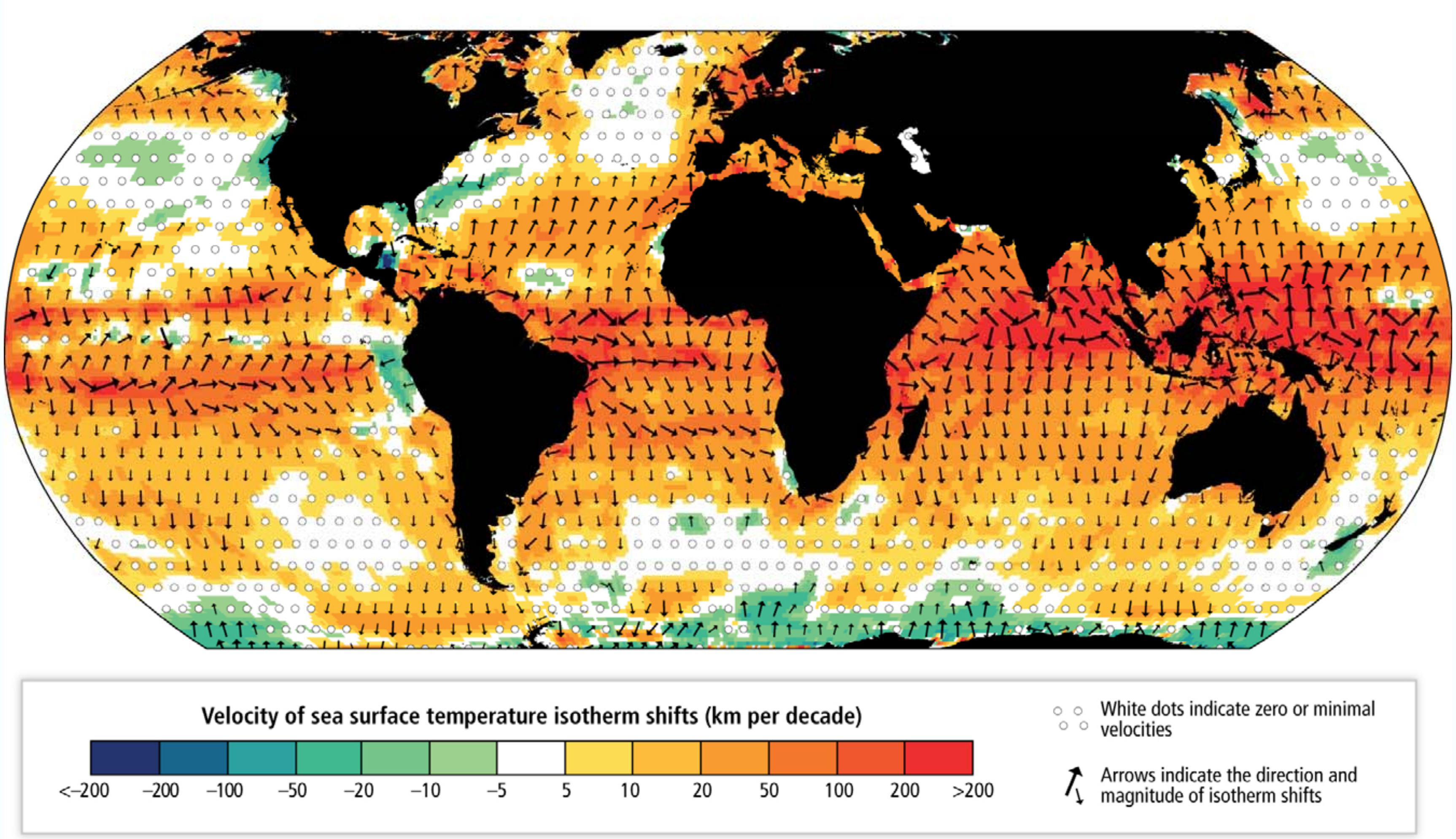


1960-2009

Burrows et al. 2011 Science

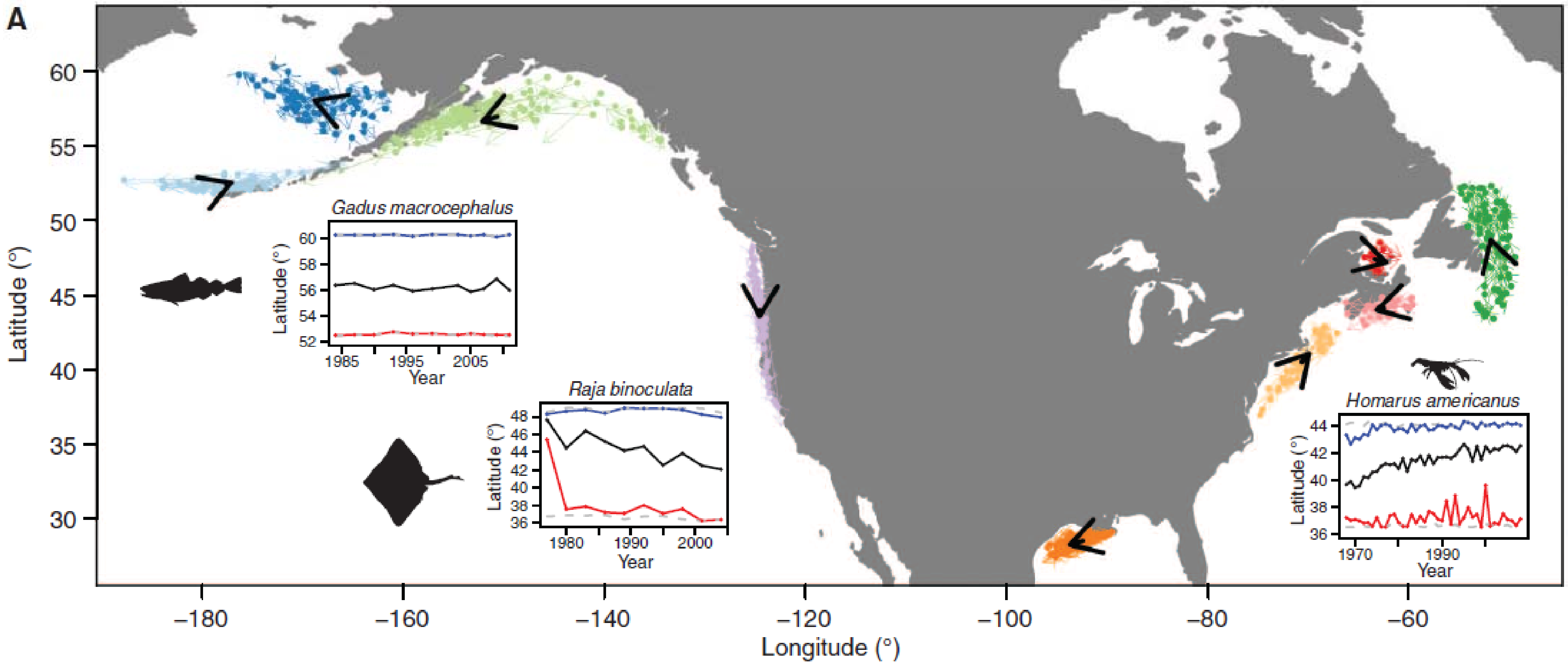
CSIRO

Velocity of climate change in the Ocean 1960-2010



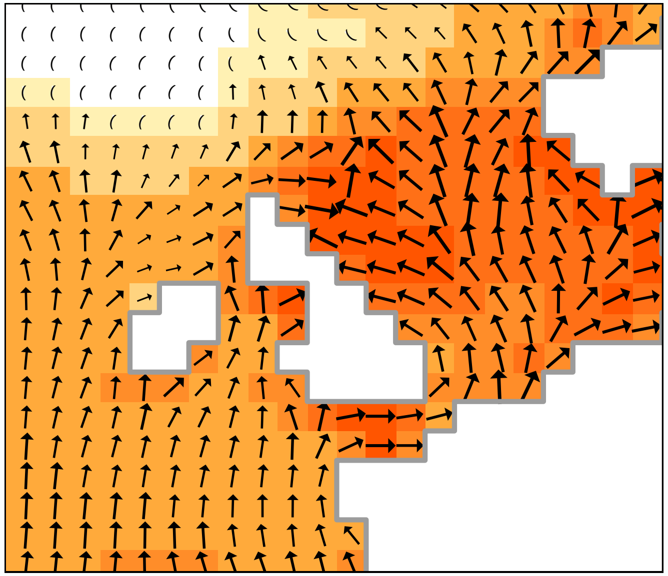
Burrows et al 2011 Science, IPCC WGII Chp 30 Fig 30-3

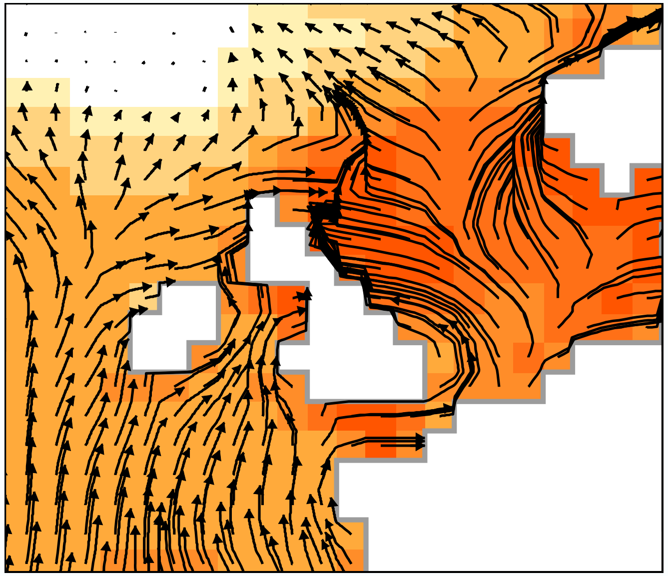
Marine taxa track local climate velocities

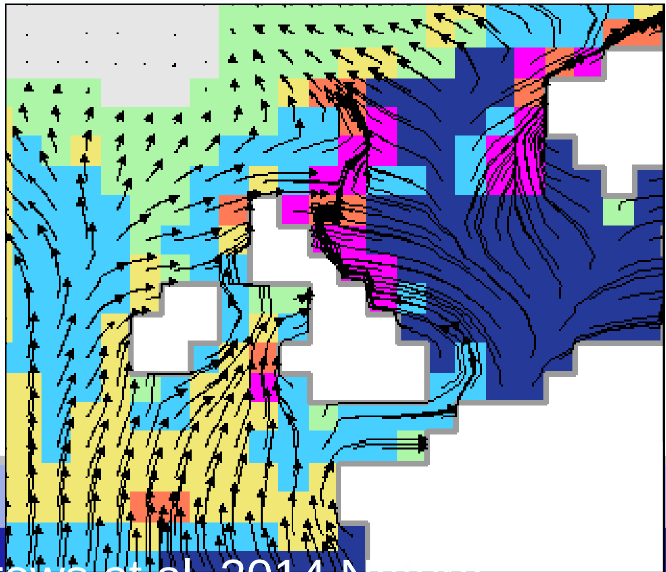


128 million individuals across 360 marine taxa sampled from 1968-2011

Trajectories from velocity of climate change





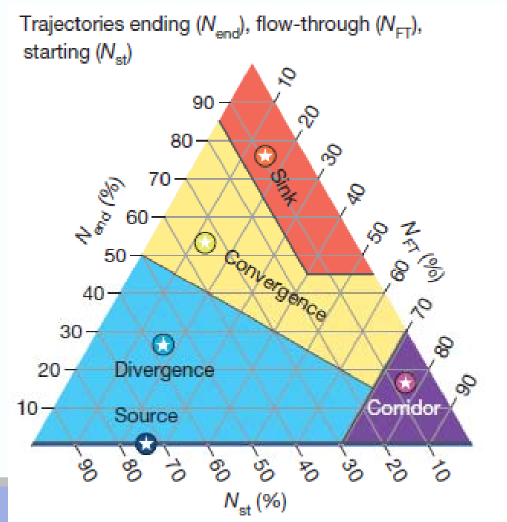


Non-moving
Slow-moving

Sources strong
Sources weak

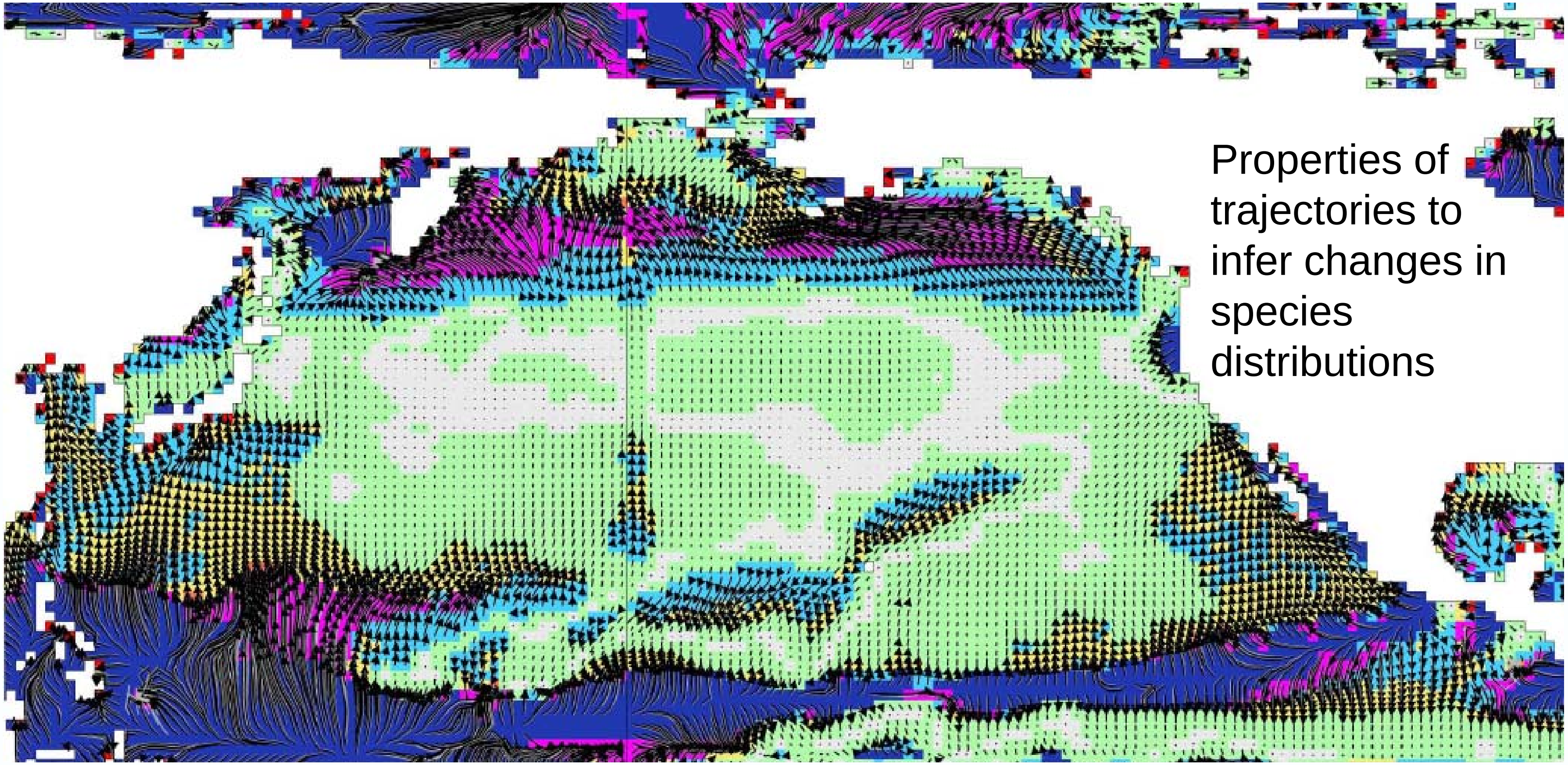
Corridors

Sinks weak
Sinks strong



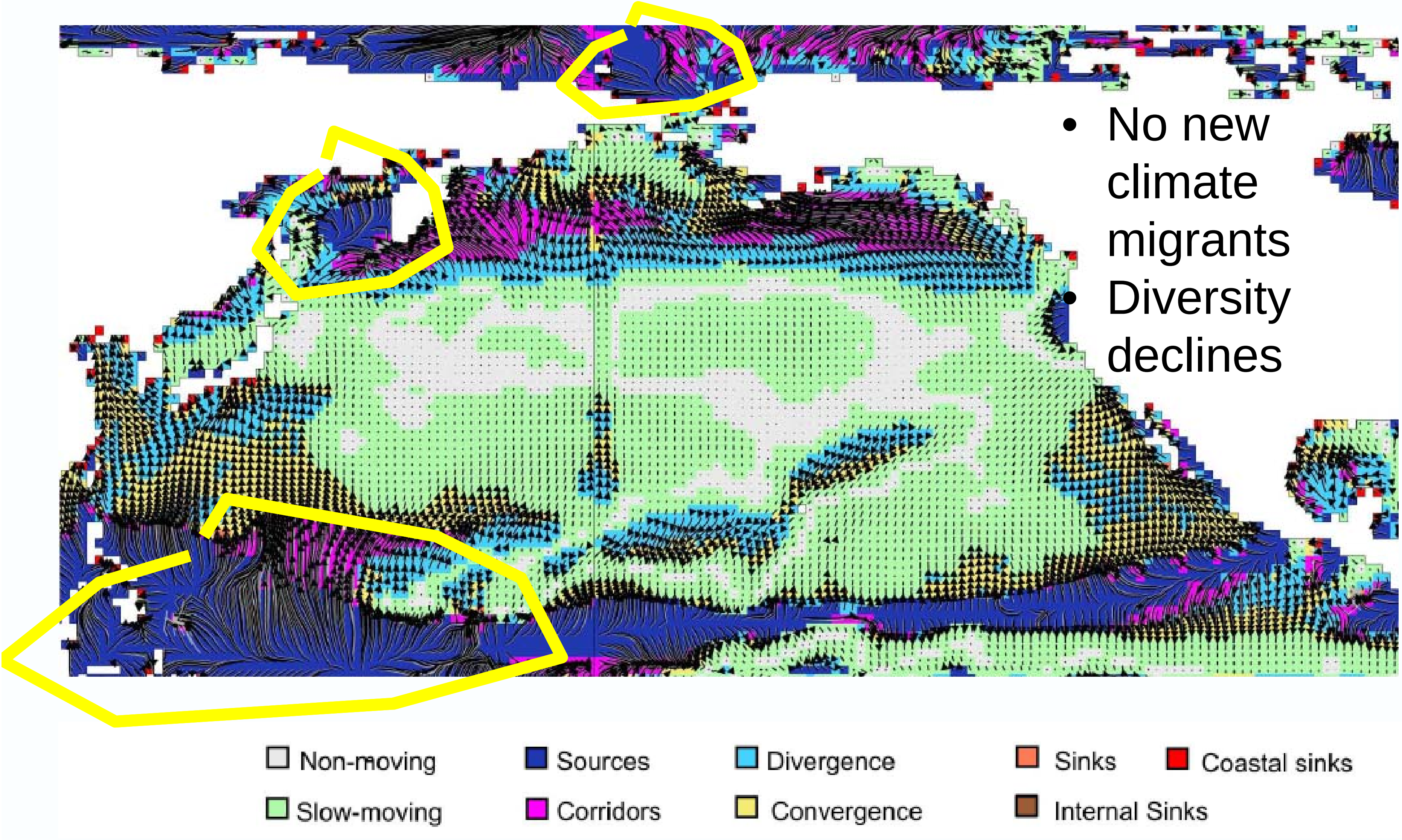
Burrows et al. 2014 Nature

Use climate velocity to derive changes in climate niches



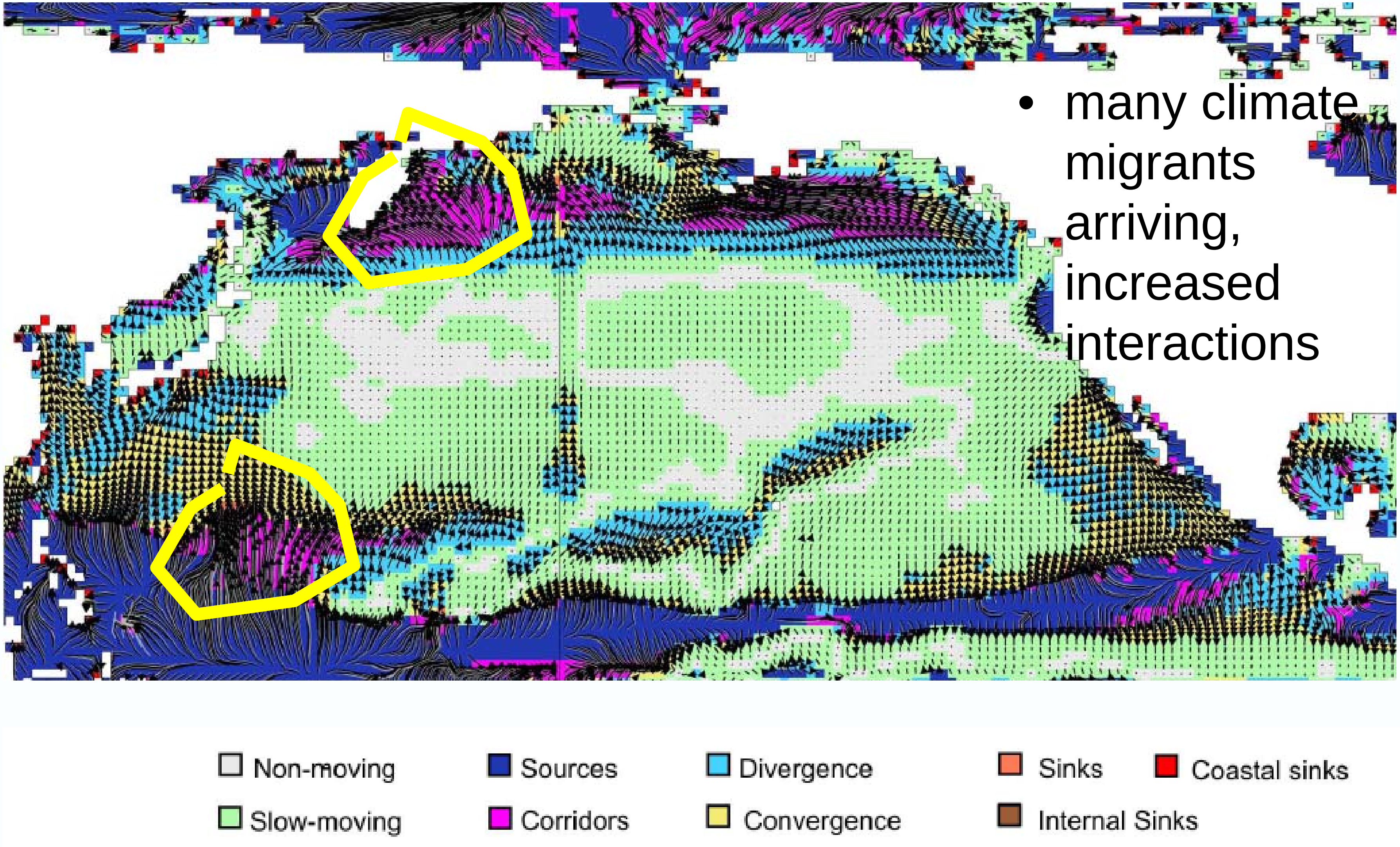
Properties of trajectories to infer changes in species distributions

"Climate sources" not connected to warmer climate



- No new climate migrants
- Diversity declines

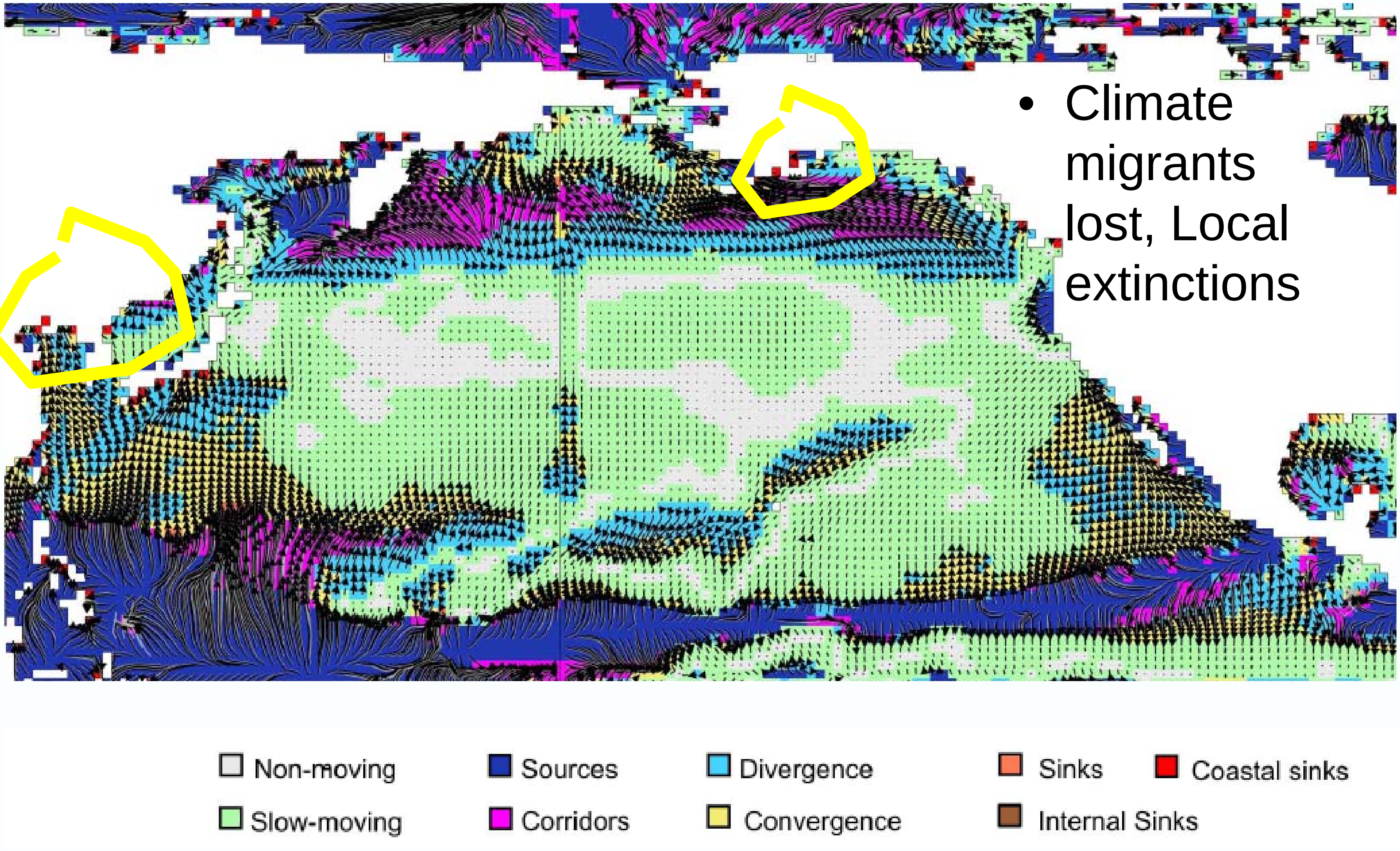
“Corridor” pathways of converging climate



- many climate migrants arriving, increased interactions

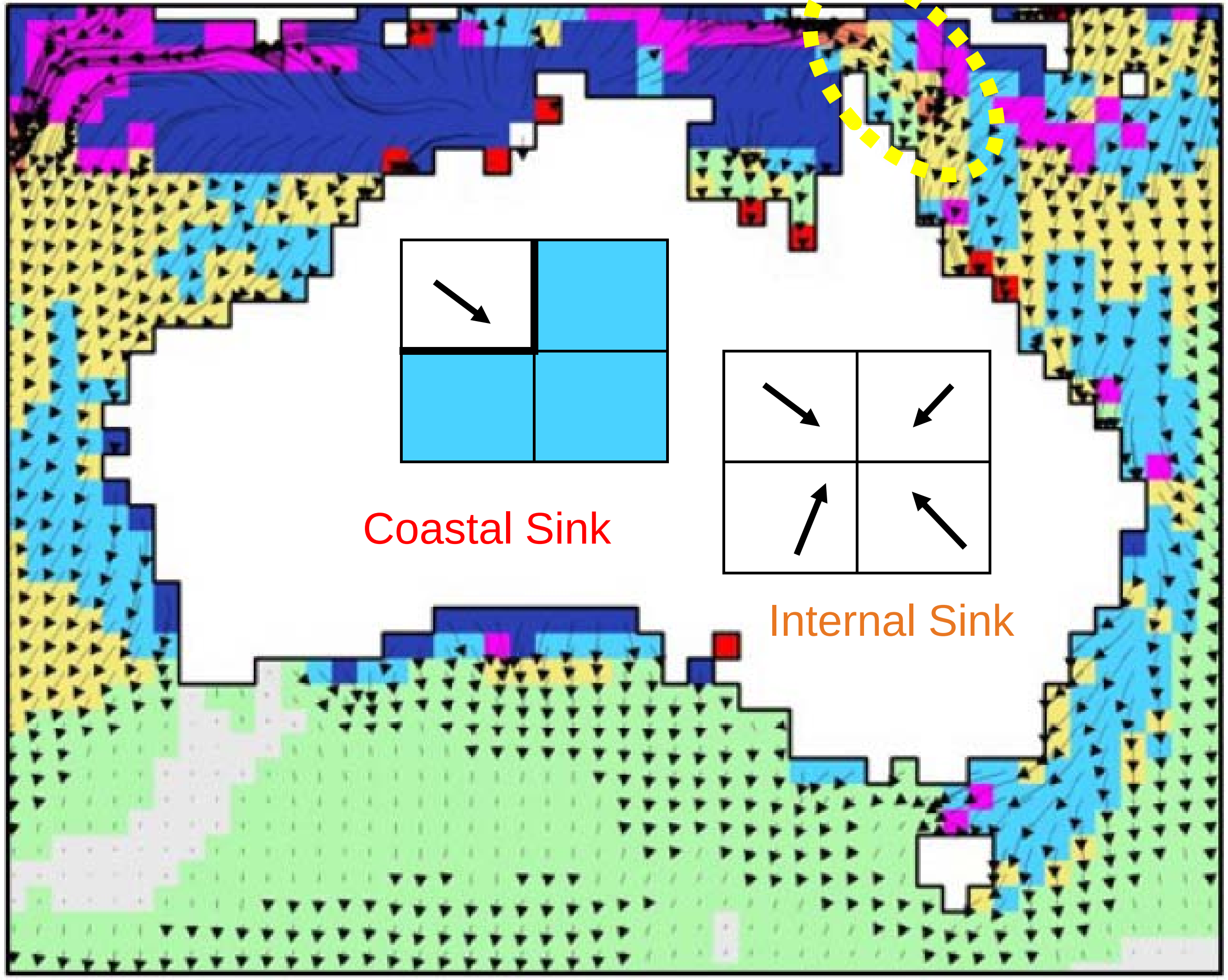
Burrows et al 2014 Nature

"Coastal sinks" not connected to cooler climate



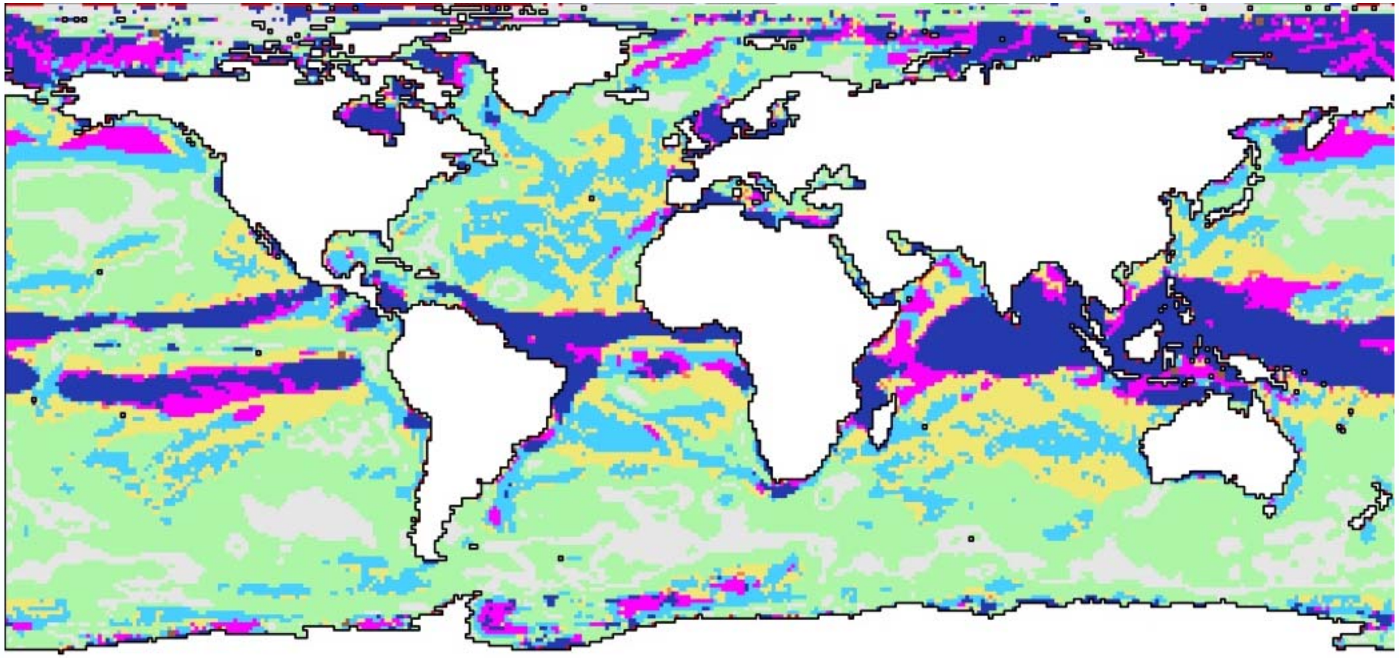
- Climate migrants lost, Local extinctions

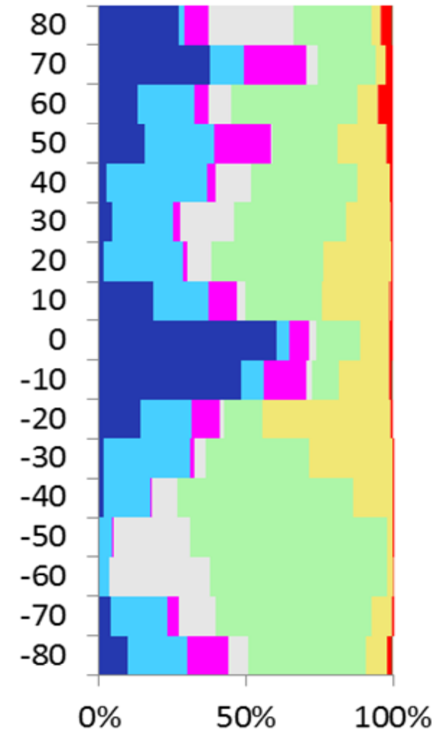
"Internal sinks" not connected to cooler climate



- Not connected to cooler climate
  - where warming
- Thermal environments locally lost
- Climate migrants lost
- Local extinctions likely

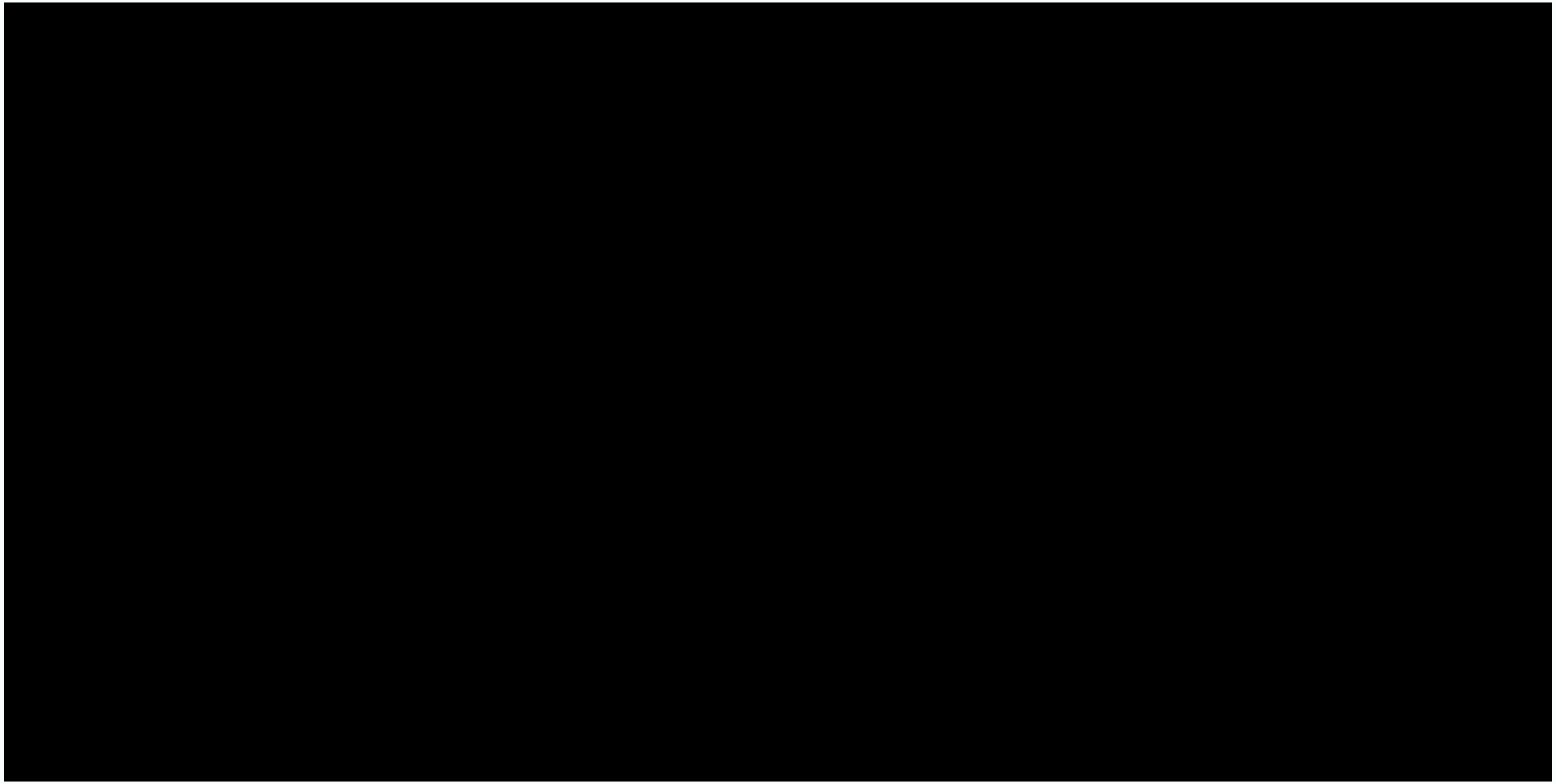
Global patterns: oceans





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

Trajectory Class (warming)	Distribution effect	Diversity effect
Sources disconnected from warmer locales	Leading edges cannot invade. Climate migrants not replaced.	Species diversity **declines**. Empty niches available (for invaders)
Sinks disconnected from cooler locales	Climate migrants have nowhere to go.	Local extinction possible, but lost species replaced. Diversity **stable.**
Corridors	Increased interactions among species.	Diversity **stable or increased.**
Convergence / Divergence	Areas for rapid shifts.	Diversity change depends on balance of migrants.
Low-velocity areas	Little change.	Little change.



Thank you

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