Analyses of observed and projected shifts in marine life

Elvira Poloczanska, Jorge García Molinos, Michael T Burrows, and NCEAS Marine Impacts Working Group
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

Poloczanska et al 2013 Nature Climate Change, IPCC WGII Chp 30 Box CC-MB
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

Poloczanska et al 2013 Nature Climate Change
Consistency using all data (black) and multi-species only (red)

<11% were single-species studies

Poloczanska et al 2013 Nature Climate Change
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

1. Expectations
   - Theories
   - Experiments
   - Historical data

2. Time-series data
   - Biological variables
   - Climate variables

3. Statistical Analyses

Conclusion: Biological change is (or is not) attributable to climate change

# Best practices for ecological attribution

<table>
<thead>
<tr>
<th>Lines of evidence</th>
<th>Tropical coral reefs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paleo data:</strong> document associations between historical climate change and ecological responses</td>
<td>Over the past 490 My, coral reef die-off coincided with increases in CO$_2$, methane, and/or warm temperatures$^1$</td>
</tr>
<tr>
<td><strong>Experiments:</strong> document a significant role of climate in species’ biology</td>
<td>Laboratory experiments show corals bleach under stresses such as warm temperatures, extreme salinities and high rates of sedimentation$^2$</td>
</tr>
<tr>
<td><strong>Long-term observations:</strong> significant and consistent associations between a climate variable and a species’ response</td>
<td>Coral bleaching events consistently follow warm sea surface temperature events (e.g. El Niño)$^4$</td>
</tr>
<tr>
<td><strong>Fingerprints:</strong> responses that uniquely implicate climate change as causal factor</td>
<td>First observations of mass tropical coral bleaching in 1979, concurrent with accelerating SST warming$^7$</td>
</tr>
<tr>
<td>Change in climate variable at relevant scale has been linked to GHG forcing</td>
<td>Ocean warming has been linked to GHG forcing with some GHG projections indicating the Pacific will move towards a more ‘El Niño-like’ state$^{10}$</td>
</tr>
<tr>
<td><strong>Meta-analyses:</strong> global coherence of responses across taxa and regions</td>
<td>16% of tropical coral reefs lost globally in 1997/98 El Niño event$^{12}$</td>
</tr>
</tbody>
</table>

Parmesan et al 2013 Ecol Lett
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?
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.

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

\[ \text{Velocity} = \frac{\text{Temperature trend}}{\text{Spatial gradient}} \]
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

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1960-2009

Burrows et al. 2011 Science
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

Pinsky et al 2013 Science
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

Burrows et al 2014 Nature
“Climate sources” not connected to warmer climate

- No new climate migrants
- Diversity declines

Burrows et al 2014 Nature
“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

Burrows et al 2014 Nature
“Internal sinks” not connected to cooler climate

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

Burrows et al. 2014 Nature
Global patterns: oceans

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

Burrows et al. 2014 Nature
<table>
<thead>
<tr>
<th>Trajectory Class (warming)</th>
<th>Distribution effect</th>
<th>Diversity effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sources</strong> disconnected from warmer locales</td>
<td>Leading edges cannot invade. Climate migrants not replaced.</td>
<td>Species diversity <strong>declines</strong>. Empty niches available (for invaders)</td>
</tr>
<tr>
<td><strong>Sinks</strong> disconnected from cooler locales</td>
<td>Climate migrants have nowhere to go.</td>
<td>Local extinction possible, but lost species replaced. Diversity <strong>stable</strong>.</td>
</tr>
<tr>
<td><strong>Corridors</strong></td>
<td>Increased interactions among species.</td>
<td>Diversity <strong>stable or increased</strong>.</td>
</tr>
<tr>
<td><strong>Convergence / Divergence</strong></td>
<td>Areas for rapid shifts.</td>
<td>Diversity change depends on balance of migrants.</td>
</tr>
<tr>
<td><strong>Low-velocity</strong> areas</td>
<td>Little change.</td>
<td>Little change.</td>
</tr>
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</table>
Thank you

Download WGII assessment here:
http://ipcc-wg2.gov/AR5/

NEW open access journal:
http://www.frontiersin.org/marine_science