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POLICY BRIEF

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Intertwined ocean and climate: implications for international climate negotiations

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INTRODUCTION

The atmosphere and ocean are two components of the Earth system that are essential for life, yet humankind is altering both. Contemporary climate change is now a well-identified problem: anthropogenic causes, disturbance in extreme events patterns, gradual environmental changes, widespread impacts on life and natural resources, and multiple threats to human societies all around the world. But part of the problem remains largely unknown outside the scientific community: significant changes are also occurring in the ocean, threatening life and its sustainability on Earth.

This Policy Brief explains the significance of these changes in the ocean. It is based on a scientific paper recently published in *Science* (Gattuso *et al.*, 2015), which synthesizes recent and future changes to the ocean and its ecosystems, as well as to the goods and services they provide to humans. Two contrasting CO_2 emission scenarios are considered: the high emissions scenario (also known as "business-as-usual" and as the Representative Concentration Pathway 8.5, RCP8.5) and a stringent emissions scenario (RCP2.6) consistent with the Copenhagen Accord[1] of keeping mean global temperature increase below 2°C in 2100.

1. Copenhagen Accord, *Decision 2/CP.15: Copenhagen accord* (United Nations Framework Convention on Climate Change, Geneva, 2009).

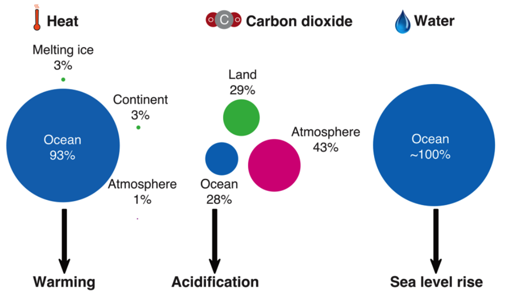
KEY MESSAGES

- Climate and ocean are inseparable: the ocean moderates anthropogenic climate change by absorbing significant proportions of the heat and CO_2 that accumulate in the atmosphere, as well as by receiving all water from melting ice.
- This climate-regulating function happens at the cost of profound alterations of the ocean's physics and chemistry, leading to ocean warming and acidification, as well as to sea level rise. These changes significantly affect the ocean's ecology (organisms and ecosystems) and eventually marine and coastal human activities (fisheries, aquaculture, tourism, health…).
- As atmospheric CO_2 increases, possible human responses become fewer and less effective.
- This scientific statement provides further compelling arguments for immediate and ambitious CO_2 emissions reduction at the international level. This conclusion applies to COP21 as well as to the post-2015 climate regime at large.

1. THE OCEAN STRONGLY INFLUENCES THE CLIMATE SYSTEM

The global ocean (including enclosed seas) is a "climate regulator" (Figure 1) that *(i)* has absorbed 93% of the Earth's additional heat since the 1970s, keeping the atmosphere cooler; *(ii)* has captured 28% of human-caused CO_2 emissions since 1750; and *(iii)* has received virtually all water from melting ice. Without the ocean, climate change would thus be far more intense, jeopardizing many species on Earth. Such important services have however come at a price: the rise in atmospheric greenhouse gases concentration from 278 to 400 ppm over the industrial period has driven a series of major environmental changes in the ocean, namely warming, acidification, oxygen loss and sea-level rise.

Figure 1. Distribution of heat, carbon dioxide and ice-melt water in the main Earth reservoirs and consequences for the ocean



There is strong evidence that the ocean warmed between the years 1971 and 2010, and it is very likely that warming was occurring earlier (Rhein *et al.*, 2013). Ocean warming has occurred at all depths but is most pronounced at the surface. Over the last four decades, the average temperature of the upper 75m has increased by around 0.11°C per decade.

At the same time, the uptake of CO_2 in seawater causes a decrease in pH (i.e., increase in acidity), as well as in the concentration of carbonate ions (CO_3^{2-}). This process is called "ocean acidification" and it alters conditions inside many organisms, which are less able to build their skeletons and shells. There is high confidence that surface ocean pH has declined by 0.1 pH units since the beginning of the Industrial Era, representing a 30% increase of ocean acidity in 250 years (Rhein *et al.*, 2013).

Finally, ocean warming (i.e., thermal expansion) and continental ice melting caused sea-level rise. Global mean sea level has risen by approximately 1.7 mm per year over the period 1901 to 2010, with an accelerated rate between 1993 and 2010 (+3.2 mm per year) (Church *et al.*, 2013).

2. IMPACTS ARE ALREADY DETECTABLE AND CONTRASTING FUTURES DEPEND ON FUTURE GREENHOUSE GAS EMISSIONS

Together, ocean warming, ocean acidification, and sea level rise form a chain of impacts that links changes in the ocean to human well-being. Yet, the scientific evidence is clear. First, ocean changes have already started to have major consequences for organisms and ecosystems especially in terms of abundance, geographical distribution, invasive species and prey-predator relations (Pörtner *et al.*, 2014). Second, several organisms and ecosystems face a high risk of impact before 2100 (Figure 2), even under the stringent mitigation scenario (RCP2.6). These impacts are occurring from high to low latitudes, making this issue a global concern beyond the traditional North/South divide.

2.1. Ocean physics and chemistry

Future conditions for the ocean depend on the amount of CO_2 that will be emitted in the coming decades (see panel A of Figure 2). The more stringent scenario (RCP2.6) allows less than one-sixth of 21st century emissions expected under business-as-usual (RCP8.5). Ocean physics and chemistry in 2100 will thus be significantly different under these two emissions scenarios.

Obviously, the ocean will be much warmer under RCP8.5 than under RCP2.6, as the global mean change in sea surface temperature will differ by a factor close to 4 (+2.73 *vs.* +0.71°C). Open-ocean surface acidity will increase by 100% under RCP8.5 as opposed to only 17% under RCP2.6.

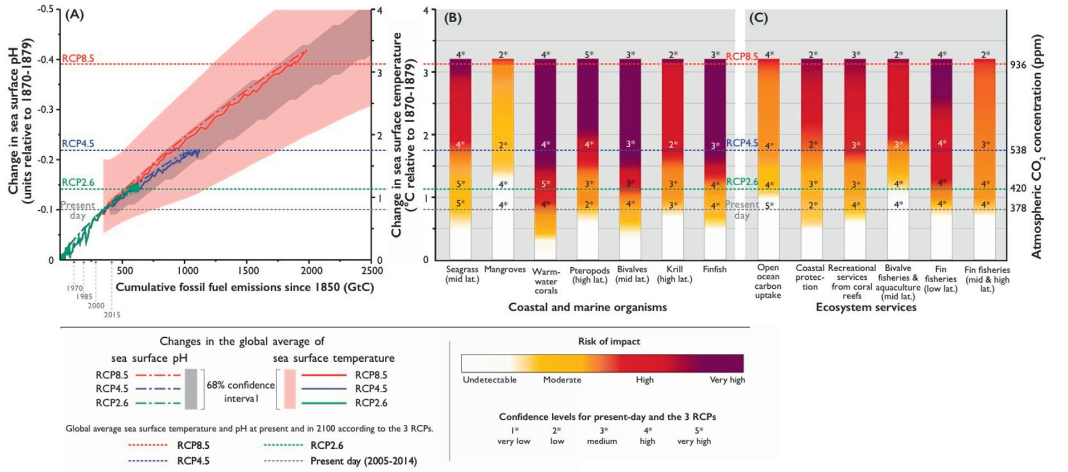
Finally, and although the two emission scenarios result in a less pronounced contrast, the average global increase in mean sea level relative to the preindustrial period is projected to be 0.86 m for RCP8.5 and 0.60 m for RCP2.6. The seemingly small difference between these sea-level rise estimates may still equate to a difference of tens of millions of people affected by severe flooding.[2]

2.2. Organisms and ecosystems

While warm-water corals are at the frontline of ocean changes, mid-latitude seagrass and many other species are already being affected, including high-latitude pteropods (snails that feed salmon

2. See for example the Sea Level Rise programme at Climate Central for simulations in the United States of America (http://www.climatecentral.org/what-we-do/our-programs/sea-level-rise).

Figure 2. Observed impact and risk scenarios of ocean warming and acidification for important organisms and critical ecosystem services



Source: Gattuso *et al.* (2015), reproduced with permission by *Science*.

and other finfish) and krill, mid-latitude bivalves (mussels and oysters), and finfishes (see panel B of Figure 2). In a low-CO_2 emissions scenario (RCP2.6), ocean changes still carry high risks of impact for warm-water corals and mid-latitude bivalves, but the risks of other impacts remain moderate—although worrying. The situation would be considerably worse with the business-as-usual scenario (RCP8.5): almost all marine organisms considered (e.g., corals, pteropods, finfish, and krill) would face very high risks of impact, such as mass mortalities or species displacement. These results—derived from experiments, field observations, and modelling—are consistent with evidence from high-CO_2 periods in the geological record, giving even more credence to those future projections.

2.3. Ecosystem services

The ocean's capacity to absorb CO_2—a key ecosystem service—will decrease with increasing emissions: the fraction of anthropogenic emissions absorbed by the ocean in the 21st century is projected to decline from 56% for RCP2.6 to 22% for RCP8.5. More generally, impacts to the ocean's ecosystem services follow a trajectory which parallels the impacts on organisms and ecosystems (Weatherdon *et al.*, 2015), with risks of impact ranging from "moderate" with RCP2.6 to "high to very high" with RCP8.5 (see panel C of Figure 2).

Low-latitude fisheries and aquaculture, which are key sources of protein and income for millions of people, will likely be severely affected under the business-as-usual scenario. And severe implications at the national and international levels are expected due to cascading effects (Magnan *et al.*, 2015). Changes in fisheries catch potential in a given area, for example, will most probably challenge international fishery agreements between the countries concerned, which will have in turn consequences for the industry (profitability, jobs, etc.), markets and prices in several countries, as well as for international competitiveness. In the end, the greater the changes to ocean ecosystems and productivity, the greater the threat to current international agreements and the greater the risk to food and human security, geopolitics and development at the global scale.

Likewise, the risk of impact to ecosystem services such as coastal protection (e.g., by coral reefs and mangroves) would become high or very high by 2100, thus exacerbating the risks of marine flooding in low-lying areas.

Impacts of ocean warming, oxygen loss and acidification on marine ecosystems will be cumulative or synergistic with other human-induced changes such as overexploitation of living resources, habitat destruction and pollution. In addition, given the extent of the expected changes, no country is safe, making this issue a worldwide problem and highlighting the importance of climate negotiations for the international community to avoid moving towards an unsustainable future.

3. OPTIONS TO OVERCOME OR LIMIT THE RISKS BECOME FEWER AND LESS EFFECTIVE AS GREENHOUSE GAS CONCENTRATION INCREASES

Various options exist to address ocean impacts, with some evidence of success. They can be clustered into four categories: *mitigating* CO_2

emissions, *protecting* marine and coastal ecosystems from non-climate stressors (e.g., through protected areas, or regulation of exploitation of natural resources), *repairing* ecosystems that have already experienced damages (e.g., assisted evolution of corals and/or coral farming), and *adapting* (e.g., economic activities diversification, or coastal setback zones). However, the number of options and their efficiency narrows as the ocean warms and increases in acidity. That is to say, in addition to negatively affecting a range of ecosystems and services directly, moving away from the +2°C path will also limit the availability of policy responses to those impacts. For example, one cannot manage coral reef resilience if there are no healthy reefs remaining. Further, as coastal ecosystems become more pervasively damaged, restoration activities will become more expensive, labour-intensive and less guaranteed to succeed, thus exacerbating the adverse consequences for humans.

4. IMMEDIATE AND SUBSTANTIAL REDUCTION OF CO_2 EMISSIONS IS CRUCIALLY NEEDED

The three previous sections lead to a fourth key message: immediate and substantial reduction of CO_2 emissions is required in order to prevent the massive and effectively irreversible impacts on ocean ecosystems and their services that are projected with more severe emission scenarios than RCP2.6. Scientific evidence demonstrates that the high mitigation scenario (RCP2.6) will not lead to an ideal ocean, and that significant impacts will nevertheless occur. This means that RCP2.6 is at best an upper boundary for any global climate agreement to be consistent with United Nations Framework Convention on Climate Change (UNFCCC) fundamental objective of preventing 'dangerous anthropogenic interference with the climate system ... within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner' (United Nations, 1992).

Yet, the international climate negotiations under the UNFCCC have only minimally considered the impacts of greenhouse gas emissions on the ocean as well as the ocean's potential for solutions for setting long-term global goals through climate change mitigation and adaptation. We argue here that given the recent progress in scientific knowledge, COP21 represents a key opportunity to address the challenge of better integrating these important ocean issues into the post-2015 international climate regime. The contrasted futures described recently and summarized in the present Policy Brief make it obvious that the ocean provides further compelling arguments for immediate and ambitious reduction of CO_2 emission. Therefore, any new global climate agreement that does not significantly contribute to minimize the impacts on the ocean will be incomplete and inadequate

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