Marine Biodiversity and Climate Change

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Contents

Abstract

Climate change involves shifts in environmental conditions which will affect the distribution and biological performance of species. Global patterns of marine biodiversity are strongly driven by ocean temperature. Rising ocean

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temperatures, in combination with other climate changes and human pressures, will have both direct and indirect effects on marine species, and there will be both "winners" and "losers." On a global scale, biological communities and interactions within them will change as physiological demands increase and some species replace others. On a local scale, impacts of climate change on marine biodiversity will be greatest when foundation species are affected because the effects will cascade through associated communities within and between trophic levels. In many cases, climate change will reduce the resilience of marine communities to other human pressures. It is therefore important that effects of climate change on marine biodiversity are understood in combination with multiple stressors.

Keywords
Global warming • Human impacts • Ocean acidification • Multiple stressors • Habitat-forming species • Ecosystem engineers • Range-shifts • Direct and indirect effects • Interactions

Definition

Climate change will have both direct and indirect effects on marine species, and there will be both "winners" and "losers." Globally, biological communities will change as species shift poleward at different rates. Locally, the impacts of climate change on marine biodiversity will be greatest when foundation species are affected because the effects will cascade through associated communities within and between trophic levels.

Introduction

Global marine biodiversity is under increasing pressure from environmental change caused by human activities including, but not restricted to, climate change (Hoegh-Guldberg and Bruno 2010; Wernberg et al. 2011). Biodiversity refers to the variety of living organisms, and it can be explored across levels of biological organization from genes, species, functional types, habitats to ecosystems. Here, we focus on species diversity, that is, the variety of species within a site or an ecosystem. All levels of biodiversity are however inherently linked and governed by many of the same problems and mechanisms.

Global Patterns of Marine Biodiversity

Marine biodiversity is not evenly distributed across the planet. Most marine taxa have more species toward the equator than toward the poles, and for coastal species in particular, there is also a strong concentration of species richness in the Western Pacific (Tittensor et al. 2010). However, while species such as corals and mangroves clearly conform to this pattern, other species do not. Seaweeds, for example, have greatest species richness at mid to high latitudes. There are many possible explanations for these global patterns, including that rates of speciation are faster in warmer environments, and that the tropical Western Pacific has had the most extensive shallow coastal areas over geological and evolutionary time and therefore might be the point of origin for the evolution of many species (Tittensor et al. 2010). Sea surface temperature, and to a lesser extent habitat availability and geological history, shows strong relationships to global patterns of known marine biodiversity (Tittensor et al. 2010). Temperature, in particular, plays a fundamental role in the distribution of marine life, where the distribution of many species is tightly linked to their thermal tolerance limits (Sunday et al. 2012). Moreover, areas of high marine species richness are disproportionately concentrated in areas with medium to high human impacts, highlighting the vulnerability of marine biodiversity to human activities (Tittensor et al. 2010). Consequently, there are strong indications that changes in ocean temperature, in conjunction with other human impacts, may rearrange the global distribution of life in the ocean (Tittensor et al. 2010). In itself this in nothing new; species have always shifted and communities been rearranged, in pace with changing continents and climate. The problem now is the unprecedented combination of both magnitude and rate of change, where many species might not be able to move or adjust fast enough. The predictions are dramatic, with as much as 60 % species turnover of current biodiversity within the coming 50 years (Cheung et al. 2009). These predictions are however highly uncertain, and this is highlighted by the fact that we might have only discovered as little as 10 % of the existing marine species (Mora et al. 2011).

Impacts of Climate Change on Biodiversity

Climate change involves several concurrent changes in the physical environment, ultimately caused by human emissions of atmospheric CO_2 and other greenhouse gasses. In the marine realm, key climate changes likely to drive shifts in biodiversity are increasing sea temperatures, decreasing ocean pH (see chapter ► "Ocean Acidification and Oceanic Carbon Cycling"), increasing frequency and magnitude of extreme events (e.g., storms and heat waves), and sea level rise. Climate change has already impacted marine species and communities, with most documented cases relating to effects associated with rising temperatures (Hoegh-Guldberg and Bruno 2010; Wernberg et al. 2011).

Shifts in key environmental factors such as temperature (global warming) or pH (ocean acidification) will have direct physiological effects on individuals and species (Fig. 23.1). Physiological stress is metabolically expensive and can directly increase mortality rates or reduce the ecological competency of organisms by, for example, reducing the time that can be spent foraging or the energy that can be allocated to growth and reproduction. Climate change can also have indirect

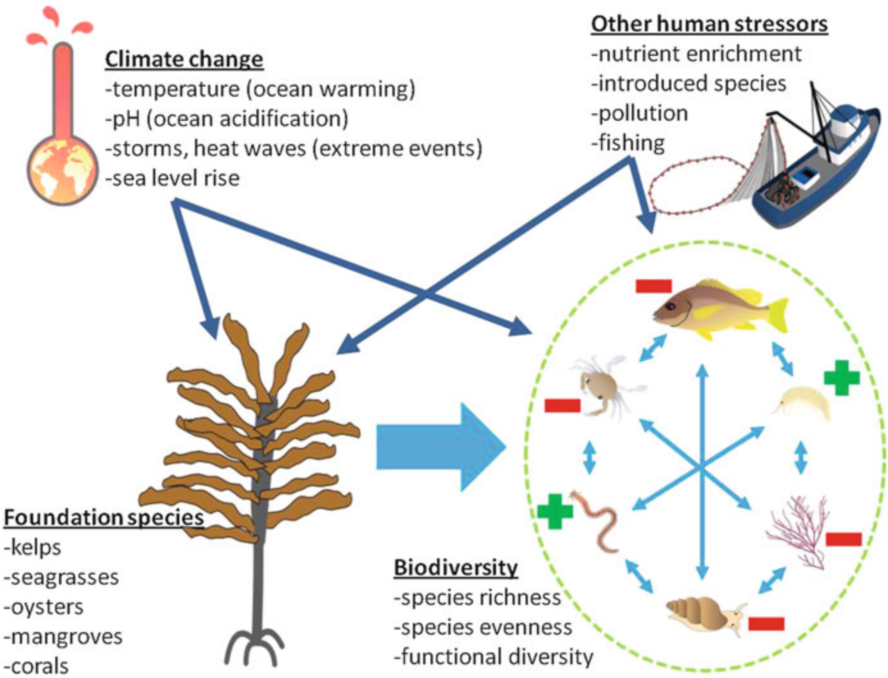

Fig. 23.1 Climate change (e.g., global warming or ocean acidification) will have direct physiological effects on individual species (*dark blue arrows*), both foundation species and all those that live within a biogenic habitat. This will change the performance of each species depending on their specific tolerances; some species will perform better ("winners," green plusses) under the new conditions whereas others will perform worse ("losers," red minuses), and this will shift the balance of their interactions, causing indirect effects (*light blue arrows*). The existence of numerous species is conditional of the presence of foundation species which provide habitat, protection, and food so that any impacts on foundation species will have disproportionately large effects on ecosystems and biodiversity (*fat light blue arrow*). Climate change is only one of several pressures, and these pressures combine in their impacts on species. Climate change will reduce the resilience of ecosystems by increasing the sensitivity of species to additional pressures such as pollution. Images and symbols used in the figure courtesy of the Integration and Application Network (ian.umces.edu/symbols/)

effects on individuals and species through shifts in species interactions. Species interactions change because new species encounter each other for the first time (species ranges shift at different velocities and magnitudes) and because physiological requirements alter species interaction strengths (e.g., Wernberg et al. 2010). For example, basic metabolic rates usually increase with temperature and so must the consumption rates of herbivores and predators to sustain their basic life processes; often, however, rates of change differ between prey and predators. The indirect effects of climate change on species distributions and marine biodiversity resulting from changes in species interactions are much more difficult to predict, yet are likely to be much greater, than the direct effects on individual species (Kordas et al. 2011).

Temperature has a fundamental effect on biochemical reaction rates and virtually all biological processes have an optimum temperature above which performance declines, often rapidly (Kordas et al. 2011). In contrast, pH primarily affects the availability of different forms of calcium carbonate, making it difficult for calcifying organisms to maintain accretion rates as CO_2 concentrations increase (causing ocean acidification). Consequently, the direct impacts of increasing ocean temperatures will be pervasive across taxa and biogeographical regions whereas effects of ocean acidification will likely be more idiosyncratic, except where habitat formers such as tropical corals are negatively impacted. Still, effects of ocean acidification go beyond the direct negative effects on calcifying organisms such as sea urchins, molluscs, and calcareous algae. For example, small filamentous seaweeds, which can prevent the recruitment of large habitat-forming seaweeds, can be positively affected by acidification and changes in carbon availability, particularly under eutrophied conditions (Russell et al. 2009). In addition, the impacts of ocean acidification are likely to intensify with increasing temperatures.

Marine species show a stronger link between their thermal tolerance limits and their distributions than do terrestrial species (Sunday et al. 2012), and shifts in species distributions have been one of the most widely recorded responses to ocean warming (e.g., Wernberg et al. 2011, 2013). Similar observed changes attributable to ocean acidification have not been observed, although changes in communities along natural pH gradients suggest such changes are likely. It is possible that marine organisms are more robust to ocean acidification than previously anticipated (Hendriks et al. 2010). Importantly, most marine species have several distinct life stages, which often have different tolerances to environmental conditions. Similarly, different species within a community have different susceptibilities to climate change, and because they also have different ecological functions, the ultimate population- and community-level impacts of climate change will reflect that of the most sensitive species or life stages (Russell et al. 2012).

Importance of Foundation Species

Some species have a disproportionately large influence on local biodiversity. These "foundation species" are typically large, abundant, and structurally complex species which provide habitat, protection from predators, amelioration of environmental stress (e.g., desiccation), and food to a range of associated species (Thomsen et al. 2010). Typical marine foundation species include kelps, sea grasses, corals, oysters, and mangroves (Fig. 23.1). Climate change can, directly or indirectly, modify the distribution and abundance of these foundation species with sweeping impacts across entire marine communities. For example, in Tasmania (Australia), a sea urchin (*Centrostephanus rodgersii*) has extended its range poleward by ca. 500 km over the past 50 years because ocean temperatures now exceed a 12 °C survival threshold for urchin larvae. During its range expansion, the urchin has overgrazed previously dense seaweed beds, leaving little erect vegetation behind.

This climate-mediated habitat change, from large structurally complex species to minute turf and encrusting species, has caused an estimated local loss of at least ~150 taxa (67 %), from the original species pool of 221 seaweed-associated species (Ling 2008). Similarly, during a marine heat wave in Western Australia, ocean temperatures soared to unprecedented levels for several weeks. The heating exceeded the physiological tolerances of habitat-forming seaweeds, which died and caused a shift in community state (Wernberg et al. 2013).

Interactions with Other Human Pressures

Climate change is superimposed onto other human pressures such as eutrophication, species introductions, pollution, and harvesting of marine species (Wernberg et al. 2011). Many of the physical changes associated with climate change appear to be relatively subtle (e.g., a 1–3 °C increase in ocean temperature over 50 years). Nevertheless, they cause large changes in the underlying physiology and ecological performance of key species, thereby reducing the resilience of the ecosystem to perturbations from non-climate stressors. For example, elevated temperatures can suppress reproduction and recruitment of large habitat-forming temperate seaweeds, resulting in reduced capacity to recover from disturbances (e.g., caused by large storms) (Wernberg et al. 2010). Similarly, invasive species pose substantial threat to global biodiversity. Climate change can facilitate the establishment of invasive species in temperate marine systems (Wernberg et al. 2011). Thus, climate change can make marine communities more sensitive to other stressors such as invasions, storms, and eutrophication with potential detrimental cascading impacts on important foundation species.

Conclusions

Climate change involves several concurrent changes in the physical environment, such as increasing sea temperatures, decreasing ocean pH, increasing frequency and magnitude of extreme events (e.g., storms and heat waves), and sea level rise. These physical changes will have direct mechanical or physiological effects on marine species as well as indirect effects through changes in species interactions. Importantly, there will be both winners and losers: depending on their specific tolerance limits, some species will benefit and increase in abundance and distribution whereas others will be negatively affected by the impending changes and decline in abundance and distribution. The impact of climate change on biodiversity is the sum of changes in individual species and, consequently, will be complex.

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Cross-References

► Ocean Acidification and Oceanic Carbon Cycling
► Ecosystem Resilience and Resistance to Climate Change
► Sea-Surface Temperature

References

Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Pauly D (2009) Projecting global marine biodiversity impacts under climate change scenarios. Fish Fish 10:235–251

Hendriks IE, Duarte CM, Álvarez M (2010) Vulnerability of marine biodiversity to ocean acidification: a meta-analysis. Estuar Coast Shelf Sci 86:157–164

Hoegh-Guldberg O, Bruno JF (2010) The impact of climate change on the world's marine ecosystems. Science 328:1523–1528

Kordas RL, Harley CDG, O'Connor MI (2011) Community ecology in a warming world: the influence of temperature on interspecific interactions in marine systems. J Exp Mar Biol Ecol 400:218–226

Ling S (2008) Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new and impoverished reef state. Oecologia 156:883–894

Mora C, Tittensor DP, Adl S, Simpson AGB, Worm B (2011) How many species are there on Earth and in the ocean? PLoS Biol 9:e1001127

Russell BD, Thompson J-AI, Falkenberg LJ, Connell SD (2009) Synergistic effects of climate change and local stressors: CO_2 and nutrient-driven change in subtidal rocky habitats. Glob Chang Biol 15:2153–2162

Russell BD, Harley CDG, Wernberg T, Mieszkowska N, Widdicombe S, Hall-Spencer JM, Connell SD (2012) Predicting ecosystem shifts requires new approaches that integrate the effects of climate change across entire systems. Biol Lett 8:164–166

Sunday JM, Bates AE, Dulvy NK (2012) Thermal tolerance and the global redistribution of animals. Nat Clim Change. doi:10.1038/NCLIMATE1539

Thomsen MS, Wernberg T, Altieri A, Tuya F, Gulbransen D, McGlathery KJ, Holmer M, Silliman BR (2010) Habitat cascades: the conceptual context and global relevance of facilitation cascades via habitat formation and modification. Integr Comp Biol 50:158–175

Tittensor DP, Mora C, Jetz W, Lotze HK, Ricard D, Berghe EV, Worm B (2010) Global patterns and predictors of marine biodiversity across taxa. Nature 466:1098–1101

Wernberg T, Thomsen MS, Tuya F, Kendrick GA, Staehr PA, Toohey BD (2010) Decreasing resilience of kelp beds along a latitudinal temperature gradient: potential implications for a warmer future. Ecol Lett 13:685–694

Wernberg T, Russell BD, Moore PJ, Ling SD, Smale DA, Campbell A, Coleman MA, Steinberg PD, Kendrick GA, Connell SD (2011) Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming. J Exp Mar Biol Ecol 400:7–16

Wernberg T, Smale DA, Tuya F, Thomsen MS, Langlois TJ, de Bettignies T, Bennett S, Rousseaux CS (2013) An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. Nat Clim Change 3:78–82

Additional Recommended Reading

Doney SC, Ruckelshaus M, Emmett Duffy J, Barry JP, Chan F, English CA, Galindo HM, Grebmeier JM, Hollowed AB, Knowlton N, Polovina J, Rabalais NN, Sydeman WJ, Talley LD (2012) Climate change impacts on marine ecosystems. Ann Rev Mar Sci 4:11–37