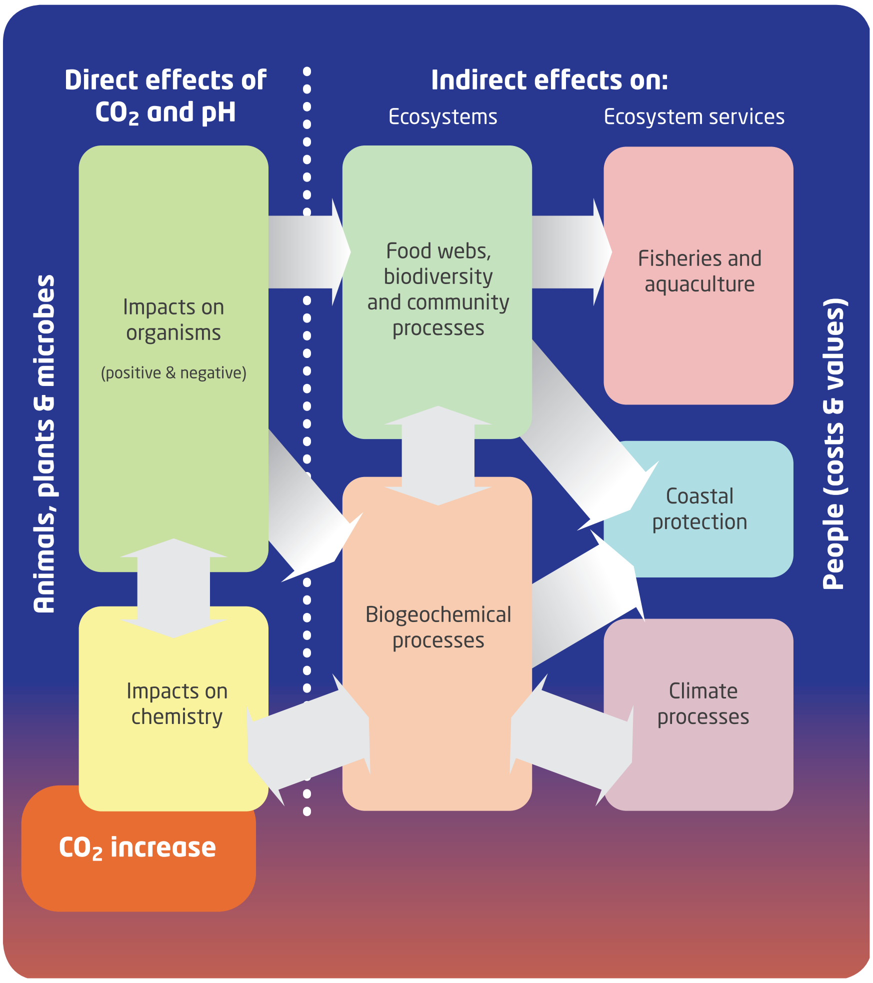
What has the UK Ocean Acidification research programme told us?

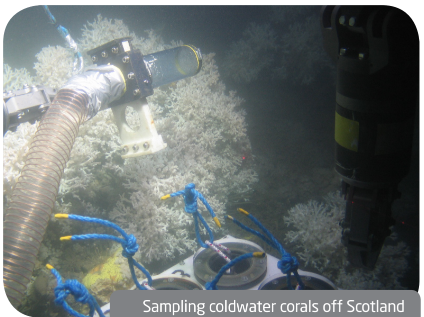
UK Ocean Acidification Research Programme

Ocean acidification - obtaining evidence

The global ocean currently absorbs more than a quarter of the carbon dioxide (CO_2) produced by burning fossil fuel and other human activities, slowing the rate of climate change. Global warming would therefore be far worse if it were not for the ocean. However, there is a cost: when CO_2 dissolves in seawater it forms carbonic acid, decreasing the pH and causing other chemical changes. These processes are known as ocean acidification.

The acidity (hydrogen ion concentration) of the surface ocean has already increased by nearly 30% due to these processes, mostly in the past 50 years. The implications of increasing atmospheric CO_2 for ocean chemistry, marine life and human society have only recently been recognised and investigated: more than 75% of the total scientific literature (more than 3000 articles) on ocean acidification has been published in the past 5 years. There is still much more to learn about ocean acidification, and its interactions with other marine stressors. Nevertheless, it now seems likely that worst-case scenarios can be avoided, under commitments made to reduce emissions of greenhouse gases, including CO_2, under the 2015 Paris Agreement.





Sampling coldwater corals off Scotland
Image: Murray Roberts/Changing Oceans

The UK response to the ocean acidification challenge

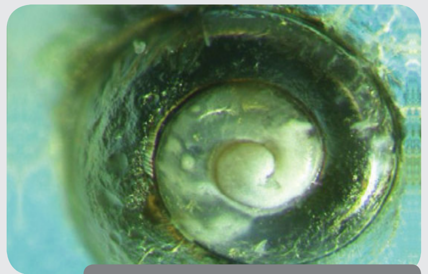
Widespread concern about ocean acidification emerged after the Royal Society report *Ocean acidification due to increasing atmospheric carbon dioxide* in 2005. A range of research initiatives were subsequently developed at both the national and international level.

The £12m, five year UK Ocean Acidification research programme (UKOA) was the UK's response, starting in 2010 and jointly funded by the Natural Environment Research Council (NERC), the Department for Environment, Food and Rural Affairs (Defra) and the Department of Energy and Climate Change (DECC, now part of the Department for Business, Energy & Industrial Strategy, BEIS).

The overall aims of UKOA were to increase understanding of processes, reduce uncertainties in estimating future impacts, and improve policy advice. Scientific studies have included observations and surveys; impacts on upper-ocean biogeochemistry; responses by seafloor organisms; effects on commercially-important species, foodwebs and human society; ocean acidification in the geological past; and regional and global modelling. As might be expected, early ideas have been modified and new avenues of research have been identified. There have also been some surprising revelations from the UKOA research.

Polar food webs at risk

Pteropods, small marine swimming snails ('sea butterflies') seem especially vulnerable to ocean acidification. Thus their aragonite shells are at risk of dissolving in cold, low pH water that is also low in carbonate. As ocean acidification progresses, aragonite undersaturation is an increasing feature in polar seas and upwelling areas, and evidence of shell damage has been found during UKOA research cruises. Since pteropods are a crucial part of food webs in many areas of the ocean, major reductions in their numbers and distributions would therefore have wider consequences for food webs, potentially affecting higher predators (fish, seabirds and sea mammals) of high commercial, ecological or conservation value. Pteropods are not just important in food chains, they also are significant in global biogeochemistry. It had been thought that the contribution they made to the downward flux of calcium carbonate from the upper ocean was around 10%-20% but it is now estimated they could account for as much as 95% of the global total.



Pteropod shell showing signs of dissolution
Image: Geraint Tarling (BAS)

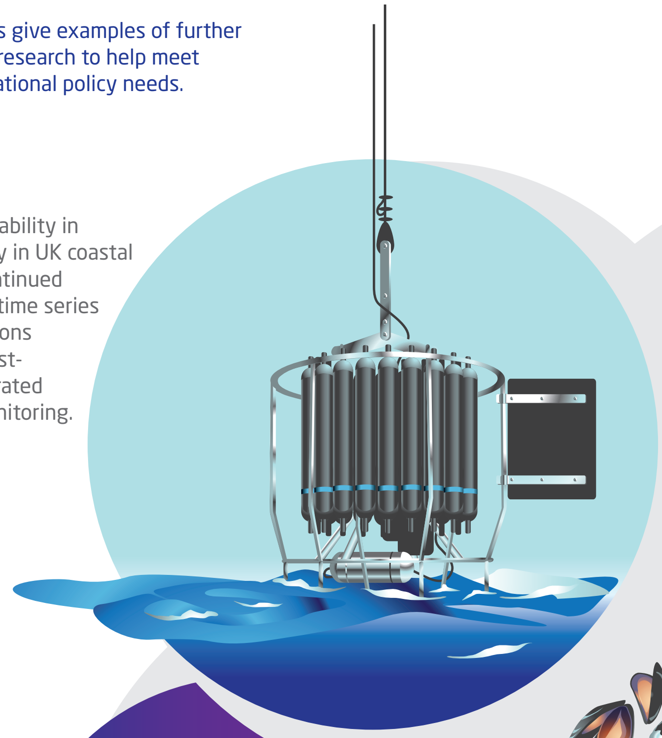
Food security

Low pH waters are already having economic implications for aquaculture in the northwest USA. For the UK, consequences for commercially-exploited shellfish and finfish - and for marine food security more generally - are less direct, and seem less severe. The good news from UKOA studies on herring and seabass (with focus on their larvae) is that those two species seem tolerant of ocean acidification. Nevertheless, there is no room for complacency, for several reasons. Firstly, the wider scientific literature shows that, for other finfish, sensitivity to ocean acidification seems much more common than tolerance, with ~75% of species negatively affected at CO_2 levels up to 850 ppm; second, tolerance may depend on the availability of high quality food (likely to be the case in experiments, less certain under natural conditions); third, fish behaviour can be altered by low pH, but such effects are difficult to assess and their wider implications are uncertain; and finally, insufficient is known about the natural range of pH conditions currently experienced (that may already exceed 850 ppm CO_2 for demersal fish at some sites). Models estimating the ecosystem - and food security - consequences of ocean acidification have been developed by UKOA and others, yet are considered to be preliminary, because of these many complexities.

What next?

Emerging issues for ocean acidification research

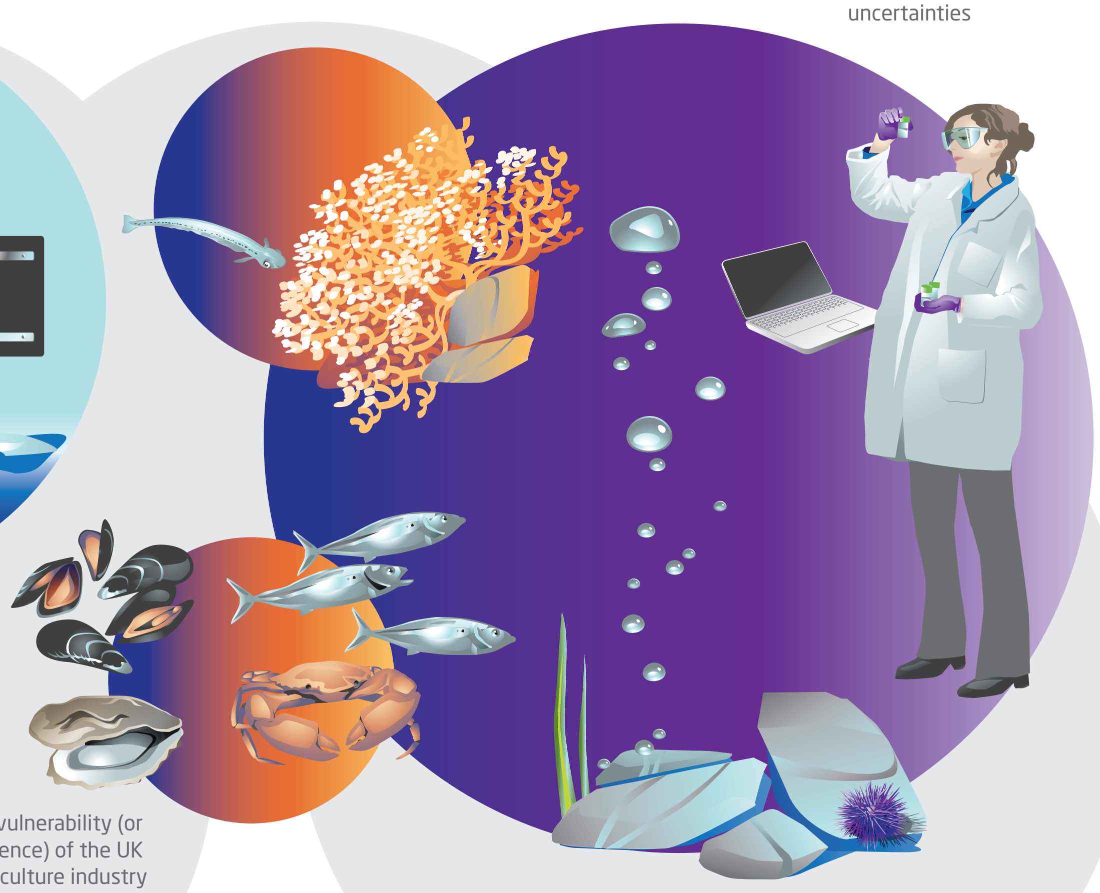
The following topics give examples of further ocean acidification research to help meet national and international policy needs.



Investigate the variability in carbonate chemistry in UK coastal waters, through continued ocean acidification time series and other observations in the context of cost-effective and integrated biogeochemical monitoring.

Use free-ocean CO_2 enrichment (FOCE) techniques for in situ experiments, e.g. on cold-water corals, with the option for raising, as well as lowering, pH (i.e. restoring water quality to a more pristine state) and separately manipulating pH and carbonate saturation state.

Focus modelling effort on up-scaling and whole-system impacts, using that approach to identify further knowledge gaps and uncertainties

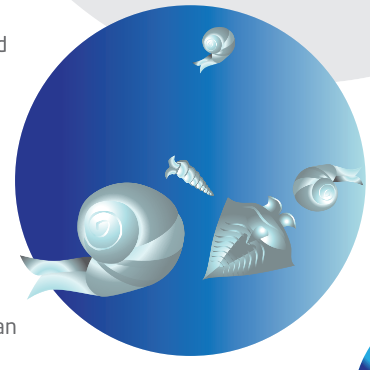


The vulnerability (or resilience) of the UK aquaculture industry to future ocean acidification needs to be better assessed.

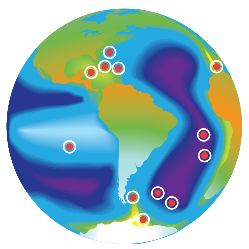
Impacts, negative or positive, of large-scale removal of carbon dioxide from the atmosphere ("negative emissions"), eg enhanced weathering, need to be investigated for ocean acidification.

The potential for genetic adaptation to ocean acidification (and its possible regional variability) needs to be much better known.

Multi-stressor interactions need further attention. Not just with temperature, but also interactions with toxic metals (such as copper), oxygen and food supply.



What are the ocean acidification risks for the 14 British Overseas Territories, from polar to tropical regions, and their highly biodiverse Marine Protected Areas?



Uncertainties regarding the sensitivity of pteropods to ocean acidification in polar seas and upwelling areas need to be resolved, to assess their suitability for monitoring (as indicator species).

Improve estimates of scenario-based socio-economic impacts of ocean acidification for different regions and for different scales, linking to policy actions that mitigate its causes.

What can 'natural laboratories' tell us?

Marine CO_2 vents and seeps - where CO_2 bubbles out from the seafloor - provide natural laboratories for studying ocean acidification. At Vulcano, off the Sicilian coast, UKOA researchers, working with colleagues from other projects, directly observed that biodiversity decreases as the higher CO_2 water from the vent is approached. Furthermore, the adult shells of two species of dog whelk were about a third smaller closer to the seeps than those in normal environments. This dwarfism, the 'Lilliput Effect', is a genetic change brought about by metabolic adaptation to high CO_2/ low pH conditions, rather than a response to short-term conditions such as food availability. Linking back to the past, fossil records demonstrate that calcified organisms that survived marine mass extinctions, likely involving OA, have also been smaller than those occurring previously. Looking to the future, the possibility of smaller-sized shellfish could have wider ecological as well as economic consequences.

Coldwater corals at risk

Marine organisms that grow a calcium carbonate shell, exoskeleton or other supporting and protective structures (calcifiers) appear to be most sensitive to ocean acidification. In most cases, the effect on calcification seems to be due to low pH rather than low levels of available carbonate ions. However, when carbonate levels are below saturation values, unprotected calcium carbonate structures dissolve. Such reef-like structures formed from the dead coral skeletons are themselves home for myriad other marine organisms. Weakened structural strength can lead to physical damage and threaten the survival of these valuable habitats. The effect is greatest at low temperatures, which is why there are few calcifiers in the deep ocean: in the North Atlantic, few coldwater corals occur at depths greater than 1000m or so, and their depth limit is much shallower in the North Pacific.

UKOA research and other studies show that this lower depth limit is moving upwards as atmospheric CO_2 increases, so impacts seem inevitable. In the longest-ever simulation of high CO_2 conditions and their effects on the coldwater coral *Lophelia pertusa* (a reef-former found off the coast of Scotland, and elsewhere in UK and European seas), UKOA scientists found that future ocean acidification could change the shape of coral skeletons, and make them 20-30% weaker. That effect could cause reef disintegration, depriving their rich biodiversity of suitable habitat. Inhabitants of the reefs include young fish which are likely to be of high ecological and potentially economic importance. Since the current distributions of such corals is largely unknown, and their study is difficult, any decline in reef habitat is unlikely to be well-monitored.

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Laboratory studies: insights and limitations

UKOA improved on previous short-term, single stressor studies that did not necessarily allow for organisms to get used to manipulated changes in experimental conditions. Most UKOA experiments were therefore carried out over months, rather than days or weeks, using different combinations of temperature and pH treatments. Many important insights were gained; it also become clear that a range of other interactions could affect the response to ocean acidification. Such factors include food/nutrient supply, light intensity (for marine plants and algae), metal pollution, oxygen levels, genetic adaptation and interactions between species: they reflect the variability and complexity of natural systems, whilst greatly complicating the concept of experimental 'control' conditions. It also became clear that different organisms, and/or different life stages, can respond to different components of changes in carbonate chemistry.

Sediment cores showing a natural ocean acidification event 56 million years ago
Image: James Zachos/UC Santa Cruz

What can we learn from the past?

Geological changes in climatic conditions have also involved ocean acidification, and therefore might provide analogues for current and future events. There have been at least eight natural ocean acidification events over the last 450 million years and most involved mass extinctions of corals and other seafloor organisms that use calcium carbonate in their shells and skeletons. Whilst some of these events were caused by meteorite impacts, one of the best-studied events, the Paleocene-Eocene Thermal Maximum (PETM), around 56 million years ago, is considered to be the result of volcanic activity. That release took place over several thousand years, relatively rapid in geological terms! The current rate of ocean acidification is around 10 times more rapid. And it is thought that It will take tens of thousands of years for the ocean carbonate chemistry to recover, while the evolution of new species to replace any that are lost is likely to be on a timescale of millions of years.

Communicating ocean acidification information to policy formers is crucial
Image: Philip Williamson

International collaboration to face a global challenge

The UKOA research programme followed a partnership approach from the beginning, with UK scientists from a wide range of disciplines working closely together; international collaborations also became a feature. Through the UKOA programme, the UK has been a driving force in the instigation of the Global Ocean Acidification Observing Network (GOA-ON) and the Ocean Acidification International Coordination Centre (OA-ICC) and its Ocean Acidification international Reference User group (OAiRUG). Dissemination of scientific results and key points for policy and other stakeholders is greatly enhanced by such links through shared press and media coverage, multi-lingual publication of non-technical summaries and the production and distribution of other media such as DVDs. In addition to national policy liaison, UKOA has played a major role in science-to-policy at the international level and made significant contributions to the work of the Intergovernmental Panel on Climate Change (IPCC), the UN Framework Convention on Climate Change (UNFCCC), the UN Convention on Biological Diversity (CBD), the Intergovernmental Oceanographic Commission (IOC-UNESCO), the RIO+20 Conference on Sustainable Development (including input into drafting the Sustainable Development Goals, SDGs, and many other governmental and non-governmental initiatives and activities.

Meeting the next generation at COP 22
Image:Philip Williamson

Making a difference

UKOA has played a key role throughout the programme's duration in bringing the phenomenon of ocean acidification to the attention of fellow scientists, policy makers and industry, through presentations, publications, and participation in international meetings and conferences. Attendance at Conferences of the Parties (COPs) of the UN Framework Convention on Climate Change (UNFCCC) since 2009 has had a direct result at high level. Awareness of the ocean has been raised in what had been terrestrially-oriented discussions, and the potential impacts of ocean acidification as a phenomenon related to climate change through the common cause of increased CO_2 emissions have been highlighted. Particular effort was made at the last two climate change conferences in Paris (COP 21 in 2015) and Marrakesh (COP22 in 2016). UKOA scientists manned exhibition booths on ocean stressors, engaged delegates, and both organized and participated in side events to help bring the plight of the ocean to the attention of government delegates, other conference participants, the media and the general public.

To date more than 250 scientific publications have been generated by the UKOA programme and many topics have been included in more accessible publications for stakeholders, including the wider public (http://www.oceanacidification.org.uk/About_Us/Publications_and_outputs). UKOA enjoyed close relationships with international, national and local broadcast media and press, which picked up on many topics, enhancing the programme's reach and ensuring widespread dissemination of key messages. A particular 'highlight' product has been the *Hot, Sour and Breathless* publication which has been translated into 6 languages and distributed to many thousands of people, worldwide. Six synopses of the programme have been produced, each dealing with one of the main programme components. (Non-technical summaries, films and animations can be accessed at www.oceanunderstress.com).

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Department for Environment Food & Rural Affairs

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