SECOND INTERNATIONAL SYMPOSIUM ON THE OCEAN IN A HIGH-CO_2 WORLD

MONACO - OCTOBER 6-9, 2008

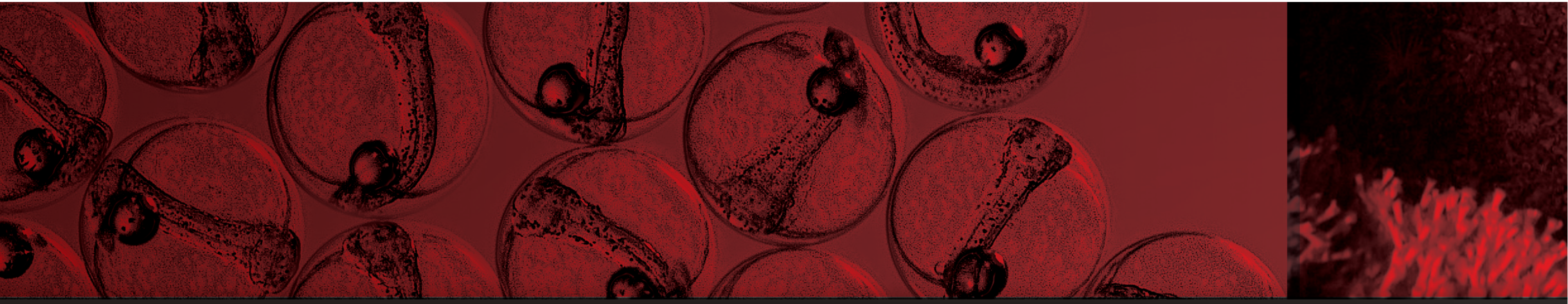
Monaco Declaration

It was while taking part in the working sessions of the scientific community, which met in Monaco last October for the second international symposium *The Ocean in a High-CO_2 World*, that I expressed my earnest wishes for the *Monaco Declaration* to be drafted. The seas and oceans absorb one-fourth of the carbon dioxide emitted to the atmosphere from human activities, which in turn is driving their acidification at a rate that is unprecedented.

This chemical modification will alter marine ecosystems, upon which over half of the world's population depends for its primary source of food. This declaration, based on irrefutable scientific findings and signed by 155 scientists from 26 nations, sets forth recommendations, calling for policymakers to address this immense problem.

I strongly support this declaration, which is in full accord with my efforts and those of my Foundation to alleviate climate change. I hope that it will be heard by all the political leaders meeting in Copenhagen in December 2009.

H.S.H. Prince Albert II



We scientists who met in Monaco to review what is known about ocean acidification declare that we are deeply concerned by recent, rapid changes in ocean chemistry and their potential, within decades, to severely affect marine organisms, food webs, biodiversity, and fisheries. To avoid severe and widespread damages, all of which are ultimately driven by increasing concentrations of atmospheric carbon dioxide (CO_2), we call for policymakers to act quickly to incorporate these concerns into plans to stabilize atmospheric CO_2 at a safe level to avoid not only dangerous climate change but also dangerous ocean acidification.

Ocean acidification is underway

The surface ocean currently absorbs about one-fourth of the CO_2 emitted to the atmosphere from human activities, namely from fossil-fuel combustion, deforestation, and cement production. As this CO_2 dissolves in seawater, it forms carbonic acid, increasing ocean acidity. Since industrialization began in the 18th century, surface-ocean acidity has increased by 30%. This ongoing ocean acidification is decreasing the ability of many marine organisms to build their shells and skeletal structure. Increasing acidity and related changes in seawater chemistry also affect reproduction, behaviour, and general physiological functions of some marine organisms, such as oysters, sea urchins, and squid.

Ocean acidification is already detectable

Observations collected over the last 25 years show consistent trends of increasing acidity in surface waters that follow increasing atmospheric CO_2. These trends match precisely what is expected based on basic marine chemistry and continuous measurements of atmospheric CO_2. A range of field studies suggest that impacts of acidification on some major marine calcifiers may already be detectable. Also, naturally high-CO_2 marine environments exhibit major shifts in marine ecosystems following trends expected from laboratory experiments. Ocean acidification has altered some coastal waters to the extent that recently during spring they have become corrosive to the shells of some bottom-dwelling organisms. Within decades these shell-dissolving conditions are projected to be reached and to persist throughout most of the year in the polar oceans.

Ocean acidification is accelerating and severe damages are imminent

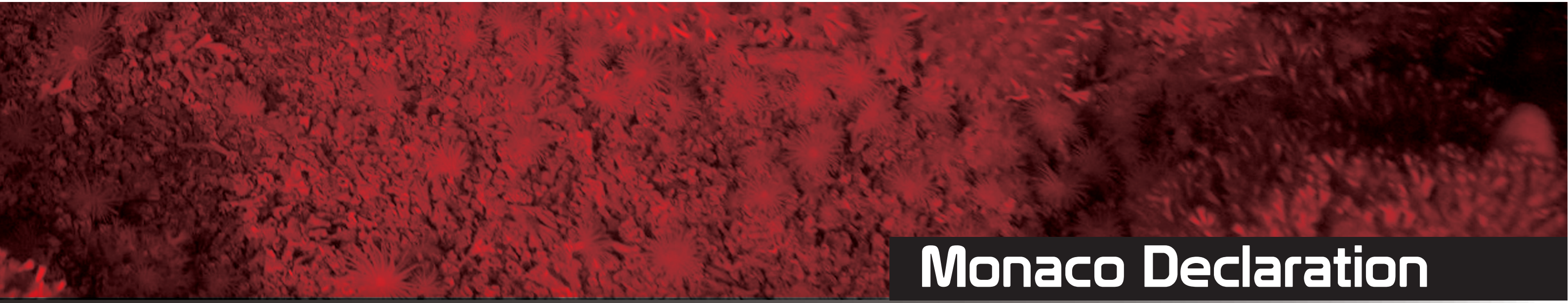
Currently the average concentration of atmospheric CO_2 is 385 parts per million (ppm), which is 38% more than the preindustrial level of 280 ppm. Half of that increase has occurred in the last 30 years. Current CO_2 emissions are greater than projected for the worst-case scenario formulated a decade ago. And along with increasing emissions, the increase in atmospheric CO_2 is accelerating. By mid-century, the average atmospheric CO_2 concentration could easily reach double the preindustrial concentration. At that 560-ppm level, it is expected that coral calcification rates would decline by about one-third. Yet even before that happens, formation of many coral reefs is expected to slow to the point that reef erosion will dominate. Reefs would no longer be sustainable. By the time that atmospheric CO_2 reaches 450 ppm, it is projected that large areas of the polar oceans will have become corrosive to shells of key marine calcifiers.

Ocean acidification will have socioeconomic impacts

Ocean acidification could affect marine food webs and lead to substantial changes in commercial fish stocks, threatening protein supply and food security for millions of people as well as the multi-billion dollar fishing industry. Coral reefs provide fish habitat, generate billions of dollars annually in tourism, protect shorelines from erosion and flooding, and provide the foundation for tremendous biodiversity, equivalent to that found in tropical rain forests. Yet by mid-century, ocean acidification may render most regions chemically inhospitable to coral reefs. These and other acidification-related changes could affect a wealth of marine goods and services, such as our ability to use the ocean to manage waste, to provide chemicals to make new medicines, and to benefit from its natural capacity to regulate climate. For instance, ocean acidification will reduce the ocean's capacity to absorb anthropogenic CO_2, which will exacerbate climate change.

Ocean acidification is rapid, but recovery will be slow

The current increase in ocean acidity is a hundred times faster than any previous natural change that has occurred over the last many millions of years. By the end of this century, if atmospheric CO_2 is not stabilized, the level of ocean acidity could increase to three times the preindustrial level. Recovery from this large, rapid, human-induced perturbation will require thousands of years for the Earth system to reestablish ocean chemical conditions that even partially resemble those



found today; hundreds of thousands to millions of years will be required for coral reefs to return, based on the past record of natural coral-reef extinction events.

Ocean acidification can be controlled only by limiting future atmospheric CO_2 levels

So-called *geo-engineering* strategies that would not aim to restrict future atmospheric CO_2 concentrations would not reduce ocean acidification. Mitigation strategies that aim to transfer CO_2 to the ocean, for example by direct deep-sea disposal of CO_2 or by fertilising the ocean to stimulate biological productivity, would enhance ocean acidification in some areas while reducing it in others. Climate-change negotiations focused on stabilizing greenhouse gases must consider not only the total radiation balance; they must also consider atmospheric CO_2 as a pollutant, an acid gas whose release to the atmosphere must be curtailed in order to limit ocean acidification. Hence, limits (stabilization targets) for atmospheric CO_2 defined based on ocean acidification may differ from those based on surface temperature increases and climate change.

Despite a seemingly bleak outlook, there remains hope. We have a choice, and there is still time to act if serious and sustained actions are initiated without further delay. First and foremost, policymakers need to realize that ocean acidification is not a peripheral issue. It is *the other CO_2 problem* that must be grappled with alongside climate change. Reining in this double threat, caused by our dependence on fossil fuels, is the challenge of the century. Solving this problem will require a monumental world-wide effort. All countries must contribute, and developed countries must lead by example and by engineering new technologies to help solve the problem. Promoting these technologies will be rewarded economically, and prevention of severe environmental degradation will be far less costly for all nations than would be trying to live with the consequences of the present approach where CO_2 emissions and atmospheric CO_2 concentrations continue to increase, year after year.

Fortunately, partial remedies already on the table, if implemented together, could solve most of the problem. We must start to act now because it will take years to change the energy infrastructure and to overcome the atmosphere's accumulation of excess CO_2, which takes time to invade the ocean.

Therefore, we urge policymakers to launch four types of initiatives:

→ to help improve understanding of **impacts of ocean acidification** by promoting research in this field, which is still in its infancy;

→ to help build **links between economists and scientists** that are needed to evaluate the socioeconomic extent of impacts and costs for action versus inaction;

→ to help **improve communication between policymakers and scientists** so that *i*) new policies are based on current findings and *ii*) scientific studies can be widened to include the most policy-relevant questions;

→ to **prevent severe damages from ocean acidification** by developing ambitious, urgent plans to cut emissions drastically.

An example to illustrate the intense effort needed:

To stay below an atmospheric CO_2 level of about 550 ppm, the current increase in total CO_2 emissions of 3% per year must be reversed by 2020. Even steeper reductions will be needed to keep most polar waters from becoming corrosive to the shells of key marine species and to maintain favourable conditions for coral growth. If negotiations at COP-15 in Copenhagen in December 2009 fall short of these objectives, still higher atmospheric CO_2 levels will be inevitable.

***Declaration approved by 155 scientists from 26 countries**, leaders of research into ocean acidification and its impacts.
This document is based on the report *Research Priorities for Ocean Acidification*
(available at **http://ioc3.unesco.org/oanet/HighCO2World.html** along with the Declaration, endorsements, and photo credits).

This declaration does not necessarily reflect the views of the organizers and financial sponsors of the symposium or the organizations to which the approving scientists are associated.

Eric Achterberg, NOCS Southampton, *UK*
Simone Alin, Seattle, *USA*
Denis Allemand, Centre Scientifique de Monaco, *Monaco*
Andreas Andersson, BIOS, *Bermuda*
Pia Andersson, SMHI, *Sweden*
Murat V. Ardelan, NTNU, *Norway*
Joana Barcelos e Ramos, IFM-GEOMAR Kiel, *Germany*
James P. Barry, MBARI, *USA*
Nina Bednarsek, British Antarctic Survey, *UK*
Olivier Bernard, INRIA Sophia-Antipolis, *France*
Anthony Bertucci, Centre Scientifique de Monaco, *Monaco*
Maria Betti, IAEA-MEL, *Monaco*
Jelle Bijma, AWI, *Germany*
Jerry Blackford, Plymouth Marine Laboratory, *UK*
Christian Bock, AWI, *Germany*
Antje Boetius, AWI and MPI Bremen, *Germany*
Florence Boisson, IAEA-MEL, *Monaco*
Michel Boisson, *Monaco*
Laurent Bopp, LSCE/CNRS, *France*
Andrea Borghi, Université de Neuchâtel, *Switzerland*
Eike Breitbarth, University of Otago, *New Zealand*
Emily Breviere, SOLAS IPO UEA, *UK*
Wendy Broadgate, IGBP, *Sweden*
Lucy Buxton, *Australia*
Ken Caldeira, Carnegie Institution Stanford, *USA*
Juan-Carlos Miquel, IAEA-MEL, *Monaco*
Nicolas Cassar, Princeton University, *USA*
Ana I. Catarino, BIOMAR-ULB, *Belgium*
Anastasia Charalampopoulou, NOC Southampton, *UK*
Lei Chou, Université LIbre de Bruxelles, *Belgium*
Catriona Clemmesen, IFM-GEOMAR Kiel, *Germany*
Steeve Comeau, CNRS-University of Paris 6, *France*
Kim Currie, NIWA, *New Zealand*
Jan Czerny, IFM-GEOMAR Kiel, *Germany*
Mike DeGrandpre, University of Montana, *USA*
Andrew Dickson, Scripps Institution of Oceanography, *USA*
Delphine Dissard, AWI, *Germany*
Philippe Dubois, Marine Biology Laboratory ULB, *Belgium*
Cynthia Dumousseaud, NOCS Southampton, *UK*
Sam Dupont, Marine Ecology Göteborg University, *Sweden*
Hronn Egilsdottir, *Iceland*
Jonathan Erez, Hebrew University, *Israel*
Victoria J. Fabry, California State University San Marcos, *USA*
Richard Feely, Seattle, *USA*
Helen Findlay, Plymouth Marine Laboratory, *UK*
Maoz Fine, Interuniversity Institute for Marine Science, *Israel*
Jan Helge Fosså, Institute of Marine Research, *Norway*
Reidun Gangstø, University of Bern, *Switzerland*
Jean-Pierre Gattuso, CNRS-University of Paris 6, *France*
Marion Gehlen, LSCE, *France*
Claire Godinot, Centre Scientifique de Monaco, *Monaco*
Nicolas Gruber, ETH Zurich, *Switzerland*
Magdalena Gutowska, AWI, *Germany*
Jason Hall-Spencer, Marine Institute University of Plymouth, *UK*
Henrietta Hampel, EC, *Belgium*
Lina Hansson, CNRS-University of Paris 6, *France*
Judith Hauck, AWI, *Germany*
Peter M. Haugan, University of Bergen, *Norway*
Chris Hauton, NOC Southampton, *UK*
Jon Havenhand, Univ. Gothenburg, *Sweden*
Eric Heinen De Carlo, University Of Hawaii, *USA*
Christoph Heinze, UiB/BCCR, *Norway*
Hermann Held, PIK, *Germany*
Nathalie Hilmi, HFRI/IUM, *Monaco*
Maria Hood, UNESCO-IOC, *France*
Frances Hopkins, University of East Anglia,*UK*
Fanny Houlbreque, IAEA-MEL, *Monaco*
Will Howard, Antarctic Climate & Ecosystems CRC, *Australia*
Tatjana Ilyina, University of Hawaii, *USA*
Lars Inge Enstad, University of Bergen, *Norway*
Kirsten Isensee, IOW, *Germany*
Masao Ishii, MRI, *Japan*
Ross Jeffree, IAEA-MEL, *Monaco*
Philip Kerrison, University of Essex, *UK*
Joanie Kleypas, National Center for Atmospheric Research, *USA*
Andrew Knoll, Harvard University, *USA*
Sebastian Krug, IFM-GEOMAR Kiel, *Germany*
Bonnie Laverock, Plymouth Marine Laboratory, *UK*
Will Le Quesne, CEFAS, *UK*
Julien Leblud, University of Mons, *Belgium*
Louis Legendre, Villefranche Oceanography Laboratory, *France*
Patrick Lehodey, CLS, *France*
Orly Levitan, Bar Ilan University, *Israel*
Michael MacCracken, Climate Institute Washington DC, *USA*
Chandan Mahanta, Centre for the Environment IIT Guwahati, *India*
Cornelia Maier, CNRS-University of Paris 6, *France*
Sophie Martin, IAEA-MEL, *Monaco*
Francesca Marubini, Joint Nature Conservation Committee, *UK*
Evin McGovern, Marine Institute, *Ireland*
Triona McGrath, Marine Institute, *Ireland*
Christina McGraw, University of Otago, *New Zealand*
Ben McNeil, University of New South Wales, *Australia*
Frank Melzner, IFM-GEOMAR Kiel, *Germany*
Agostino Merico, GKSS, *Germany*
Joanna Miest, Hamburg, *Germany*
Ahmed Ali Mohamud, Nairobi, *Kenya*
Pedro MS Monteiro, CSIR, *South Africa*
Aurélie Moya, Univ. Nice, *France*
Marius N. Müller, IFM-GEOMAR Kiel, *Germany*
Guy Munhoven, University of Liège, *Belgium*
Anne-Marin Nisumaa, CNRS-Université Paris 6, *France*
Jón Ólafsson, University of Iceland, *Iceland*
Anna Orlikowska, IOW, *Germany*
James Orr, IAEA-MEL, *Monaco*
Ronald Osinga, Wageningen University, *Netherlands*
Christian Pansch, IFM-GEOMAR Kiel, *Germany*
Silvio Pantoja, University of Concepcion, *Chile*
Laura Parker, University of Western Sydney, *Australia*
Matti Perttila, FMI, *Finland*
Gian-Kasper Plattner, ETH Zurich, *Switzerland*
Annika Pollani, HCMR, *Greece*
Hans Pörtner, AWI, *Germany*
Lucia Porzio, Stazione Zoologica A.Dohrn Naples, *Italy*
Rosa Ma. Prol-Ledesma, Universidad Nacional Autonoma de Mexico, *Mexico*
Sophie Rabouille, CNRS, *France*
Stéphanie Reynaud, Centre Scientifique de Monaco, *Monaco*
Sophie Richier, CNRS-University of Paris 6, *France*
Andy Ridgwell, University of Bristol, *UK*
Ulf Riebesell, IFM-GEOMAR Kiel, *Germany*
Lisa Robbins, St. Petersburg FL, *USA*
Donna Roberts, Antarctic Climate & Ecosystems CRC, *Australia*
Riccardo Rodolfo-Metalpa, University of Plymouth Marine Institute, *UK*
Christopher L. Sabine, Seattle, *USA*
Joan-Albert Sanchez-Cabeza, IAEA-MEL, *Monaco*
Julia Saphörster, IFM-GEOMAR Kiel, *Germany*
Yoshikazu Sasai, JAMSTEC, *Japan*
Toru Sato, University of Tokyo, *Japan*
Daniela Schmidt, University of Bristol, *UK*
Birgit Schneider, University of Kiel, *Germany*
Kai G. Schulz, IFM-GEOMAR Kiel, *Germany*
Miriam Schutter, Wageningen University, *The Netherlands*
Joachim Segschneider, MPI-MET Hamburg, *Germany*
Kyoungsoon Shin, KORDI, *Republic of Korea*
Yoshihisa Shirayama, Kyoto University, *Japan*
Yasmin Shirin Appelhans, IFM-GEOMAR Kiel, *Germany*
Kiminori Shitashima, CRIEPI, *Japan*
Lisa Suatoni, Natural Resources Defense Council, *USA*
Coleen Suckling, British Antarctic Survey & Cambridge University, *UK*
Stefanie Sudhaus, IFM-GEOMAR Kiel, *Germany*
Toru Suzuki, MIRC/JHA, *Japan*
Sylvie Tambutté, Centre Scientifique de Monaco, *Monaco*
Jean-Louis Teyssie, IAEA-MEL, Monaco
Michael Thorndyke, Royal Swedish Academy of Sciences, *Sweden*
Erik V. Thuesen, Evergreen State College, *USA*
Trisha Towanda, University of Rhode Island, *USA*
George Triantafyllou, HCMR, *Greece*
Carol Turley, Plymouth Marine Laboratory, *UK*
Toby Tyrrell, National Oceanography Centre Southampton, *UK*
Thomas Vance, Newcastle University, *UK*
Sue-Ann Watson, National Oceanography Centre Southampton, *UK*
Markus Weinbauer, CNRS-University of Paris 6, *France*
Steve Widdicombe, Plymouth Marine Laboratory, *UK*
Hannah Wood, Plymouth Marine Laboratory, *UK*
Rachel Wood, Edinburgh University, *UK*
Takeshi Yoshimura, Abiko, *Japan*