Ocean Acidification THE FACTS

A special introductory guide for policy advisers and decision makers

There is a clear consensus from the many scientific statements that are now being made about ocean acidification, that rapid, unprecedented changes are occurring.

This introductory guide is written especially for policy advisers and decision makers worldwide and is a wake-up call about the double impact on our seas of climate change and ocean acidification caused by increasing atmospheric carbon dioxide levels. It sets out the basic facts about the alarming and progressive acidification of the ocean that is threatening our marine ecosystems. The Earth's geological record shows that previous episodes of ocean acidification were linked to mass extinctions of some species, and it is reasonable to assume that this episode could have the same consequences. There can be little doubt that the ocean is undergoing dramatic changes that will impact many human lives now and in the coming generations, unless we act quickly and decisively.

EPOCA
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COOPERATION

FAST FACTS...

- Currently, each year the ocean absorbs approximately 25% of all the carbon dioxide (CO_2) we emit.
- This hidden ocean 'service' has been estimated to represent an annual subsidy to the global economy of US\$60 – US\$400 billion per year.[1]
- The increasing volume and rate of our CO_2 emissions is progressively impacting the ocean system, causing the acidity of sea water to increase – this phenomenon is termed 'ocean acidification'.
- Ocean acidity has increased by 30% since the beginning of the Industrial Revolution and the rate of acidification will accelerate in the coming decades. This rate of change, to the best of our knowledge, is many times faster than anything previously experienced over the last 55 million years.
- Numerous animals and plants in the sea have calcium carbonate skeletons or shells. Some are especially sensitive to small changes in acidity and there is some evidence they are already being affected. Many of these sensitive species are directly or indirectly of great cultural, economic, or biological importance as primary producers, reef builders, etc.
- The impact of ocean acidification on marine species and food webs will affect major economic interests and could increasingly put at risk food security, particularly in regions especially dependent on seafood protein.
- Valuable ecosystems may be damaged or destroyed by ocean acidification – it is predicted that if atmospheric CO_2 levels continue to rise as expected, by 2050 conditions for warm water coral reefs will be marginal and we can expect extinctions of some species. By 2100 70% of cold water corals may be exposed to corrosive waters.
- The impact of ocean acidification on coral reefs will compromise community security in low-lying areas that are protected from erosion and inundation by these ecosystems.
- Aggressive and immediate cuts in CO_2 emissions leading to stabilization and ideally reductions in atmospheric CO_2 levels will be necessary to slow the progression of ocean acidification, as well as global climate change.

1 This assumes a theoretical replacement cost based on sequestration of 2Gt C/yr at an expected future carbon credit price of \$30 – \$200/t CO_2.

The simple facts – what you *really* need to know about ocean acidification...

What is ocean acidification?

The ocean absorbs around 25% of atmospheric CO_2 derived from burning fossil fuels and land use changes, and this CO_2 dissolves in sea water to form carbonic acid. As we have emitted more and more CO_2 into the atmosphere the ocean has absorbed greater amounts at increasingly rapid rates. This is altering the system's ability to adjust to changes in CO_2 that naturally occur over the millennia, significantly changing the chemistry of the seas, and leading to progressive acidification.

Since the beginning of the Industrial Revolution 250 years ago, sea water acidity has increased by 30%. It should be noted that increasing sea water acidity lowers the ocean's natural 'basic' or 'alkaline' status and unnaturally forces the acid-base balance of sea water towards acid. If this accelerates for the next four decades as forecasted, the consequential increase in ocean acidity will be greater than anything experienced in the past 21 million years. Future projections show that by 2060, seawater acidity could have increased by 120%. To the best of our knowledge, the current rate of change is many times faster than anything previously experienced in the last 55 million years.

Why is it important?

Many of the animals and plants in the ocean have calcium carbonate skeletons or shells. Some of them such as the microscopic plankton at the base of the food chain, the shellfish and molluscs used day to day in our diets, and even encrusting plants that cement the coral reefs together, secrete a form of calcium carbonate (aragonite) that will readily dissolve should the seas continue to become more acidic. A trend towards more acidic conditions will therefore reduce such species' ability to make their shells. We have taken such plants and animals for granted up to now, but ocean acidification may threaten their very existence.

The ocean not only provides us with food but it indirectly supports us in many other ways; the air we breathe largely depends on a healthy ocean for its production of oxygen, and the productive surface layers of the seas stimulate clouds that help to shade the planet. The ocean provides about half of the Earth's productivity and humankind takes direct advantage of this through our fisheries and shellfisheries. Ocean acidification is taking us along an uncharted voyage and we only have a few hints about how many of these essential processes will be impacted.

The calcifying microalgae *Calcidiscus leptoporus* – these tiny cells each about 0.01mm diameter represent a key component at the base of the marine food web. Inset: *Calcidiscus leptoporus* after experimental exposure to CO_2 levels of 700 ppm as projected for the year 2100.

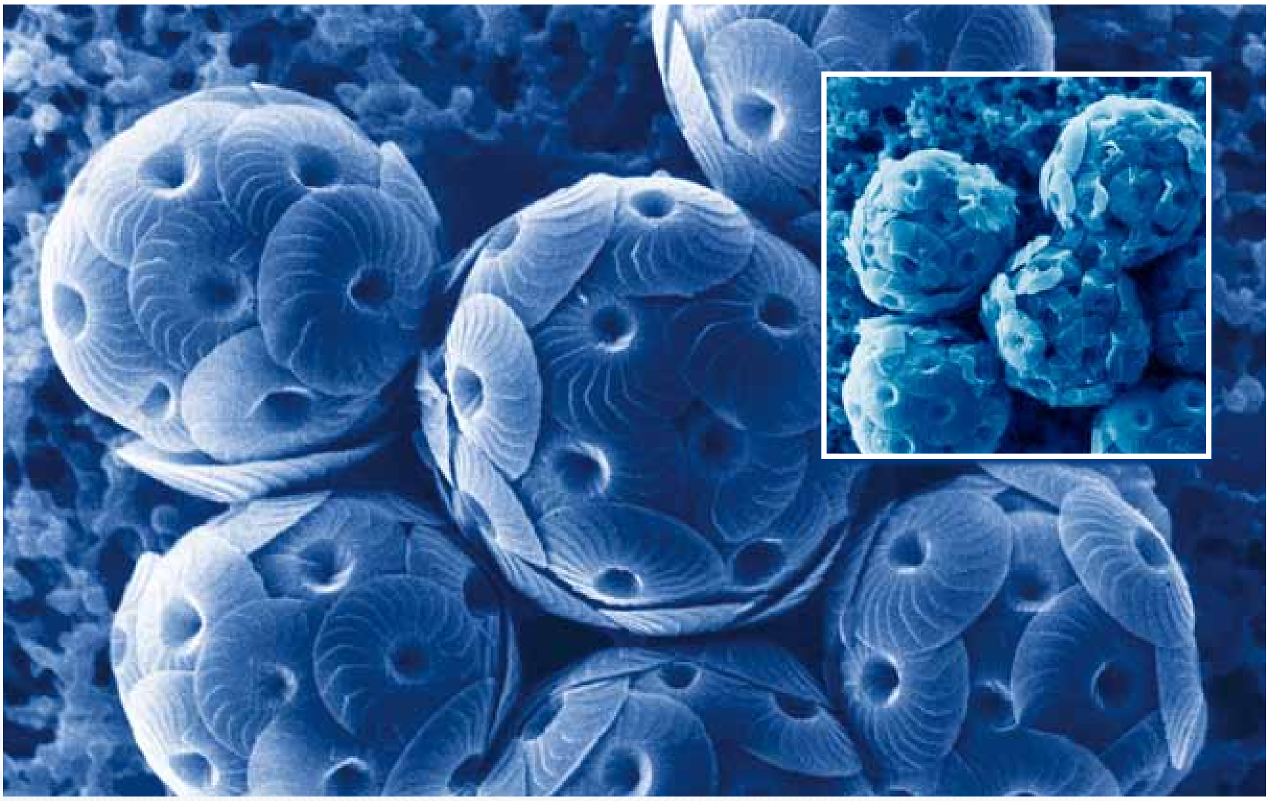


Photo © Ulf Riebesell, IFM-GEOMAR

Economic impacts?

Deep water in the ocean is naturally more acidic than that closer to the sea surface. One of the impacts of the combined effects of strong upwelling and acidification along the Northern American west coast is that these processes can accelerate the movement of corrosive 'acidified' water onto the continental shelf, potentially impacting shallower marine habitats and species closer to the coast.

In 2007, on the west coast of the United States, these naturally more acidic waters were found to be swept into coastal waters, which could pose risks to shellfish-dependent areas along this western coastline.

Alongside this discovery, and since 2005, there has been progressive decline in the $111 million/annum oyster industry in the US Pacific North-west region as year-after-year oyster larvae have failed to survive. Now, as the oyster industry heads into the fifth summer of its greatest crisis in decades, scientists are pondering a disturbing theory. They suspect that the naturally acidic sea water that rises from deep in the Pacific Ocean is now getting pumped into seaside hatcheries – and it may be corrosive enough to kill oyster larvae.

Molluscs alone accounted for $748 million (19%) of 2007 US domestic ex-vessel revenues. Fishery losses due to ocean acidification would drive job losses in affiliated industries through economic linkages that are currently difficult to quantify. It is clear, however, that secondary economic losses following decreased fishery harvests would be concentrated in specific regions, many of which have less economic resilience for enduring losses of fishing revenues.

Ref: http://oceanacidification.wordpress.com/2009/06/15/oysters-in-deep-trouble/

http://www.iop.org/EJ/abstract/1748-9326/4/2/024007/

Photo © Dan Laffoley

What is happening now?

Over the last 250 years there has been a steady trend of increasing acidity in the surface waters of the ocean. Ocean acidification is not a theoretical marine chemistry issue. The trend towards more acidic ocean conditions is already being measured in the open ocean, and this has been recorded with increasing accuracy in recent years. Ocean waters in high latitude regions are where the largest relative changes towards more acidic conditions are predicted to occur over the next two or three decades. Also the acidity of naturally upwelling deep water in some areas is exacerbated by ocean acidification, so that upwelling corrosive water now affects shallower marine habitats and species closer to the coast.

What could happen in the future?

Ocean acidification is not only progressively decreasing the ability of many organisms to build their shells, but will also progressively affect ecosystems' structure and function. Ocean acidification could trigger a chain reaction of impacts through the marine food web, beginning with larval fish and shellfish, which are particularly vulnerable. This will affect the multibillion-dollar fishing industry and threaten the food security of many of the world's poorest. Most regions of the ocean will become inhospitable to coral reefs thus affecting food security, tourism, shoreline protection and biodiversity.

As acidity and sea temperature increase, the ocean's ability to absorb atmospheric CO_2 will be reduced, thus exacerbating the rate of climate change. The rate at which the acidification of the ocean occurs

The cold water coral *Lophelia pertusa* with a shrimp living in its branches.

Photo © Armin Form, IFM-GEOMAR

depends on the speed at which we emit CO_2 to the atmosphere. The deeper and sooner the cuts are, the more likely it is that the situation can be stabilized and ultimately reversed. But some changes are inevitable, and impacts will be felt earliest in the Arctic Ocean and the Southern Ocean, where the measured and predicted changes in ocean chemistry, relative to pre-industrial conditions, will be largest.

How is ocean acidification different from climate change?

Climate change is the consequence of a suite of greenhouse gases causing the Earth to absorb more of the sun's energy, whereas ocean acidification is caused solely by increased levels of atmospheric CO_2 dissolving into the ocean. Whilst there remains a degree of uncertainty about the impacts that will arise as a result of climate change, the chemical changes that are occurring in the ocean are certain and predictable. The process of CO_2 dissolving in sea water to form carbonic acid is largely independent of climate change, although increasing sea water temperature reduces the solubility of CO_2. Reducing the concentrations of other greenhouse gases will have no effect on ocean acidification.

Mitigating ocean acidification may require targets which differ from climate-mitigation targets, as effects may occur at different thresholds than in the atmosphere. Similarly geo-engineering proposals to alter the atmosphere's radiation budget, making it more reflective by putting sulphate particles into the upper atmosphere, will have no impact on atmospheric CO_2 levels and will not help to aleviate ocean acidification.

What can we do about it?

Now is the time to act on ocean acidification and the target for action must be to reduce the rapid increase in atmospheric CO_2 and limit future levels. Ocean acidification will be incremental. Today the impacts remain relatively minor, but the rate of change is accelerating. Furthermore, there is a lag between CO_2 emissions and an equilibrium state – assuming we manage to reduce rather than (implausibly) halt CO_2 emissions, acidity in the ocean will increase for some years. This property of the system puts a premium on early emissions cuts and a penalty on delaying making significant cuts in emissions. So whilst both acidification and climate change will impact all our lives, the former adds considerable weight to the argument to make immediate and significant cuts in CO_2 emissions.

Turning up the volume?

A future more acidic ocean might be a noisier place for marine mammals such as whales and dolphins. Ocean chemists have known for decades that the absorption of sound in sea water changes with the chemistry of the water itself. As sound moves through sea water, it causes groups of atoms to vibrate, absorbing sounds at specific frequencies. This involves a variety of chemical interactions that are not completely understood. However, the overall effect is strongly controlled by the acidity of the sea water: the more acidic the sea water, the less low and mid-frequency sound it absorbs.

Thus, as the oceans become more acidic, sounds will travel farther underwater, apparently particularly sounds below about 3,000 cycles per second (two and one half octaves above "middle C" on a piano). This range of sounds includes most of the "low frequency" sounds used by marine mammals in finding food and mates. It also includes many of the underwater sounds generated by industrial and military activity, as well as by boats and ships. Such human-generated underwater noise has increased dramatically over the last 50 years, as human activities in the ocean have increased.

Research suggests that sound already may be travelling 10% farther in the ocean than it did a few hundred years ago. However, it is predicted that

Photo © Reinhard Dirscherl/FLPA

by 2050, under conservative projections of ocean acidification, sounds could travel as much as 70% farther in some ocean areas (particularly in the Atlantic Ocean). This could dramatically improve the ability of marine mammals to communicate over long distances. It could also increase the amount of background noise that they have to live with.

Ref: Hester, K.C., E. T. Peltzer, W. J. Kirkwood, and P. G. Brewer (2008). Unanticipated consequences of ocean acidification: A noisier ocean at lower pH. *Geophysical Research Letters*, 35L19601. DOI:10.1029/2008GL034913

See also http://www.mbari.org/news/news_releases/2008/co2-sound/co2-sound-release.html

Broader ocean impacts?

The impacts of ocean acidification may have much deeper consequences for ocean life beyond affecting the ability of species to build calcium carbonate shells, or the survivorship of sensitive young larval stages of some species.

We are only at the very start of thinking about some of the consequences of these more complex impacts on ocean chemistry. A major area of interest is biologically important nutrients such as nitrogen, phosphates, silica and iron which often limit plankton growth in large parts of the ocean. As conditions become more acidic this could, at least in theory, reduce their availability. Altered availability may also result from changes in stratification due to ocean warming from climate change. This may in turn affect primary production. It is possible that the primary producers that power marine food chains may have different responses to these changing conditions, possibly altering or influencing food chains that are dependent on them.

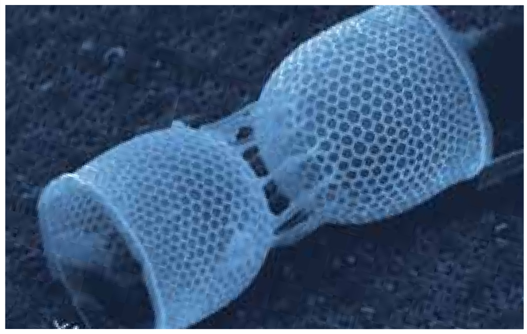


Photo © Marcus Shirley/Plymouth Culture Collection

Significant research and results will be needed before we have more confidence about how ocean chemistry will change in the future, and what this may mean for marine ecosystems, species and the benefits we derive from this global environment.

Ref: Turley, C.M. and H. A. Findlay (2009). Ocean acidification as an indicator for climate change. In: *Climate and Global Change: observed impacts on Planet Earth* (ed. T. M. Letcher), Elsevier, Oxford, U.K.

Ocean acidification must be recognized for what it is: a global challenge of unprecedented scale and importance that requires immediate action to halt the trend of increasing acidification. There are no practical solutions to remediate ocean acidification once it has occurred and we may have to rely on nature to take its course. This will inevitably be a long-term recovery process that could take upwards of 10,000s of years for the ocean to be restored to its carbonate equilibrium, with biological recovery taking perhaps even longer. This can only be done through a real, sustained and substantial reduction in emissions to stabilize atmospheric CO_2 levels, through cuts in what we emit and by technology that actively removes CO_2.

In support of global action on emissions there is also a range of regional and local measures that should be undertaken to sustain and recover ocean health, so we are in the best position possible to ride out some of the changes that ocean acidification will bring. The severity of ocean acidification impacts is likely to depend, in part, on the interaction of acidification with other environmental stresses, such as rising ocean temperatures, over-fishing and land-based sources of pollution. We need to identify any regions of the ocean that seem most resilient to acidification. We need to ensure through good management and protection that the resilience of such areas is maintained or restored to create future refuges. For broad areas of the ocean we similarly need to look at ways to increase the resilience of ecosystems to withstand the pressures that ocean acidification will impose, so they have the ability to resist change and to recover quickly.

Photo © Keith Hiscock/SNH/JNCC

The weakest links?

The world's best but least known recycling system is the ocean. Unseen, tide after tide, and year after year, a multitude of species living hidden in the sea bed ensure that nutrients vital to life are released back to the water to support the plankton that drive ocean productivity and life in the sea. These hidden 'recycling' species are bacteria aided in their work by molluscs, worms, burrowing shrimps and various sea urchins and starfish.

Research is underway but it seems that ocean acidification might weaken the links in marine systems. One of the organisms that helps the recycling process is the brittle star, which lives on or in the sea bed, waving its arms into the water currents to pluck food as it passes by. Acidification may affect this species in several ways. When larvae are exposed to only slightly more acidic sea water it appears that mass mortality may occur in some species of brittle star. When adults are exposed to only slightly more acidic sea water the brittle star seems to have to work harder to make its spiny calcium carbonate skeleton, and as a result it has less energy available to produce muscles in its eight arms – in effect muscle wastage seems to occur.

Ref: http://oceanacidification.wordpress.com/2008/12/24/near-future-level-of-co2-driven-ocean-acidification-radically-affects-larval-survival-and-development-in-the-brittlestar-ophiothrix-fragilis/

http://rspb.royalsocietypublishing.org/content/275/1644/1767.abstract

A global problem – our changing ocean world...

Photo © Russ Hopcroft/UAF

Hit high, hit hard

The cold polar oceans are amongst the most productive on the planet. Towards the base of the food chain are multitudes of small free swimming snails called *pteropods* that use their modified foot to swim their way through the ocean waters. All life is ultimately dependent on such microscopic plants and animals, as larger animals that we are more familiar with feed on smaller, less well-known species.

Because cold water can absorb more CO_2 than warm water the polar regions are being hit hardest and earliest by ocean acidification. Increasing acidification can now be measured throughout the waters of these regions and biological responses are already detectable (Moy *et al*., 2009). Pteropods and other planktonic calcifiers may be particularly susceptible to increases in acidity. In experiments their shells, which protect them from small predators and acts as a ballast for daily vertical migrations grew more slowly in more acidic water (Comeau *et al*., 2009) and seem to be readily damaged by pitting, peeling and partial dissolution when placed into acidified sea water (Orr *et al*., 2005). The scale of the impact of ocean acidification on these mainstays of life in our cold ocean water is unknown, but is maybe considerable and magnified as such changes ripple up through food chains in these most sensitive of ecosystems.

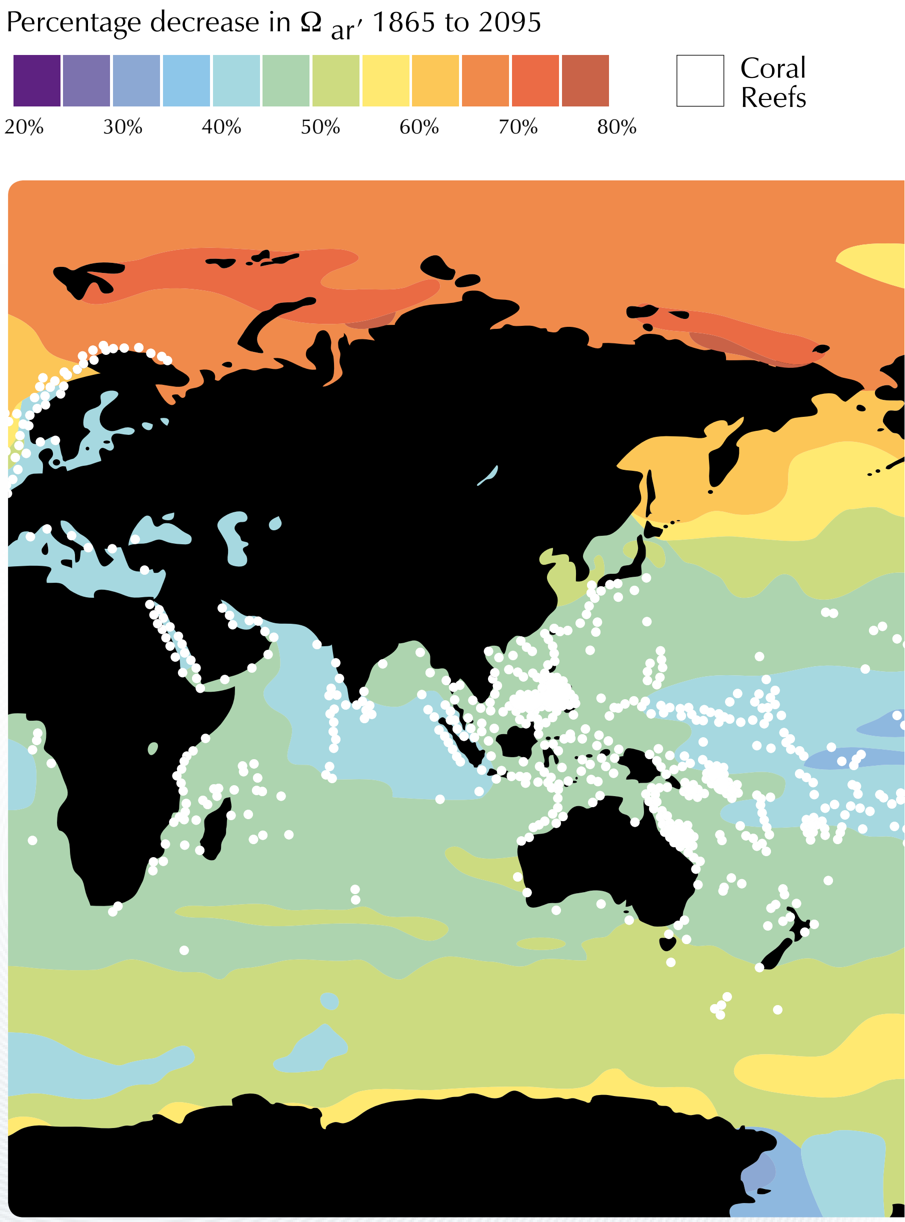
Ref: Comeau, S., G. Gorsky, R. Jeffree, J. L. Teyssié and J.-P. Gattuso (2009). Impact of ocean acidification on a key Arctic pelagic mollusc (*Limacina helicina*). *Biogeosciences*, 6, 1877-1882

Moy, A.D., W.R. Howard, S.G. Bray and T.W. Trull (2009). The reduced calcification in modern Southern Ocean planktonic foraminifera. *Nature Geoscience*, 2,276-280. DOI: 10.1038/ngeo460

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, *et al*. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature*, 437 (7059), 681-686

As our emissions continue, so we continue to impact the system the ocean uses to absorb the increasing amounts of atmospheric CO_2. Due to the complexities of the ocean and its chemistry the consequences will not be simple. The impacts of ocean acidification will vary in intensity and timing, with polar regions undergoing the greatest relative changes first. The impacts of ocean acidification will also act in combination with other effects from climate change and how we have used and abused the seas in the past in ways that have lowered their resistance and resilience to change. The resulting effects *will* be felt throughout the ocean – the blue heart of the planet covering over 70% of the Earth's surface.

This map shows the percentage decrease in aragonite saturation from 1865 to 2095 in a business-as-usual CO_2 emission scenario. The largest relative changes are in the high northern and southern latitudes where the waters are coldest and absorb more CO_2 from the atmosphere.



Nemo – lost at sea?!

We seldom realize that the very character of our ocean is shaped by the ability of juveniles of species cast away on the ocean currents to find their way back to habitats occupied by their species – suitable habitats to call home!

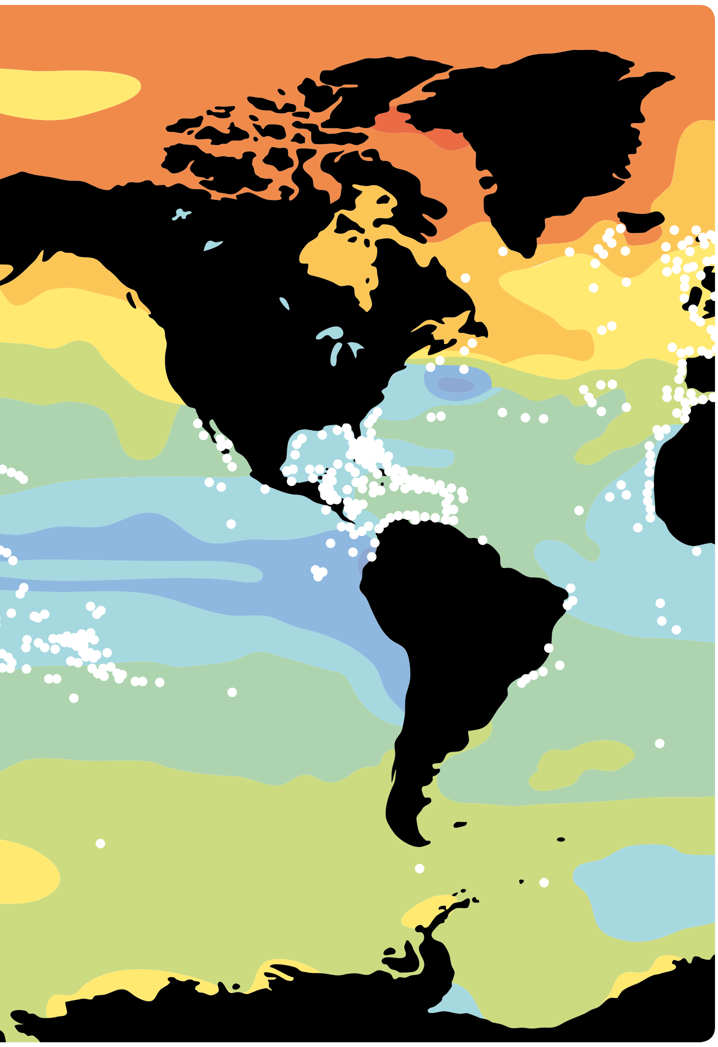
The juveniles of many species do this by detecting chemicals in the sea water ('olfactory cues') from where adults of the species live. For example, the clownfish, known to many moviegoers as Nemo, finds its way home to its favourite sea anemone by sensing these olfactory cues. These senses may be detrimentally affected as the acidity of the sea water increases, resulting in confusion and even organisms being attracted to things that they had previously avoided. Experiments at more extreme levels of seawater acidification show that the olfactory cues are lost completely.

Ref: http://www.pnas.org/content/106/6/1848

Munday, P.L., D.L. Dixson, J.M. Donelson, G.P. Jones, M.S.Pratchett, G.V. Devitsina and K.B. Døving (2009). Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. *Proceedings of the National Academy of Sciences*, 106(6), 1848-1852 doi:10.1073/pnas.0809996106

Photo © Dan Laffoley

Photo © Dan Laffoley/IUCN



Paradise lost?

Coral reefs are the most biologically diverse habitats on Earth and provide food, resources and coastal protection to hundreds of millions of people. They are under significant and sustained threat from climate change, leading to ocean temperatures higher than those which corals can survive (causing coral bleaching), coupled with the increasing ocean acidification. Great Barrier Reef corals have aleady reduced their calcification rates, probably in response to a combination of acidification and warming impacts (De'Ath *et al.*, 2009).

Corals have populated the world's tropical oceans for over 200 million years. It is expected that if atmospheric CO_2 levels continue to rise as predicted, by 2050 conditions for warm water coral reefs will be marginal (e.g. Hoegh-Guldberg *et al.*, 2007). We can expect extinctions of some species. By 2100 70% of cold water corals could be exposed to corrosive waters (Guinotte *et al.*, 2006) which may disrupt these important ecosystems.

Ref: http://www.zsl.org/science/news/coral-reefs-exposed-to-imminent-destruction-from-climate-change,605,NS.html

http://www.wwnorton.com/cgi-bin/ceilidh.exe/pob/forum/?C350e5a913KHc-7127-411-90.htm

De'Ath, G., J.M. Lough and K.E. Sabricius (2009). Declining coral calcification on the Great Barrier Reef. *Science* 323,116-119 doi:10.1126/science.1165283

Guinotte, J.M., J. Orr, S. Cairns, A. Freiwald, L. Morgan and R. George (2006). Will human induced changes in seawater chemistry alter the distribution of deepsea scleractinian corals? *Frontiers in Ecology and the Environment* 4(3), 141-146

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, *et al.* (2007). Coral reefs under rapid climate change and ocean acidification. *Science*, 318(5857), 1737-1742 doi:10.1126/science.1152509

Many questions, few answers, little time to act...

Since ocean acidification became widely recognized in 2005 on publication of the Royal Society report there has been an unprecedented expansion in work on this issue, as well as many calls for urgent action from the world's leading scientists, organizations and institutions.

What the scientists are saying

The breadth and depth of concern is reflected in an amazing and growing variety of scientific consensus statements on ocean acidification, some of which are listed below.

- 2005: Royal Society, *Ocean acidification due to increasing atmospheric carbon dioxide*.
- 2006: German Advisory Council on Global Change released *The Future Oceans – Warming Up, Rising High, Turning Sour*.
- 2007: International coral reef initiative recommendations on acidification and coral reefs.
- 2007: IPCC 4th AR on Climate Change: IPCC recognizes the immediate and future threat of ocean acidification on ocean ecosystems.
- June 2008: *Position analysis: CO_2 emissions and climate change: Ocean impacts and Adaptation issues*. The Australian Antarctic Climate and Ecosystems – cooperative research centre.
- August 2008: The Honolulu Declaration on Ocean acidification and reef management. Prepared by TNC and published by IUCN.
- December 2008: *Position statement of the European Geosciences Union position on Ocean Acidification*.
- January 2009: Monaco Declaration.
- June 2009: The Inter Academy Panel statement on ocean acidification.
- June 2009: European Science Foundation – *Science Policy Briefing on the impacts of ocean acidification*.
- June 2009: Synthesis Report from the conference on Climate Change: *Global Risks, Challenges & Decisions*. Prepared following the Climate Change Congress 10-12 March 2009.
- July 2009: *A Summary for Policy Makers from the Second Symposium on the Oceans in a High-CO_2 World*.
- July 2009: Zoological Society of London, the International Programme on the State of the Ocean (IPSO) and the Royal Society *Statement on the future of coral reefs*.

Photo © US National Oceanic and Atmospheric Administration

The trend towards more acidic ocean conditions is already being measured in the open ocean.

What studies are under way?

In the last few years there has been a significant growth in scientific studies to understand what is happening now and what may happen in the future due to ocean acidification.

Time is not on our side – the ocean is already measurably more acidic. Decisive action on CO_2 emissions and precautionary measures to best protect vulnerable ecosystems are needed now.

Current studies focus on understanding the consequences and mechanisms of this global problem to identify the best strategies for addressing it. There is a need to ensure that the concerns of developing countries are adequately addressed, and also that new findings are rapidly disseminated as they emerge in the research community.

Major studies underway or in advanced stages of planning include:

- **European Union:** The European Commission has funded the European Project on Ocean Acidification (EPOCA), an initiative to investigate ocean acidification and its consequences as a multinational effort that includes 29 laboratories located in nine European countries.

EPOCA research, already underway, aims to monitor ocean acidification and its effects on marine organisms and ecosystems, to identify the risks of continued acidification, and to understand how these changes will affect the Earth system as a whole.

- **United Kingdom:** In 2004 – 2007 a study was undertaken on the Implication for the Marine Environment of CO_2 ($IMCO_2$), funded by the Department for Environment, Food and Rural Affairs (Defra) and Department of Trade and Industry (DTI). In spring 2009 the U.K. announced a 5-year £11.8 million programme to investigate changes in ocean ecosystems in response to ocean acidification (costs shared by the Natural Environment Research Council, Defra and the Department of Energy and Climate Change (DECC)).

- **Germany:** Biological Impacts of Ocean Acidification (BIOACID). This coordinated project involving 18 research institutions is funded by the Federal Ministry of Education and Research (BMBF) for an initial 3-year period starting in September 2009. Its main focus is on the effects of ocean acidification on the marine biota at the sub-cellular to ecosystem level and their potential impacts on ecosystem services and biogeochemical feedbacks.

- **United States:** The Federal Ocean Acidification Research and Monitoring Act of 2009. The FOARAM Act was signed by President Obama in March 2009. The Act requires that the National Oceanic and Atmospheric Administration, the National Science Foundation and other federal agencies work together to develop a national programme on ocean acidification starting in 2010.

- **Japan:** Five major programmes in Japan fund research relevant to ocean acidification. Japan's Ministry of Environment supports research programmes to elucidate the future impact of ocean acidification on various marine organisms using sophisticated mesocosm facilities (e.g. AICAL, Acidification Impact on CALcifiers). MEXT (Ministry of Education, Science, Sport and Culture) and JAMSTEC (Japan Agency for Marine Science and TEChnology) also support ocean acidification research such as modelling efforts on the Earth Simulator supercomputer to predict future ocean conditions.

- **China:** Ministry of Science and Technology (MOST) and National Science Foundation of China (NSFC) have started to support researches on ocean acidification. CHOICE-C is a newly funded 5-year project to study high CO_2 and ocean acidification issues in Chinese marginal seas, a joint project of seven major institutions with the fund of 34 million RMB. NSFC started to fund projects on ocean acidification in 2006, and there are several ongoing national level projects exploring the impacts of ocean acidification on calcifying organisms.

Photo © Armin Form, IFM-GEOMAR

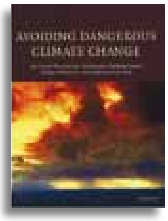
The cold water coral *Lophelia pertusa* with its polyps extending out to collect food.

- **Korea:** The Korea Science and Engineering Foundation is funding the 5-year Korea Mesocosm Project to examine the effects of elevated CO_2 and temperature on natural phytoplankton assemblages, which involves five Korean laboratories.

- **Australia:** Ocean acidification research in Australia extends from Antarctic through Australasian regions. The Antarctic Climate & Ecosystems Cooperative Research Centre (a partnership of CSIRO, AAD, Bureau of Meteorology and University of Tasmania) research in the Southern Ocean includes monitoring seawater chemistry changes and the responses of key species. In the tropics, a collaborative observational and modelling programme between CSIRO, NOAA (USA), NIES (Japan) and University of Queensland has begun in the Great Barrier Reef and South Pacific regions. The vulnerability of the Great Barrier Reef to ocean acidification is also being addressed by the Australian Institute of Marine Science and several universities (Australian National University, University of Queensland, University of Sydney, James Cook University,) through large-scale monitoring of reef waters, paleontological reconstructions from coral cores, and field and laboratory experiments on reef organisms.

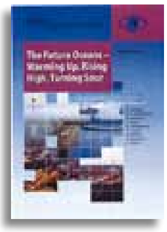
Some key reports on ocean acidification

In addition to the scientific consensus statements and studies that are underway or planned, a number of key reports have already been produced on ocean acidification.



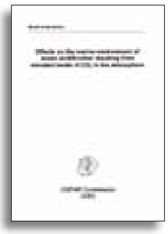
The first time many policy advisers became aware of ocean acidification was through the 2005 international conference on *Avoiding Dangerous Climate Change: A Scientific Symposium on Stabilisation of Greenhouse Gases*. This took place under the United Kingdom's presidency of the G8, with the participation of around 200 internationally renowned scientists from 30 countries and examined the link between atmospheric greenhouse gas concentration, and the 2°C (3.6°F) ceiling on global warming thought necessary to avoid the most serious effects of global warming. Previously this had generally been accepted as being 550 ppm.

The first major publication of this issue rapidly followed. The Royal Society 2005 policy document *Ocean acidification due to increasing atmospheric carbon dioxide* recognized ocean acidification is a significant threat to many calcifying organisms that would alter food chains and other ecosystem processes and lead to a reduction of biodiversity in the oceans. The appointed working group made specific policy recommendations, including limiting the accumulation of CO_2 emissions to avert impending damages from ocean acidification.



In 2006 the German Advisory Council on Global Change released *The Future Oceans – Warming Up, Rising High, Turning Sour*. This document presents the hazards of acidification within the context of other climate change processes in the ocean. Policy makers were urged to acknowledge the role of CO_2 as an ocean hazard during future negotiations under the United Nations Framework Convention on Climate Change.

Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research came from a joint effort by NSF, NOAA and USGS. This is a 2006 summary report on the state of the science regarding the biological consequences of acidification, particularly as they affect calcifying organisms. The report concludes with a recommended research agenda and underscores the need for research to place the long term biological changes induced by acidification into a historical context.



In 2006 a second report was produced, this time from The Convention for the Protection of the Marine Environment of the North East Atlantic (the OSPAR Convention). *Effects on the Marine Environment of Ocean Acidification Resulting from Elevated Levels of CO_2 in the Atmosphere* was a product of The Scoping Workshop on Ocean Acidification Research.

From 2007 onwards ocean acidification began to regularly feature in reporting in the UK on marine climate change impacts. These took the form of *Annual Report Cards* produced by the Marine Climate Change Impacts Partnership (MCCIP). In April 2009 more significant coverage was provided on ocean acidification through their publication *Ecosystem Linkages*. This builds on previous work to show how the interconnected nature of the marine ecosystem magnifies the many discrete impacts of climate change, documented in the Annual Report Cards.

The U.S. Ocean Carbon and Biogeochemistry Program (OCB) sponsored a workshop in conjunction with NOAA, NASA and NSF at the Scripps Institution of Oceanography to develop a U.S. research strategy. With the cooperation of ~100 scientists, a plan was developed to investigate the impacts of ocean acidification on four marine ecotypes: coral reefs, coastal margins, tropical subtropical open ocean systems and high latitude regions. The recommended research was reported in 2008 in *Present and Future Impacts of Ocean Acidification on Marine Ecosystems and Biogeochemical Cycles*.

Also in 2008, a significant policy document was provided for the Australian government: *Position Analysis: CO_2 Emissions and Climate Change: Ocean Impacts and Adaptation Issues*. This document was drafted to describe the process of acidification, outline the biological and human effects and to advise the Australian government on issues relevant to policy development. It was accompanied by a one page fact sheet *Ocean Acidification: Australian Impacts in the Global Context* that discussed ocean acidification in terms of the science: what is known, what needs to be known and what can be done.

In 2009 a further milestone report was produced. *The Monaco Declaration* is supported by H.S.H. Prince Albert of Monaco who, whilst taking part in the working sessions of the second international symposium The Ocean in a High-CO_2 World, expressed his earnest wishes for the Monaco Declaration to be drafted. The resultant Declaration is approved by 155 scientists from 26 countries, all leaders of research into ocean acidification and its impacts. It calls on policymakers to act quickly to avoid severe and widespread damages, all of which are ultimately driven by increasing concentrations of atmospheric CO_2. By acting quickly to incorporate these concerns into plans to stabilize atmospheric CO_2 at a safe level not only would this avoid dangerous climate change but also dangerous ocean acidification.

Another result of the same meeting of the second international symposium The Ocean in a High-CO_2 World was the production of *A Summary for Policymakers* of the new research findings presented at the symposium. More detailed information is synthesized in a scientific report, *Research Priorities for Ocean Acidification* (2009), available from www.ocean-acidification.net.

What is the Ocean Acidification Reference User Group?

A key challenge is ensuring that ground-breaking science on issues such as ocean acidification addresses the questions that need to be answered and that these answers get quickly and effectively into the hands of policy advisers and decision makers so that action can be taken. The Ocean Acidification Reference User Group (RUG) draws on UK, European and international experience in fast-tracking the exchange of information between scientists and end-users.

The RUG was established in 2008 to support the work of the European Project on OCean Acidification (EPOCA), and is now being expanded to support complementary studies in Germany (BIOACID) and the UK, with strong links into similar processes in the USA. The RUG draws together a wide range of end users to support the work of leading scientists on ocean acidification, to facilitate the rapid transfer of knowledge, and help the effective delivery of quality science.

This guide draws on the experience of the RUG, coupled with the knowledge of the leading experts on ocean acidification, to provide an introduction for policy advisers and decision makers on this most critical and urgent of issues.

Photo © Marie-Dominique Pizay, CNRS

EPOCA scientists and divers collecting organisms living on the sea floor as well as environmental data in the Arctic.

- **The RUG is formed of representatives from:** Alfred Wegener Institute of Polar and Marine Research, BP, Euro-Mediterranean Center on Climate Change (CNRS), Canadian Tourist Industry Authority, Centre National de la Recherche Scientifique (CNRS), Climate Central (Princeton University), Conservation International, Directorate of Fisheries (Norway), Fondazione Eni Enrico Mattei (FEEM), Greenpeace, International Atomic Energy Agency, Leibniz Institute of Marine Sciences (IFM – GEOMAR), International Geosphere-Biosphere Programme (IGBP), International Union for the Conservation of Nature (IUCN), Laboratoire des Sciences du Climat et de l'Environment (LSCE), Marine Institute (Ireland), Natural England, Observatoire national sur les effets du réchauffement climatique (ONERC), Potsdam Institute for Climate Impact Research (PIK), Plymouth Marine Laboratory, Rolls Royce, Royal Institution, Scientific Committee on Oceanic Research (SCOR), Scottish Natural Heritage, Stockholm Resilience Center, The Nature Conservancy, UK Climate Impacts Programme, UNEP World Conservation Monitoring Center, WWF.
- **Observers:** European Commission, the UK Marine Climate Change Impacts Partnership, the Oak Foundation, Oceana.

Photo © Dan Laffoley/IUCN

Online guide

Download a copy of this introductory guide to ocean acidification including hyperlinks and find out more about the latest research on this issue.http://www.epoca-project.eu/index.php/Outreach/RUG/

Further details and contacts

Further details on the work of the Ocean Acidification Reference User Group and the European Project on Ocean Acidification can be found on our website: **http://www.epoca-project.eu/index.php/Outreach/RUG/**

If you have any further enquiries please contact us at: **policyguide-epoca@obs-vlfr.fr**

List of sources and contributors

This introductory guide draws on a body of work already available on ocean acidification. We acknowledge the following publications that have helped shape this guide: the frequently asked questions from ocean-acidification.net, the Summary for Policy Makers from the Second Symposium on The Ocean in a High-CO_2 World, the IAP Statement on Ocean Acidification, the European Science Foundation Science Policy Briefing, the Honolulu Declaration on Ocean acidification, an unpublished report by the Nature Conservancy (Carbon Dioxide Induced Ocean Acidification: An Intemperate Issue), and newsletter 73 from the International Geosphere-Biosphere Programme (IGBP).

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Quality assurance

This guide has been produced by the Ocean Acidification Reference User Group, who invited leading scientists to peer-review the quality of the science. We wish to thank these individuals for taking the time to help develop this guide.

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