

Observed Global Responses of Marine Biogeography, Abundance, and Phenology to Climate Change

Elvira Poloczanska (Australia), Ove Hoegh-Guldberg (Australia), William Cheung (Canada), Hans-Otto Pörtner (Germany), Michael T. Burrows (UK)

IPCC WGII AR4 presented the detection of a global fingerprint on natural systems and its attribution to climate change (AR4, Chapter 1, SPM Figure 1), but studies from marine systems were mostly absent. Since AR4, there has been a rapid increase in studies that focus on climate change impacts on marine species, which represents an opportunity to move from more anecdotal evidence to examining and potentially attributing detected biological changes within the ocean to climate change (Section 6.3; Figure MB-1). Recent changes in populations of marine species and the associated shifts in diversity patterns are resulting, at least partly, from climate change-mediated biological responses across ocean regions (*robust evidence, high agreement, high confidence*; Sections 6.2, 30.5; Table 6-7).

Poloczanska et al. (2013) assess a potential pattern in responses of ocean life to recent climate change using a global database of 208 peer-reviewed papers. Observed responses ($n = 1735$) were recorded from 857 species or assemblages across regions and taxonomic groups, from phytoplankton to marine reptiles and mammals (Figure MB-1). Observations were defined as those where the authors of a particular paper assessed the change in a biological parameter (including distribution, phenology, abundance, demography, or community composition) and, if change occurred, the consistency of the change with that expected under climate change. Studies from the peer-reviewed literature were selected using three criteria: (1) authors inferred or directly tested for trends in biological and climatic variables; (2) authors included data after 1990; and (3) observations spanned at least 19 years, to reduce bias resulting from biological responses to short-term climate variability.

The results of this meta-analysis show that climate change has already had widespread impacts on species' distribution, abundance, phenology, and subsequently, species richness and community composition across a broad range of taxonomic groups (plankton to top predators). Of the observations that showed a response in either direction, changes in phenology, distribution and abundance were overwhelmingly (81%) in a direction that was consistent with theoretical responses to climate change (Section 6.2). Knowledge gaps exist, especially in equatorial sub-regions and the Southern Hemisphere (Figure MB-1).

The timing of many biological events (phenology) had an earlier onset. For example, over the last 50 years, spring events shifted earlier for many species with an average advancement of 4.4 ± 0.7 days per decade (mean \pm SE) and summer events by 4.4 ± 1.1 days per decade (*robust evidence, high agreement, high confidence*) (Figure MB-2). Phenological observations included in the study range from shifts in peak abundance of phytoplankton and zooplankton, to reproduction and migration of invertebrates, fishes, and seabirds (Sections 6.3.2, 30.5).

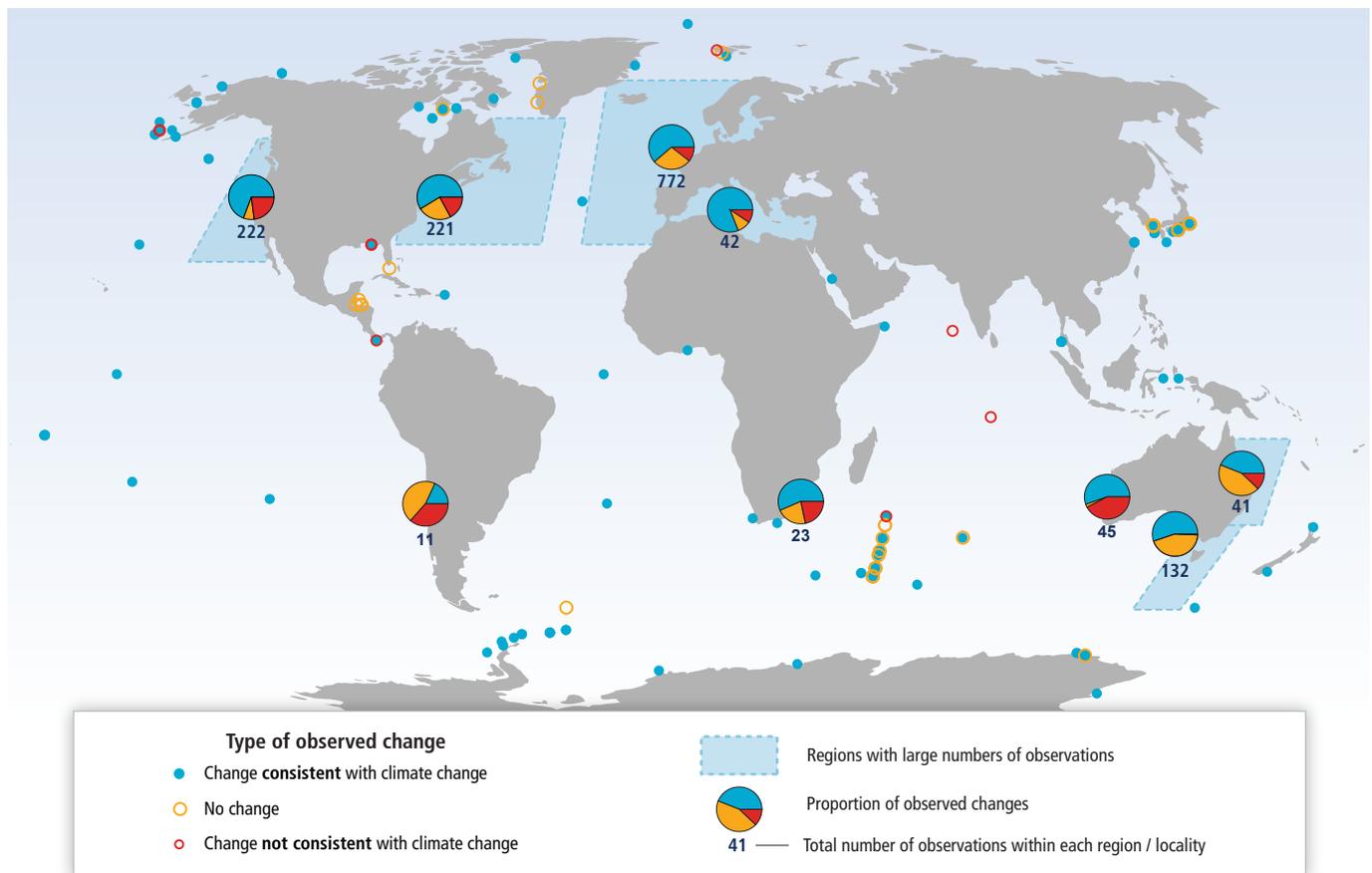


Figure MB-1 | 1735 observed responses to climate change from 208 single- and multi-species studies. Data shown include changes that are attributed (at least partly) to climate change (blue), changes that are inconsistent with climate change (red), and no change (orange). Each circle represents the center of a study area. Where points fall on land, it is because they are centroids of distributions that surround an island or peninsula. Studies encompass areas from single sites (e.g., seabird breeding colony) to large ocean regions (e.g., continuous plankton recorder surveys in north-east Atlantic). For regions (indicated by blue shading) and localities with large numbers of observations, pie charts summarize the relative proportions of the three types of observed changes (consistent with climate change, inconsistent with climate change, and no change) in those regions or localities. The numbers indicate the total observations within each region or locality. Note: 57% of the studies included were published since AR4. (From Poloczanska et al., 2013).

The distributions of benthic, pelagic, and demersal species and communities have shifted by up to a thousand kilometers, although the range shifts have not been uniform across taxonomic groups or ocean regions (Sections 6.3.2, 30.5) (*robust evidence, high agreement, high confidence*). Overall, leading range edges expanded in a poleward direction at 72.0 ± 13.5 km per decade and trailing edges contracted in a poleward direction at 15.8 ± 8.7 km per decade (Figure MB-2), revealing much higher current rates of migration than the potential maximum rates reported for terrestrial species (Figure 4-6) despite slower warming of the ocean than land surface (WGI Section 3.2).

Poleward distribution shifts have resulted in increased species richness in mid- to high-latitude regions (Hiddink and ter Hofstede, 2008) and changing community structure (Simpson et al., 2011; see also Section 28.2.2). Increases in warm-water components of communities concurrent with regional warming have been observed in mid- to high-latitude ocean regions including the Bering Sea, Barents Sea, Nordic Sea, North Sea, and Tasman Sea (Box 6.1; Section 30.5). Observed changes in species composition of catches from 1970–2006 that are partly attributed to long-term ocean warming suggest increasing dominance of warmer water species in subtropical and higher latitude regions, and reduction in abundance of subtropical species in equatorial waters (Cheung et al., 2013), with implications for fisheries (Sections 6.5, 7.4.2, 30.6.2.1).

The magnitude and direction of distribution shifts can be related to temperature velocities (i.e., the speed and direction at which isotherms propagate across the ocean's surface (Section 30.3.1.1; Burrows et al., 2011). Pinsky et al. (2013) showed that shifts in both latitude and depth of benthic fish and crustaceans could be explained by climate velocity with remarkable accuracy, using a database of 128 million individuals across 360 marine taxa from surveys of North American coastal waters conducted over 1968–2011. Poloczanska et al. (2013) found that faster distribution shifts generally occur in regions of highest surface temperature velocity, such as the North Sea and sub-Arctic Pacific Ocean. Observed marine species shifts, since approximately the 1950s, have generally been able to track observed velocities (Figure MB-3), with phyto- and zooplankton distribution shifts vastly exceeding climate velocities observed over most of the ocean surface, but with considerable variability within and among taxonomic groups (Poloczanska et al., 2013).

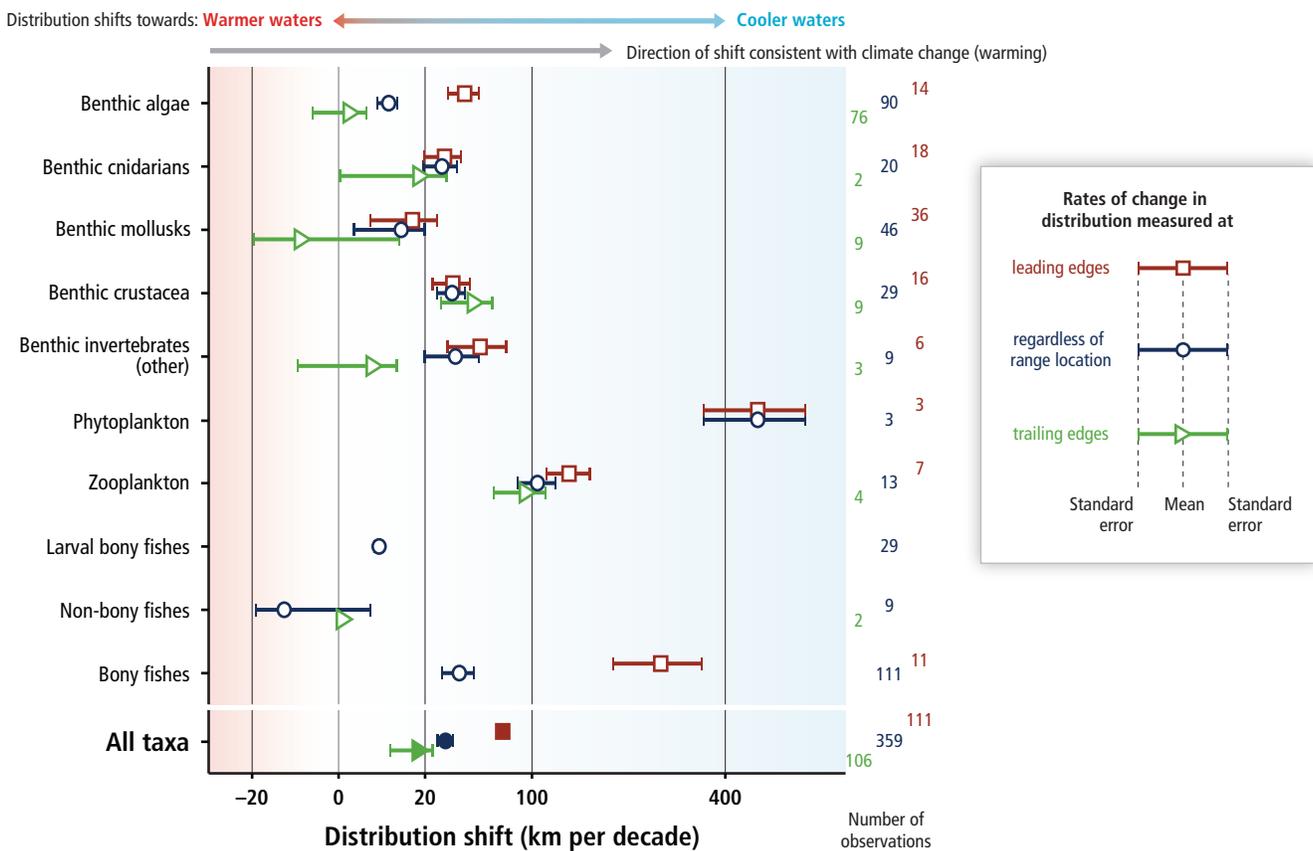


Figure MB-2 | Rates of change in distribution (kilometers per decade) for marine taxonomic groups, measured at the leading edges (red) and trailing edges (green). Average distribution shifts were calculated using all data, regardless of range location, and are in dark blue. Distribution shifts have been square-root transformed; standard errors may be asymmetric as a result. Positive distribution changes are consistent with warming (into previously cooler waters, generally poleward). Means ± standard error are shown, along with number of observations. Non-bony fishes include sharks, rays, lampreys, and hagfish. (From Poloczanska et al., 2013).

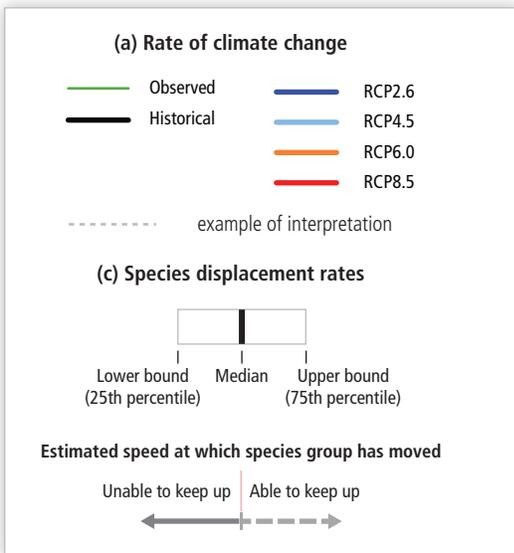
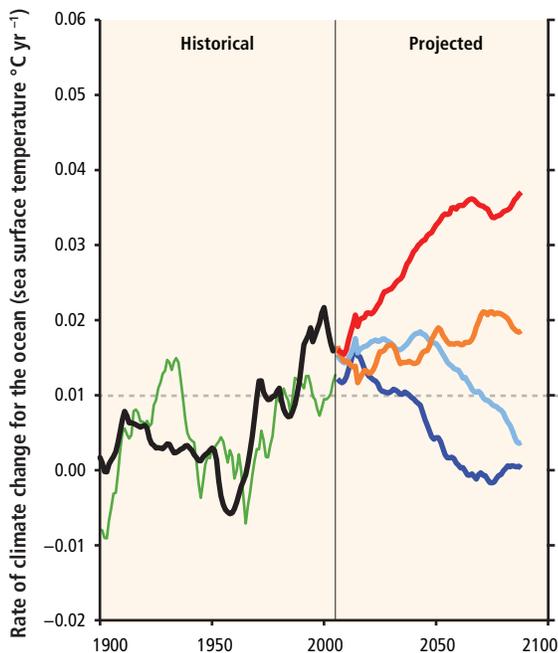
Biogeographic shifts are also influenced by other factors such as currents, nutrient and stratification changes, light levels, sea ice, species' interactions, habitat availability and fishing, some of which can be independently influenced by climate change (Section 6.3). Rate and pattern of biogeographic shifts in sedentary organisms and benthic macroalgae are complicated by the influence of local dynamics and topographic features (islands, channels, coastal lagoons, e.g., of the Mediterranean (Bianchi, 2007), coastal upwelling e.g., (Lima et al., 2007)). Geographical barriers constrain range shifts and may cause a loss of endemic species (Ben Rais Lasram et al., 2010), with associated niches filled by alien species, either naturally migrating or artificially introduced (Philippart et al., 2011).

Whether marine species can continue to keep pace as rates of warming, hence climate velocities, increase (Figure MB-3b) is a key uncertainty. Climate velocities on land are expected to outpace the ability of many terrestrial species to track climate velocities this century (Section 4.3.2.5; Figure 4-6). For marine species, the observed rates of shift are generally much faster than those for land species, particularly for primary producers and lower trophic levels (Poloczanska et al., 2013). Phyto- and zooplankton communities (excluding larval fish) have extended distributions at remarkable rates (Figure MB-3b), such as in the Northeast Atlantic (Section 30.5.1) with implications for marine food webs.

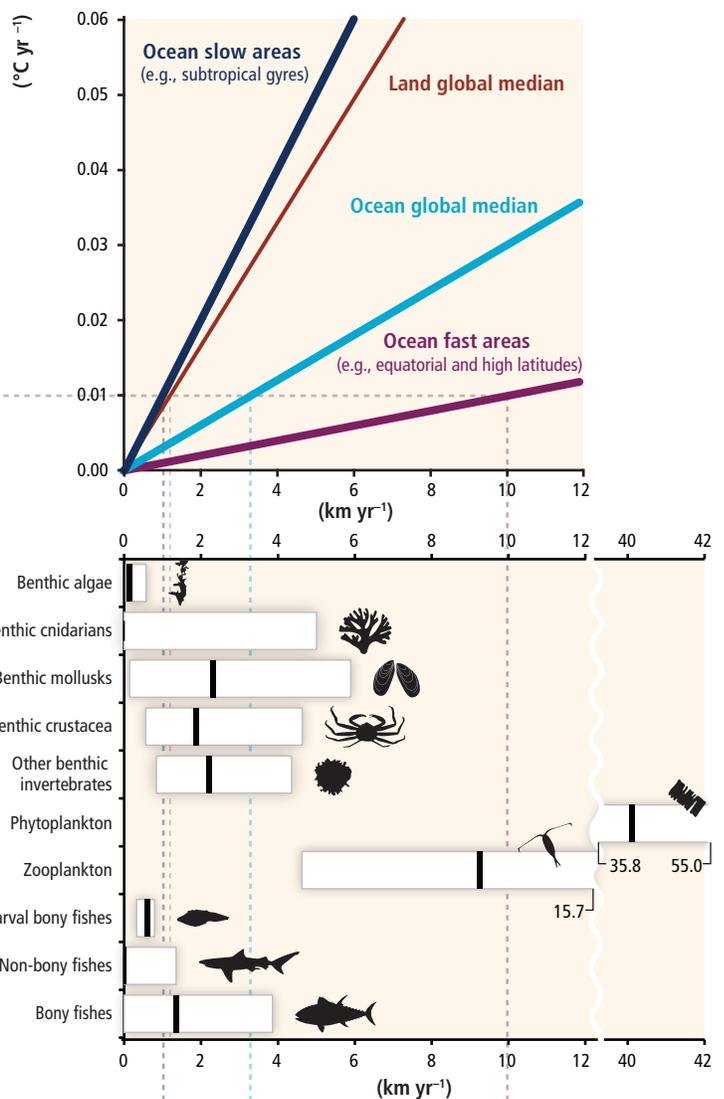
Geographical range shifts and depth distribution vary between coexisting marine species (Genner et al., 2004; Perry et al., 2005; Simpson et al., 2011) as a consequence of the width of species-specific thermal windows and associated vulnerabilities (Figure 6-5). Warming therefore causes differential changes in growth, reproductive success, larval output, early juvenile survival, and recruitment, implying shifts in the relative performance of animal species and, thus, their competitiveness (Pörtner and Farrell, 2008; Figure 6-7A). Such effects may underlie abundance losses or local extinctions, "regime shifts" between coexisting species, or critical mismatches between predator and prey organisms, resulting in changes in local and regional species richness, abundance, community composition, productivity, energy flows, and invasion resistance. Even among Antarctic stenotherms, differences in biological responses related to mode of life, phylogeny and associated metabolic capacities exist (Section 6.3.1.4). As a consequence, marine ecosystem functions may be substantially reorganized at the regional scale, potentially triggering a range of cascading effects (Hoegh-Guldberg and Bruno, 2010). A focus on understanding the mechanisms underpinning the nature and magnitude of responses of marine organisms to climate change can help forecast impacts and the associated costs to society as well as facilitate adaptive management strategies for mitigating these impacts (Sections 6.3, 6.4).



(a) Climate change scenarios



(b) Estimate of climate velocity to determine rate of displacement



(c) Species displacement rates (required to track climate velocity)

Figure MB-3 | (a) Rate of climate change for the ocean (sea surface temperature (SST) °C yr⁻¹). (b) Corresponding climate velocities for the ocean and median velocity from land (adapted from Burrows et al., 2011). (c) Observed rates of displacement of marine taxonomic groups based on observations over 1900–2010. The dotted bands give an example of interpretation. Rates of climate change of 0.01 °C yr⁻¹ correspond to approximately 3.3 km yr⁻¹ median climate velocity in the ocean. When compared to observed rates of displacement (c), many marine taxonomic groups have been able to track these velocities. For phytoplankton and zooplankton the rates of displacement greatly exceed median climate velocity for the ocean and, for phytoplankton exceed velocities in fast areas of the ocean approximately 10.0 km yr⁻¹. All values are calculated for ocean surface with the exclusion of polar seas (Figure 30-1a). (a) Observed rates of climate change for ocean SST (green line) are derived from the Hadley Centre Interpolated SST 1.1 (HadISST1.1) data set, and all other rates are calculated based on the average of the Coupled Model Intercomparison Project Phase 5 (CMIP5) climate model ensembles (Table SM30-3) for the historical period and for the future based on the four Representative Concentration Pathway (RCP) scenarios. Data were smoothed using a 20-year sliding window. (b) Median climate velocity over the global ocean surface (light blue line; excluding polar seas) calculated from HadISST1.1 data set over 1960–2009 using the methods of Burrows et al. (2011). Median velocities representative of ocean regions of slow velocities such as the Pacific subtropical gyre (dark blue line) and of high velocities such as the Coral Triangle or the North Sea (purple line) shown. Median rates over global land surface (red line) over 1960–2009 calculated using Climate Research Unit data set CRU TS3.1. Figure 30-3 shows climate velocities over the ocean surface calculated over 1960–2009. (c) Rates of displacement for marine taxonomic groups estimated by Poloczanska et al. (2013) using published studies. Note the displacement rates for phytoplankton exceed the axis, so values are given.

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This cross-chapter box should be cited as:

Poloczanska, E.S., O. Hoegh-Guldberg, W. Cheung, H.-O. Pörtner, and M. Burrows, 2014: Cross-chapter box on observed global responses of marine biogeography, abundance, and phenology to climate change. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 123-127.