Box CC-OA. Ocean Acidification

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Anthropogenic ocean acidification and global warming share the same primary cause, which is the increase of atmospheric CO_2 (Figure OA-1A; WGI, 2.2.1). Eutrophication, loss of sea ice, upwelling and deposition of atmospheric nitrogen and sulphur all exacerbate ocean acidification locally (5.3.3.6, 6.1.1, 30.3.2.2).

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Figure OA-1: A: Overview of the chemical, biological, socio-economic impacts of ocean acidification and of policy options (adapted from Turley and Gattuso, 2012). B: Multi-model simulated time series of global mean ocean surface pH (on the total scale) from CMIP5 climate model simulations from 1850 to 2100. Projections are shown for emission scenarios RCP2.6 (blue) and RCP8.5 (red) for the multi-model mean (solid lines) and range across the distribution of individual model simulations (shading). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The models that are included are those from CMIP5 that simulate the global carbon cycle while being driven by prescribed atmospheric CO_2 concentrations. The number of CMIP5 models to calculate the multi-model mean is indicated for each time period/scenario (WGI AR5 Figure 6.28). C: Effect of near future acidification (seawater pH reduction of 0.5 unit or less) on major response variables estimated using weighted random effects meta-analyses, with the exception of survival which is not weighted (Kroeker et al., 2013). The log-transformed response ratio (LnRR) is the ratio of the mean effect in the acidification treatment to the mean effect in a control group. It indicates which process is most uniformly affected by ocean acidification but large variability exists between species. Significance is determined when the 95% bootstrapped confidence interval does not cross zero. The number of experiments used in the analyses is shown in parentheses. * denotes a statistically significant effect.]

Chemistry and Projections

The fundamental chemistry of ocean acidification is well understood (*robust evidence, high agreement*). Increasing atmospheric concentrations of CO_2 result in an increased flux of CO_2 into a mildly alkaline ocean, resulting in a reduction in pH, carbonate ion concentration, and the capacity of seawater to buffer changes in its chemistry (*very high confidence*). The changing chemistry of the surface layers of the open ocean can be projected at the global scale with high accuracy using projections of atmospheric CO_2 levels (Fig. CC-OA-1B). Observations of changing upper ocean CO_2 chemistry over time support this linkage (WGI Table 3.2 and Figure 3.18; Figures 30.8, 30.9). Projected changes in open ocean, surface water chemistry for year 2100 based on representative concentration pathways (WGI, Figure 6.28) compared to preindustrial values range from a pH change of -0.14 unit with RCP 2.6 (421 ppm CO_2, +1 ºC, 22% reduction of carbonate ion concentration) to a pH change of -0.43 unit with RCP 8.5 (936 ppm CO_2, +3.7 ºC, 56% reduction of carbonate ion concentration). Projections of regional changes, especially in the highly complex coastal systems (5.3.3.6, 30.3.2.2), in polar regions (WGI 6.4.4), and at depth are more difficult but generally follow similar trends.

Biological, Ecological, and Biogeochemical Impacts

Investigations of the effect of ocean acidification on marine organisms and ecosystems have a relatively short history, recently analyzed in several metaanalyses (6.3.2.1, 6.3.5.1). A wide range of sensitivities to projected rates of ocean acidification exists within and across diverse groups of organisms, with a trend for greater sensitivity in early life stages (*high confidence*; 5.4.2.2, 5.4.2.4, 6.3.2). A pattern of positive and negative impacts emerges (*high confidence*; Fig. OA-1C) but key uncertainties remain in our understanding of the impacts on organisms, life histories and ecosystems. Responses can be influenced, often exacerbated by other drivers, such as warming, hypoxia, nutrient concentration, and light availability (*high confidence*; 5.4.2.4, 6.3.5).

Growth and primary production are stimulated in seagrass and some phytoplankton (*high confidence*; 5.4.2.3, 6.3.2.2-3, 30.5.6). Harmful algal blooms could become more frequent (*limited evidence, medium agreement*). Ocean acidification may stimulate nitrogen fixation (*limited evidence, low agreement*; 6.3.2.2). It decreases the rate of calcification of most, but not all, sea-floor calcifiers (*medium agreement, robust evidence*) such as reef-building corals (Box CC-CR), coralline algae, bivalves and gastropods reducing the competitiveness with non-calcifiers (5.4.2.2, 5.4.2.4, 6.3.2.5). Ocean warming and acidification promote higher rates of calcium carbonate dissolution resulting in the net dissolution of carbonate sediments and frameworks and loss of associated habitat (*medium confidence*; 5.4.2.4, 6.3.2.5, 6.3.5.4-5). Some corals and temperate fishes experience disturbances to behavior, navigation and their ability to tell conspecifics from predators (6.3.2.4). However, there is no evidence for these effects to persist on evolutionary timescales in the few groups analyzed (6.3.2).

Some phytoplankton and mollusks displayed adaptation to ocean acidification in long-term experiments (*limited evidence, medium agreement*; 6.3.2.1), indicating that the long-term responses could be less than responses obtained in short-term experiments. However, mass extinctions in Earth history occurred during much slower rates of ocean acidification, combined with other drivers changing, suggesting that evolutionary rates are not fast enough for sensitive animals and plants to adapt to the projected rate of future change (*medium confidence*; 6.1.2).

Projections of ocean acidification effects at ecosystem level are made difficult by the diversity of species-level responses. Differential sensitivities and associated shifts in performance and distribution will change predator-prey relationships and competitive interactions (6.3.2.5, 6.3.5-6), which could impact food webs and higher trophic levels (*limited evidence, high agreement*). Natural analogues at CO_2 vents indicate decreased species diversity, biomass and trophic complexity of communities (Box CC-CR; 5.4.2.3, 6.3.2.5, 30.3.2.2, 30.5). Shifts in community structure have also been documented in regions with rapidly declining pH (5.4.2.2).

Due to an incomplete understanding of species-specific responses and trophic interactions the effect of ocean acidification on global biogeochemical cycles is not well understood (*limited evidence, low agreement*) and represents an important knowledge gap. The additive, synergistic or antagonistic interactions of factors such as temperature, concentrations of oxygen and nutrients, and light are not sufficiently investigated yet.

Risks, Socioeconomic Impacts and Costs

The risks of ocean acidification to marine organisms, ecosystems, and ultimately to human societies, include both the probability that ocean acidification will affect fundamental physiological and ecological processes of organisms (6.3.2.1), and the magnitude of the resulting impacts on ecosystems and the ecosystem services they provide to society (Box 19-2). For example, ocean acidification under RCP4.5 to RCP8.5 will impact formation and maintenance of coral reefs (*high confidence*; Box CC-CR, 5.4.2.4) and the goods and services that they provide such as fisheries, tourism and coastal protection (*limited evidence, high agreement*; Box CC-CR, 6.4.1.1,19.5.2, 27.3.3, 30.5, 30.6). Ocean acidification poses many other potential risks, but these cannot yet be quantitatively assessed due to the small number of studies available, particularly on the magnitude of the ecological and socioeconomic impacts (19.5.2).

Global estimates of observed or projected economic costs of ocean acidification do not exist. The largest uncertainty is how the impacts on lower trophic levels will propagate through the food webs and to top predators. However, there are a number of instructive examples that illustrate the magnitude of potential impacts of ocean acidification. A decrease of the production of commercially-exploited shelled mollusks (6.4.1.1) would result in a reduction of US production of 3 to 13% according to the SRES A1FI emission scenario (*low confidence*). The global cost of production loss of mollusks could be over 100 billion USD by 2100 (*limited evidence, medium agreement*). Models suggest that ocean acidification will generally reduce fish biomass and catch (*low confidence*) and that complex additive, antagonistic and/or synergistic interactions will occur with other environmental (warming) and human (fisheries management) factors (6.4.1.1). The annual economic damage of ocean-acidification-induced coral reef loss by 2100 has been estimated, in 2009, to be 870 and 528 billion USD, respectively for the A1 and B2 SRES emission scenarios (*low confidence*; 6.4.1). Although this number is small compared to global GDP, it can represent a very large GDP loss for the economies of many coastal regions or small islands that rely on the ecological goods and services of coral reefs (25.7.5, 29.3.1.2).

Mitigation and Adaptation

Successful management of the impacts of ocean acidification includes two approaches: mitigation of the source of the problem (i.e. reduce anthropogenic emissions of CO_2), and/or adaptation by reducing the consequences of past and future ocean acidification (6.4.2.1). Mitigation of ocean acidification through reduction of atmospheric CO_2 is the most effective and the least risky method to limit ocean acidification and its impacts (6.4.2.1). Climate geoengineering techniques based on solar radiation management will not abate ocean acidification and could increase it under some circumstances (6.4.2.2). Geoengineering techniques to remove carbon dioxide from the atmosphere could directly address the problem but are very costly and may be limited by the lack of CO_2 storage capacity (6.4.2.2). Additionally, some ocean-based approaches, such as iron fertilization, would only re-locate ocean acidification from the upper ocean to the ocean interior, with potential ramifications on deep-water oxygen levels (6.4.2.2; 30.3.2.3 and 30.5.7). A low-regret approach, with relatively limited effectiveness, is to limit the number and the magnitude of drivers other than CO_2, such as nutrient pollution (6.4.2.1). Mitigation of ocean acidification at the local level could involve the reduction of anthropogenic inputs of nutrients and organic matter in the coastal ocean (5.3.4.2). Some adaptation strategies include drawing water for aquaculture from local watersheds only when pH is in the right range, selecting for less sensitive species or strains, or relocating industries elsewhere (6.4.2.1).

CC-OA References

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Box CC-TC. Building Long-Term Resilience from Tropical Cyclone Disasters

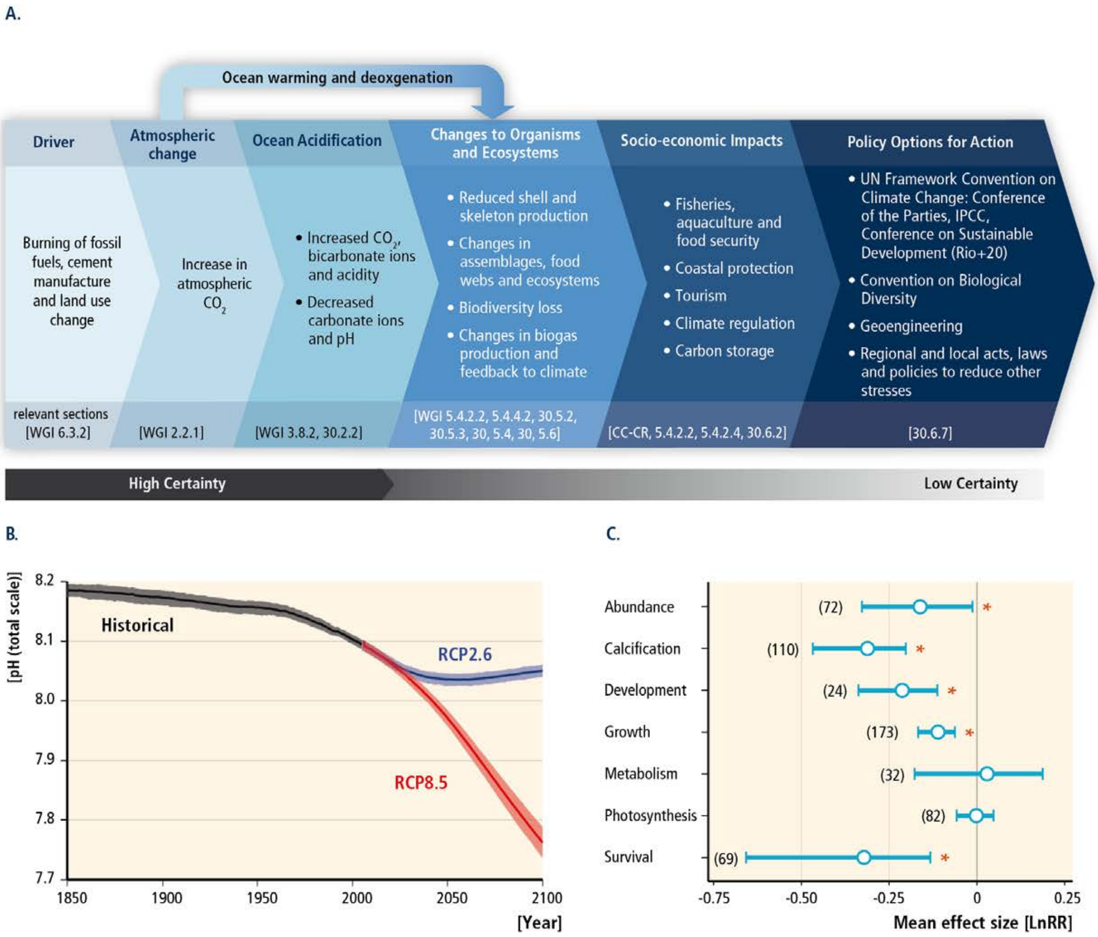
[Yoshiki Saito (Japan), Kathleen McInnes (Australia)]

Tropical cyclones (also referred to as hurricanes and typhoons in some regions or strength) cause powerful winds, torrential rains, high waves and storm surge, all of which can have major impacts on society and ecosystems. Bangladesh and India account for 86% of mortality from tropical cyclones (Murray et al., 2012), which is mainly due to the rarest and most severe storm categories (i.e. Categories 3, 4, and 5 on the Saffir-Simpson scale).

About 90 tropical cyclones occur globally each year (Seneviratne et al., 2012) although interannual variability is large. Changes in observing techniques particularly after the introduction of satellites in the late 1970s, confounds the assessment of trends in tropical cyclone frequencies and intensities. Therefore, IPCC (2012) "Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)" concluded that there is *low confidence* that any observed long-term (i.e. 40 years or more) increases in tropical cyclone activity are robust, after accounting for past changes in observing capability (Seneviratne et al., 2012; Chapter 2). There is also *low confidence* in the detection and attribution of century scale trends in tropical cyclones. Future changes to tropical cyclones arising from climate change are *likely* to vary by region. This is because there is *medium confidence* that for certain regions, shorter-term forcing by natural and anthropogenic aerosols has had a measurable effect on tropical cyclones. Tropical cyclone frequency is *likely* to decrease or remain unchanged over the 21st century, while intensity (i.e. maximum wind speed and rainfall rates) is *likely* to increase (AR5 WG1 Ch 14.6). Regionally specific projections have *lower confidence* (see AR5 WG1 Box 14.2).

Longer-term impacts from tropical cyclones include salinisation of coastal soils and water supplies and subsequent food and water security issues from the associated storm surge and waves (Terry and Chui, 2012). However, preparation for extreme tropical cyclone events through improved governance and development to reduce their impacts provides an avenue for building resilience to longer-term changes associated with climate change.

Densely populated Asian deltas are particularly vulnerable to tropical cyclones due to their large population density in expanding urban areas (Nicholls et al., 2007). Extreme cyclones in Asia since 1970 caused over 0.5 million fatalities (Murray et al., 2012) e.g., cyclones Bhola in 1970, Gorky in 1991, Thelma in 1998, Gujarat in 1998, Orissa in 1999, Sidr in 2007, and Nargis in 2008. Tropical cyclone Nargis hit Myanmar on 2 May 2008 and caused over 138,000 fatalities. Several-meter high storm surges widely flooded densely populated coastal areas of the Irrawaddy Delta and surrounding areas (Revenga et al., 2003; Brakenridge et al., 2013). The flooded areas were captured by a NASA MODIS image on 5 May 2008 (see Figure TC-1).



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