Hot, Sour & Breathless - Ocean under stress

How is the biggest ecosystem on Earth faring?

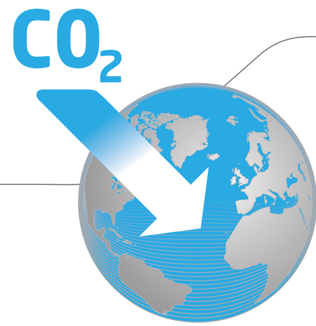
CONTAINS 96% OF THE LIVING SPACE ON EARTH ● HAS 80% OF EARTH'S LIVING ORGANISMS ● COVERS 71% OF THE EARTH ● ALMOST HALF OF THE OXYGEN WE BREATHE IS PRODUCED BY OCEAN PLANTS ● FISH PROVIDE 4.2 BILLION PEOPLE WITH AT LEAST 15% OF THEIR ANIMAL PROTEIN ● 90% OF WORLD TRADE IS CARRIED ACROSS THE OCEANS ● HOLDS AN ESTIMATED 80% OF EARTH'S MINERAL RESOURCES

Ocean and coastal regions under stress

The ocean covers nearly three quarters of the Earth's surface, contains 96% of its living space, provides around half of the oxygen we breathe and is an increasing source of protein for a rapidly growing world population. However, human activity is having an impact on this precious resource on local, regional and global scales.

Over the coming decades and centuries, ocean health will become increasingly stressed by at least three interacting factors. Rising seawater temperature, ocean acidification and ocean deoxygenation will cause substantial changes in marine physics, chemistry and biology. These changes will affect the ocean in ways that we are only beginning to understand.

It is imperative that international decision-makers understand the enormous role the ocean plays in sustaining life on Earth, and the consequences of a high CO_2 world for the ocean and society.



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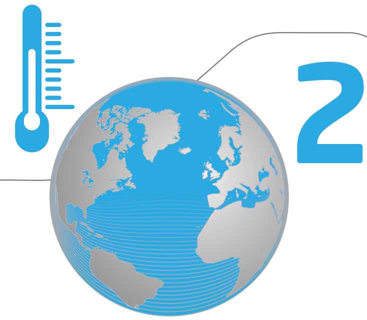
Ocean acidification

Ocean acidification is directly caused by the increase of carbon dioxide (CO_2) levels in the atmosphere. When CO_2 enters the ocean it rapidly goes through a series of chemical reactions which increase the acidity of the surface seawater (lowering its pH). The ocean has already removed about 30% of anthropogenic CO_2 over the last 250 years, decreasing pH at a rate not seen for around 60 million years.

This effect can be considered beneficial since it has slowed the accumulation of CO_2 in the atmosphere and the rate of global warming; without this ocean sink, atmospheric CO_2 levels would already be greater than 450 ppm. However, the continuation of such a fundamental and rapid change to ocean chemistry is likely to be bad news for life in the sea; it will not only cause problems for many organisms with calcium carbonate skeletons or shells (such as oysters, mussels, corals and some planktonic species) but could also impact many other organisms, ecosystems and processes with potentially serious implications for society.

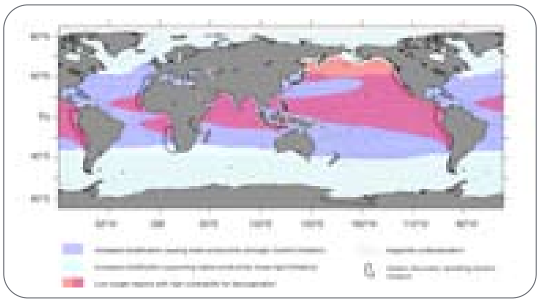
The average acidity of the upper ocean has already declined by around 0.1 pH unit (30% increase in acidity) since the industrial revolution and it is expected to further decline by about 0.3 pH units by the end of this century if CO_2 emissions continue at the current rate.

Triple trouble - multiple stressors

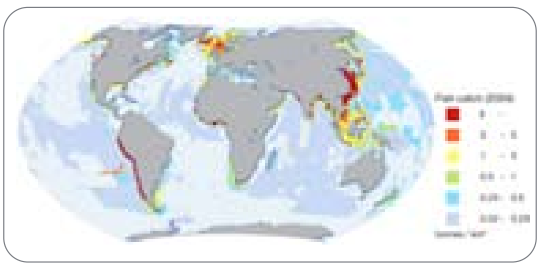


In the future many parts of the ocean are likely to experience more than one of these environmental stressors at the same time, since they are driven by the same underlying process – increases in atmospheric CO_2 and other greenhouse gases. These "hot spots" will not only be warmer, but are also likely to be more stratified, have increased acidity and contain less oxygen, increasing the stress on marine life in ways that may be more than the simple addition of each.

For example, ocean acidification can make species more susceptible to the impacts of warming waters, and higher CO_2 alongside lower oxygen levels can create respiratory difficulties. Acting together these stressors could more rapidly threaten biogeochemical cycles, ecosystems and the goods and services the ocean provides to society, thereby increasing the risk to human food security and industries depending on productive marine ecosystems. Furthermore, changes in the exchange of gases between the atmosphere and ocean will impact on climate change.



Nicolas Gruber, Phil. Trans. R. Soc. A (2011) 369, 1980-1996



UNEP 2010. UNEP Emerging Issues: Environmental Consequences of Ocean Acidification: a threat to food security

Importantly and worryingly, these "hot spots" of multiple stressors are likely to coincide with areas high in ocean productivity - and currently supporting significant fisheries and subsistence fisheries in developing countries (see maps).

Ocean warming

Over the last decades ocean warming has been a direct consequence of increasing atmospheric temperature due to the 'greenhouse effect'. This warming affects the exchange of gases between the ocean surface and the atmosphere, and their transport and storage in deeper waters. In a warmer ocean, there will also be less mixing between the nutrient-rich deep waters and the nutrient-poor surface ocean, particularly in tropical areas with detrimental consequences for ocean productivity, hence significantly diminishing food security from fisheries.

Ocean warming is also likely to have direct effects on the physiology of marine organisms and thereby alter the geographical distribution of species, including those of commercial importance, currently well-adapted to existing conditions; for example, temperature increase is almost certainly contributing to the decline of cod in the North Atlantic.

The heat content of the ocean is immense with ~90% of the energy from warming of the Earth system stored in the ocean over recent decades. There has already been a mean sea surface warming of about 0.7°C over the last 100 years, likely to increase by over 3°C in some ocean regions by the end of this century.

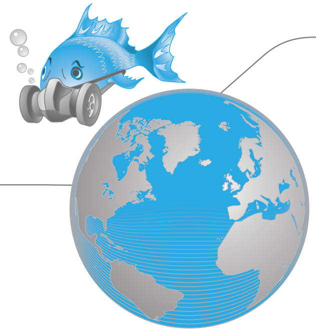
Steps ahead

Mitigation: As ocean acidification is mainly caused by CO_2, strong mitigation measures are required to reduce its emission. Atmospheric accumulation of other greenhouse gases should also be limited, as all of them contribute to ocean warming and hence deoxygenation.

Adaptation: Adaptation strategies need to be developed as the world is already committed to a substantial amount of additional warming, acidification and deoxygenation, even if atmospheric CO_2 could be stabilized at the current level. A key strategy is to ensure maximum potential for resilience in the system, e.g. by maintaining, or even increasing biodiversity and by conserving a diverse set of habitats. The reduction of other environmental stressors, such as coastal eutrophication and pollution by organic and inorganic substances will be helpful as well. However, given the unprecedented rate of change it is doubtful that adaptation measures alone, without mitigation, will be sufficient to avoid most of the harm.

Research: Research is required to improve our knowledge and understanding of these three connected stressors. For example, whilst ocean acidification has recently become a topic of high research priority, deoxygenation has not yet reached that level of recognition.

What is really missing is the joint perspective, where the combined effects of two or all three stressors acting at the same time are investigated. Already, detailed laboratory studies and field experiments from regional to global scale monitoring and modelling are beginning, through cross-disciplinary and international cooperative partnerships. Importantly, research capacity needs to be grown globally, particularly in vulnerable developing countries. In order to better understand the impacts on ecosystems and the consequences for every one of us, research will increasingly need to follow a multi-disciplinary approach across the physical, life, chemical, Earth, social and economic sciences. These studies need to be policy relevant, with a rapid exchange of knowledge between researchers and decision-makers.



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Ocean deoxygenation

Ocean deoxygenation is the reduction of dissolved oxygen (O_2) in seawater. Climate change can influence oxygen levels in the ocean in several ways. This is certain to occur in a warmer ocean since higher temperatures reduce oxygen solubility. Warming is also likely to create a more stratified ocean, decreasing the downward oxygen supply from the surface. Ocean acidification and nutrient run-off from streams and rivers can also contribute to deoxygenation.

Fish and many other marine organisms depend on sufficient levels of oxygen to function, and may therefore be stressed by declining oxygen concentrations. Extended zones of low oxygen may result in the exclusion of such organisms. However, other organisms tolerant of low oxygen, particularly microbes are likely to flourish, altering the balance of communities. Low oxygen levels in the ocean may also increase the amount of greenhouse gases in the atmosphere by changing feedback mechanisms involving methane and nitrous oxide.

Current ocean models project declines of 1 to 7% in the global ocean oxygen inventory over the next century. However, there are considerable uncertainties regarding the scale and location of oxygen changes, and their ecological impacts.

Ocean Stress Guide

What the ocean will experience this century without urgent and substantial reduction in greenhouse gas emissions.

Stressor	Causes	Result	Direct effects	Impacts	Feedback to climate
Warming ● A relatively mature study area in terms of physical changes and physiology but poorly studied at ecosystem and biogeochemical level	● Increasing greenhouse gas emissions to the atmosphere	● Temperature increase, particularly in near-surface waters ● Less ocean mixing due to increased stratification ● Increased run-off and sea-ice melt will also contribute to stratification in Arctic waters	● Decreased carbon dioxide solubility ● Increased speed of chemical and biological processes ● Reduced natural nutrient re-supply in more stratified waters	● Stress to organism physiology, including coral bleaching ● Extensive migration of species ● More rapid turnover of organic matter ● Nutrient stress for phytoplankton, particularly in warm waters ● **Changes to biodiversity, food webs and productivity, with potential consequences for fisheries, coastal protection and tourism**	● Reduced ocean uptake of carbon dioxide due to solubility effect ● Increased oxygen consumption, carbon dioxide production and decrease in oxygen transfer to the deep ocean ● Potential decrease in the export of carbon to the ocean's interior ● Decreasing primary production except in the Arctic where sea-ice loss may result in an increase
Acidification ● Developed as a research topic in past decade	● Increasing atmospheric carbon dioxide emissions ● Coastal nutrient enrichment, methane hydrates and acid gases from industrial emissions may also contribute locally	● Unprecedented rapid change to ocean carbonate chemistry ● Much of the ocean will become corrosive to shelled animals and corals, with effects starting in the Arctic by 2020	● Reduced calcification, growth and reproduction rates in many species ● Changes to the carbon and nitrogen composition of organic material	● Impeded shell or skeletal growth and physiological stress in many species, including juvenile stages ● Change to biodiversity and ecosystems, and the goods and services they provide ● **Cold and upwelling waters currently supporting key fisheries and aquaculture likely to be especially vulnerable**	● Reduced ocean uptake of carbon dioxide due to chemical effects ● Changes to the export of carbon to the ocean's interior ● Higher oxygen use throughout the water column due to changing composition of organic material
Deoxygenation ● Emerging issue, poorly studied	● Reduced oxygen solubility due to warming ● Decreased oxygen supply to the ocean interior due to less mixing ● Nutrient rich land run-off stimulating oxygen removal locally	● Less oxygen available for respiration especially in productive regions, and in the ocean interior ● Extended areas of low and very low oxygen	● Reduced growth and activity of zooplankton, fish and other oxygen-using organisms ● Endocrine disruption	● Stress to oxygen-using organisms ● Risk of species loss in low oxygen areas ● Impacts on reproductive success ● **Shift to low oxygen-tolerant organisms, especially microorganisms and loss of ecosystem services in these areas**	● Enhanced production of the two greenhouse gases methane and nitrous oxide
All three together ● Few studies	● Increasing greenhouse gas emissions, especially carbon dioxide, to the atmosphere	● More frequent occurrence of waters that will not only be warmer but also have higher acidity and less oxygen content	● Damage to organism physiology, energy balance, shell formation: e.g. coral reef degradation	● Ocean acidification can reduce organisms' thermal tolerance, increasing the impact of warming ● **Combined effects further increase risk to food security and industries depending on healthy and productive marine ecosystems**	● Major change to ocean physics, chemistry and ecosystems ● Risk of multiple positive feedbacks to atmosphere, increasing the rate of future climate change

Your awareness can make a difference

Following awareness raising concerning ocean acidification at the United Nations Framework Convention on Climate Change meetings (2009, 2010 and 2011) the international partnership as shown below is now highlighting its concern about the impacts of the multiple and interacting stressors of ocean warming, acidification and deoxygenation on ocean systems, which will occur in the coming decades in a high CO_2 world. This publication has received support from international organisations and programmes.

Please email **forinfo@pml.ac.uk** for any further details. **www.oceanunderstress.com.**

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PML Plymouth Marine Laboratory
OA-ICC
SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego
OCEANA Protecting the World's Oceans
EPOCA European Project on Ocean Acidification
BIOACID

Message supported by

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