ICES Symposium Reports 2008

ICES CM 2008/GEN:02

International Symposium "Effects of Climate Change on the World's Oceans",
Gijón, Spain, 19–23 May 2008

Symposium on the Ecosystem Approach with
Fisheries Acoustics and Complementary Technologies (SEAFACTS)
Bergen, Norway, 16–20 June

Symposium on Herring: Linking biology, ecology,
and status of populations in a changing environment,
Galway, Ireland, 26–29 August 2008

Symposium on "Coping with global change in marine social-ecological systems",
FAO, Rome, Italy 8–11 July 2008

Symposium on "The Role of Marine Mammals in the Ecosystem in the 21st Century",
Dartmouth, Canada, 29 September–1 October 2008

Symposium on the Ocean in a High-CO_2 World,
Monaco, 6–9 October 2008

World Conference on Marine Biodiversity,
Valencia, Spain, 11–15 November 2008

ICES
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1 The International Symposium "Effects of Climate Change on the World's Oceans"

Conveners: Dr John Church (IOC); Dr William T. Peterson (PICES); Dr Luis Valdés (ICES)

Venue and dates: Gijón, Spain, 19–23 May 2008

Executive summary

The International Symposium "Effects of Climate Change on the World's Oceans" co-sponsored by the International Council for the Exploration of the Sea (ICES), North Pacific Marine Science Organization (PICES) and Intergovernmental Oceanographic Commission of UNESCO (IOC), was held at the Congress Center in Gijón (Spain), 19–23 May, 2008, gathering 382 participants from 48 countries from around the world.

This International symposium was the culmination of an intensive and interactive, 2.5 years planning process, resulting from an original proposal of ICES submitted by the OCC during the ASC 2005 (Aberdeen), ICES invited PICES and IOC to collaborate with the symposium organization.

Three conveners and one scientific steering committee were responsible for preparing the scientific program. The local organization was responsibility of the Instituto Español de Oceanografía – Centro Oceanográfico de Gijón. The symposium was partially supported with funds from several international, national and local institutions (Annex 1) that covered total or partially the costs of travel and accommodation for ~60 scientist.

The full program of the Symposium included 4 workshops (1.5 days) and 5 topics divided into 10 scientific sessions. Scientific sessions accommodating a total of 215 oral presentations (10 plenary talks and 20 invited speakers included). Parallel to the oral presentations, two poster sessions exhibited 133 posters during the entire Symposium.

At the closing ceremony it was remarked that this symposium would be continued or repeated in 2011 or 2012. It was also recognized that this was the largest and most important symposium that has ever been held on the effects of climate change on the oceans. The major objectives of the symposium were fulfilled and, at the end, the Scientific Steering Committee honored with 2 Certificates of Recognition and 2 Honorable Mentions the four students who prepared the best posters and oral presentations.

A selection of the best symposium papers will be published in a volume of the ICES Journal of Marine Science in Spring/Summer 2009, invited Guest Editors will be appointed accordingly with the disciplines of the manuscripts submitted for evaluation.

Conclusions

The "Effects of Climate Change on the World's Oceans" International Symposium was the first worldwide symposium on this great concern. As such it represented an important opportunity to further develop the truly international nature of scientific research related to the effects of climate change on the world's oceans. The Symposium gathered 382 delegates coming from 48 countries. The major objectives of the Symposium were fulfilled and the exchange of views, ideas and data by oceanographers from around the world facilitated development of new research directions and ideas.

First statement, to summarize the symposium discussions, is that the global warming trend and the increasing emissions of CO_2 and other green house gases (GHG) are already affecting the environmental conditions and biota in the oceans at a global scale. Second statement is that we do not know how large and deep these effects will be in the near future and that we do not understand the mechanism and processes converting the individual responses of single species into shifts in the functioning regime of marine ecosystems. The third main statement is that we need to maintain the existing time series, establish many more in some regions, do more experimental work, and develop more complex and finer models.

The symposium covered a wide scope of topics: observations (new findings, and gaps), uncertainties in current measurements and need of new instrumentation, the effects of climate change at several levels (sea level rise and erosion in the coastal zone, temperature and acidification in biota), revision of predictions from models, role of IPCC in assessing the predictions, reporting the effects of global warming in the oceans and methods for adaptation, and finally the identification of challengers and hot spots for special consideration in the next 5 years.

The experts in CO_2 emissions revealed that the annual rate of increment of CO_2 in the atmosphere is now 4 ppm, instead 3 ppm as it was in the last decade. This acceleration confirms that the intermedium scenario in the Fourth Assessment Report of IPCC (IPCC AR4) is not the one we have to consider anymore and that future climate changes are likely to be much larger than what we have experienced so far. It was also confirmed that anthropogenic warming and sea level rise would continue for centuries, even if GHG concentrations were to be stabilized at or above today’s levels.

IPCC AR4 estimates 0.2 to 0.6 m sea level rise per ºC of warming in this century due only to thermal expansion of sea water. However, there is a big uncertainty in the rate of melting of the Greenland’s ice cover. If we assume that Greenland will melt in 5000 years, the additional sea level rise in this century will be 0.76 m, but if we assume that Greenland will melt in only 1000 years, then the additional sea level rise in this century will be 1.8 m. This makes of Greenland a hot spot to be monitored in the next decade.

Large uncertainties exist also in the response of the high latitude climate system to climate change due to poorly quantified feedbacks and thresholds associated with the ocean circulation models.

Many examples of effects of global warming in the coastal zone and oceans were reported. The potential effects of sea level rise, erosion, extreme events, etc, was evidenced and concluded that the season of hurricanes, their intensity and extension of the region where they are formed will increase, as sea is warming and accumulating more energy earlier in the year and covering a larger area. The combined effect of acidification and increasing in temperature is causing an accelerated bleaching in coral reefs. Corals are highly vulnerable to climate change and may disappear at 450 ppm or a further 1ºC above today. This is risking not only the corals, but also the entire biota (the only biological structure which can be seen from the space), which include several thousands of species of different classes (aprox. 50% of these species may disappear). It was also remarked the importance that the increase in size of the oligotrophic oceanic gyres could represent at a global scale, the depletion of nutrients should also be explored in regional seas. The depletion of O_2 in the upwelling areas should also be carefully observed in the following years.

More difficult exist to consider as effect of climate change the depletion of fisheries, as these are consequence of cumulative and interactive effects of fishing, pollution, coastal development, climate change, etc. The ecosystem impacts of fishing: habitat destruction, by-catch, species interactions and bad practices of selective catch of big old fat female fish (which undermines replenishment) were considered to have a higher signal in population's dynamics than the effect of climate change. Nevertheless climatic effects may be detected in the migratory routes of tuna and in northern displacement of small pelagic fishes in the north hemisphere (and east-west displacements in the southern hemisphere). Increased water temperatures are also likely to lead to the introduction of new species to high latitudes but are unlikely to lead to the extinction of any of the present arctic fish species.

It was mentioned that the IPCC AR4 reflects the lack of time series to assess with accuracy the trends in the different oceans and regional seas. Chapter 1 of Working Group II's report, lists only 30 marine data series (biological and physical) in the synthesis of climate impacts, compared with 622 series from the cryosphere and 527 series from terrestrial biological systems. Furthermore, only 4 out of 43 authors of this chapter were marine biologists, which results in a greater likelihood that documented changes in marine systems may be under represented. IPCC guidelines for inclusion in assessment reports demand that time series must be at least 20 years long and end in 1990 or later. A possible way to bolster confidence and enhance transparency in the IPCC process would be to specifically detail each marine observation synthesized in the report (in an appendix), as is the norm in large published meta-analyses. As well as identifying gaps, this will allow the broader scientific community to provide quality control of the data gathering and interpretation that underpin the assessment.

Our observational capacity is much lower in the oceans than in terrestrial systems. Research programmes into the oceans are transitory and concentrated in coastal waters. Inaccessibility of most marine systems prevents many nations of investing the economic resources needed to establish permanent programmes to monitor these seas. Satellite observing systems are generally restricted to the sea surface, and even shallow marine ecosystems such as seagrass meadows and coral reefs remain hidden for satellites. New and powerful instruments are now available to observe the physical properties of oceans, but there is still a lack in our technology to monitorise biological communities with the proper spatial and temporal resolution. The southern hemisphere and the Indian Ocean are vast regions that are poorly or non covered at all by monitoring programmes, this is causing a bias in our perception and in the predictions of our models, and it was suggested that international collaboration should be pursued to establish permanent research programmes in these areas.

The continuation of the existing time series was highly recommended. These will provide essential data to understand the interdecadal variability underlying the global warming, as well as the effects of the global warming *per se*. Exploring the effects of climate change does not rely only in observations: more experiments are needed (acidification is a clear example). The importance of good communication, not only to get the data in real time, but also to interchange data and to know what the other disciplines are doing to monitor the oceans was also considered (sometimes data are complementary, and the collective value of data sets is greater than its dispersed value). Finally, more complex and finer models are needed to respond to the policy makers and the society accurately and in time.

In addition to the current work done in observing the oceans, the new challengers for the next 5-10 years include the study of non-linear effects on biological processes leading to shifts in ecosystems which are not understood, the decadal variability underlying the signal of climate change, the rate of melting in Greenland, the ocean acidification, the expansion of oligotrophic gyres (how the productivity in the oceans will be in the future), the depletion of intensity and changes in upwelling systems, species sensitivity to climate change, and the interaction of climate change with other human impacts and activities.

It was remarked the importance of this symposium as a firm step toward close cooperation between marine researchers working in different disciplines related with climate change and the sustainability of marine ecosystems. It was recommended that this symposium would be continued or repeated in 2011 or 2012. A new symposium is necessary to explore and set up ways to: (1) allow the scientific community to integrate such multidisciplinary information, (2) communicate and interact with policy makers, (3) help society and scientist to find the way forward, and (4) provide the public with adequate guidelines and accurate forecast to adapt ourselves to such a changing world. At the end, the conveners initiate negotiations for the organization of the next International Symposium on the "Effects of Climate Change on the World's Oceans" to be held in Japan or in Australia.

Organisation Committee

Scientific Steering Committee

Dr Richard Feely (U.S.A.)

Dr Michael Foreman (Canada)

Dr Roger Harris (U.K.)

Dr Ove Hoegh-Guldberg (Australia)

Dr Harald Loeng (Norway)

Dr Liana McManus (U.S.A./Philippines)

Dr Martin Visbeck (Germany)

Dr Akihiko Yatsu (Japan)

Local Organizer

Instituto Español de Oceanografía (IEO),

Centro Oceanográfico de Gijón

2 Symposium on the Ecosystem Approach with Fisheries Acoustics and Complementary Technologies (SEAFACTS)

Conveners: Rudy J. Kloser (Australia), Egil Ona (Norway), and David A. Demer (USA)

Venue and dates: Bergen, Norway, 16–20 June

Overexploitation of a single aquatic species can result in significant changes in populations of other living resources and the function and structure of their ecosystem. This situation led the International Council for the Exploration of the Sea (ICES) to adopt an ecosystem-based approach to fishery management (EBFM). This requires efficient multidisciplinary monitoring with the main aim of understanding ecosystem processes by detecting significant changes in ecosystem components, and determining whether these changes are attributable to harvesting or natural or anthropogenic changes in the biotic and abiotic environment. Such monitoring requires acoustic and complementary measures of species at all trophic levels, as well as their biotic and abiotic environments, at ecologically important temporal and spatial scales.

To address these challenges, ICES sponsored the 2008 Symposium on the Ecosystem Approach with Fisheries Acoustics and Complementary Technologies (SEAFACTS), as a forum for information exchange among fishery acousticians, physicists, engineers, biologists, and ecologists. It was held in Bergen, Norway, from 16 to 20 June 2008. There were 322 participants from numerous scientific disciplines and 37 countries. SEAFACTS was the sixth symposium organized by the ICES in a series concerned with acoustics in fisheries and related fields that spans more than half a century. The focus of these symposia has changed over the years. Initially, the emphasis was almost entirely on acoustic methods for fish detection and biomass measurement in large bodies of water. As the technology developed and fishery science became more sophisticated, however, the scope of the symposia extended to include work on biota spanning all trophic levels, and interactions of biota with each other and their abiotic environments. Further, new technologies such as autonomous underwater vehicles, stereo cameras, and lidar emerged, to offer exciting prospects for supporting EBFM, especially when they are applied as complements to traditional and emerging acoustic technologies.

EBFM requires fishery acoustics and complementary technologies to be pushed to their limits to address difficult multidisciplinary issues concerning the exploitation, conservation, and sustainability of living resources in the sea and freshwater.

The steering committee selected 124 verbal presentations and 100 posters for the programme. These 224 presentations gave participants a unique overview of a wide range of technological advances and multidisciplinary research relevant to EBFM. The presentations were given within the five theme sessions:

1. Ecosystem and fisheries monitoring
2. Remote classification and identification
3. Target strength modelling and measurement
4. Behaviour and assessments
5. Data quality and integration into ecosystem models

The session chairs and rapporteurs summarized the presentations in each theme for the 2008 meeting of the ICES Working Group on Fisheries Acoustics, Science and Technology (WGFAST), held at the Science Centre, VILVITE, Bergen, Norway on 23

June. WGFAST used the symposium to review the state of the science and develop a work plan of ongoing research needs to address the relevant directions within the ICES 2009-2013 science plan (ICES, 2008). The salient points were highlighted, and the above text included, in the Introduction to the SEAFACTS proceedings (Demer et al., 2009), guest edited by David A. Demer (USA) and David N. MacLennan (Scotland), and published online early in 2009 and on paper in July 2009.

References

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ICES. 2008. Report of the Working Group on Fisheries Acoustic Science and Technology (WGFAST), 23 June 2008, Bergen, Norway. ICES Document CM 2008/FTC: 08. 40 pp, http://www.ices.dk/reports/FTC/2008/wgfast08.pdf.

3 Symposium on Herring: Linking biology, ecology, and status of populations in a changing environment

Conveners: Maruice Clarke (Ireland), Mark Dickey-Collas (The Netherlands), and Aril Slotte (Norway).

Venue and dates: Galway, Ireland, 26–29 August 2008

Are herring really important in northern ecosystems? This was one of many questions that over 100 participants of the ICES/PICES/GLOBEC symposium Linking Herring considered in Galway this August. The symposium was designed to update, synthesise and move forward our current understanding of herring and the role it plays in both the Pacific and Atlantic systems. The majority of the participants were scientists, but the symposium was also well attended by fishers and those involved in the fisheries advisory process. Galway again proved itself a great location for conferences, especially as the weather encouraged people to remain indoors and enjoy the Irish fare.

The study and management of herring has been an important innovator in fisheries science and the institutions that provide advice. The conference key note by Mike Sinclair (Canada) illustrated many of the paradigm shifts that have occurred as a result of studies on herring. There was a need for an update on the assessing of herring and recent developments in herring biology. These two subjects were introduced by John Simmonds (Scotland) who gave a thorough overview of counting herring through surveys and assessments and by Audrey Geffen (Norway) who gave a very interesting talk on advances in herring biology. It was clear that if you study herring, you should expect plasticity and change. Audrey commented that she liked studying herring "because there were no wrong answers" and her talk certainly showed that populations of herring are very adaptive through their large phenotypic plasticity. John commented that you should survey herring when "the abundance is high and the flux is low" and after a talk by Claude LeBlanc (Canada) the symposium discussed the use of commercially derived acoustic surveys to assess trends in herring populations. This developing research area requires much more work. The issue of disease and parasitism in the regulation of herring populations was raised and it was agreed that it should be considered population ecologists.

After the first day of talks the conference was keen to talk about variable production and population integrity/connectivity as these issues kept arising in the earlier sessions. The session keynote David Secor (USA) showed that different patterns in connectivity will result in different perceptions of populations than the reality. This was also highlighted by Laurie Kell (UK). Considering the variable but ubiquitous mixing at various life stages, and the mating behaviour of herring, it was not surprising that stock identification through current genetic methods was poor and the estimates of effective population size in herring was extremely large when compared to other fish. It appeared that no global model for life history closure and population integrity was applicable to herring. Many talks illustrated changes in growth, fecundity, condition, recruitment that thus impact on the intrinsic population production of herring. As stated above, when working with herring expect change.

The final sessions flowed well from the previous talks as they considered the role of herring and the management of herring in the system. Andrew Bakun (USA) showed that the complexity of the system meant that understanding the impact of herring in even simple system was going to be difficult. The role of herring as a "wasp waist" organism meant that it interacts in many different ways and it was like studying an African savanna "where the zebra also eat lion cubs". It was folly to consider stationarity in either rates of processes or in the ranking of relevant processes that determine the position of herring in an ecosystem. The session showed that herring not only impact on but are impacted by salmon, whales, seals, cod, capelin, plankton and many other organisms. Thus managing herring fisheries was also complex and this was highlighted by the final key note speaker Martin Pastoors (ICES). He commented that advisory and management structures must change to allow effective communication, trust and transparency especially when moving from single species management to the management of fisheries that exploit components of the ecosystem.

The symposium was viewed as a success as it allowed debate and synthesis to occur on many factors that are current when thinking about herring in the ecosystem. The proceedings will be reviewed and published in the ICES Journal of Marine Science in 2009.

4 Coping with global change in marine social-ecological systems

Conveners: R. Ian Perry (Canada), Rosemary Ommer (Canada), and Philippe Cury (France)

Venue and dates: FAO, Rome, Italy, 8–11 July 2008

Summary:

An international symposium on "Coping with global change in marine social-ecological systems", co-sponsored by GLOBEC, Eur-OCEANS, and FAO, was held 8–11 July 2008 at FAO Headquarters in Rome, Italy. The meeting was supported by ICES along with GLOBEC, the European Network of Excellence for Oceans Ecosystem Analysis (Eur-OCEANS), FAO, the Institut de Recherche pour le Développement (IRD), Institut français de recherche pour l'exploitation de la mer (IFREMER), Scientific Committee for Oceanic Research (SCOR), the North Pacific Marine Science Organisation (PICES), the Integrated Marine Biogeochemistry and Ecosystem Research program (IMBER), the Social Sciences and Humanities Research Council of Canada (SSHRC), the WorldFish Centre, and was endorsed by the International Human Dimensions Programme (IHDP).

ICES sponsored the participation of one invited Keynote speaker (Dr Katrina Brown, School of Development Studies, University of East Anglia, Norwich NR4 7TJ, UK) and one of the six members of the Distinguished Closing Panel (Dr Poul Degnbol, Adviser – Scientific Matters, DG Maritime Affairs and Fisheries, European Commission, 79 Rue Joseph II, Brussels 1000, Belgium). The support by ICES of this symposium and of these participants is gratefully acknowledged.

The background materials to the meeting noted that humans are integral components of social-ecological systems. Such systems have marine (including physical-biological) and human (including cultural, management, economic, and socio-political) components which are highly inter-connected and interactive. Changes in marine ecosystems have impacts on and consequences for, the human communities that depend on these systems, but how these human communities respond to these changes can have reciprocal impacts on marine ecosystems. However, "natural" marine ecosystems are usually studied independently from their human components, and by different scientific disciplines with different scientific traditions ("natural" scientists; "social" scientists and humanists). Understanding the important issues and collaborating with other disciplines is essential to correctly interpreting the causes and dealing with the consequences of global changes in marine social-ecological systems.

The central goals of the symposium were to share experiences across disciplines and to identify key next steps and common elements and approaches that promote resilience of marine social-ecological systems in the face of global changes. This involved:

1) exploring conceptual issues relating to social-ecological responses in marine systems to global changes;
2) analysing case studies of specific examples of social-ecological responses in marine systems to significant environmental changes manifested locally;

3) synthesizing the work of natural and social scientists and building comparisons of social-ecological responses in marine ecosystems subjected to major environmental variability;

4) developing innovative approaches to the use of science and knowledge in management, policy and advice;

5) identifying lessons for governance for building resilient social-ecological systems.

The symposium was highly successful, and achieved these goals. Over 150 people participated, from 38 countries. The presentations and posters dealt with issues of economics, society, environment, and technology as these relate to coastal and ocean issues in the face of both social (e.g. globalization) and natural (e.g. climate) global changes. It was noted that wild capture fisheries are fundamentally different from other food production systems, and therefore their responses to environmental and climate changes must be considered separately from those of terrestrial food production systems.

Keynote presentations (by Fikret Berkes, Bonnie McCay, Katrina Brown, and Judith Kildow) emphasized that fisheries are linked social-ecological systems which require a humans-in-ecosystems approach. Including people leads us to recognize larger and more complex "communities" (e.g. of fish and fishers) which include exploiters, drivers, and disrupters. The interactions among multiple social, economic, and environmental stressors are particular challenges (as underlined by recent rises in fuel prices) and suggest that a resilience perspective focused on adaptive capacity would be a useful approach. There was also discussion that we should move from the narrowly defined government regulatory approach to include broader concepts of governance to deal with these complex systems.

Discussion:

The final panel and summary session pointed out that not all global changes will be negative, that there will be winners and losers, and that some industrial development strategies, intended to reduce poverty in fishing communities, may inadvertently undermine their economic basis and make their poverty worse. It was also noted that exposure, susceptibility and resilience vary immensely, and that one framework and policy response may not apply to all situations. In which case, the important question is how can policies be developed which are flexible and support a wide range of adaptation situations? Fisheries stock assessments, it was noted, have yet to fully integrate the environment, climate change, ecology and human behaviour into their models and management recommendations. This is a critical step in the implementation of science-based ecosystem approaches and should be a priority. Thus, continued development of models will remain very important, as will continued synthesis and integration of the work of natural and social scientists.

Several presentations noted that, although life is mostly lived locally, we must continue to think globally, while remembering that most fishers' perspectives are decidedly local, and their lives are embedded in the particular local environment in which they live, we must also promote international cooperation and support to help humanity face the challenges posed by global change. A coordinated worldwide system to monitor global changes needs much additional development. New conventions may also be needed to help the world's nations to cooperatively engage in problem solving and coping with global change—in particular as it affects marine environments. Organizations and programmes such as ICES, FAO, UNEP, GLOBEC, and others can play important leadership roles to bring about this enhanced international cooperation.

Further information about the symposium, including links to the presentations and posters, is available on the symposium website at www.peopleandfish.org.

Publication Plans:

Publication of the symposium proceedings, in either/or a book or journal special issue, is planned for the near future.

Conclusions:

The participation at this symposium by both "natural" and "social" scientists, who do not normally meet together, and discussions during breaks and in the evenings, was extraordinary. It demonstrated the significance and timeliness of the topic of this symposium. Several comments were made that a follow-up symposium should be held in a few years, perhaps devoted to more specific topics. There is great scope for continued progress in such coupled marine social-ecological systems.

5 The Role of Marine Mammals in the Ecosystem in the 21st Century

Conveners: Garry Stenson (NAFO) and Tore Haug (ICES)

Venue and dates: Dartmouth, Canada, 29 September–1 October 2008

The Symposium "The Role of Marine Mammals in the Ecosystem in the 21st Century" was held on 29 September – 1 October 2008 in Dartmouth, Canada. The sponsors were NAFO, ICES and NAMMCO. The symposium was attended by about 70 scientists from 10 countries.

In 1995, NAFO and ICES sponsored a successful symposium on the ecological role of marine mammals. The current symposium presented new findings on the syntheses of information over ecosystem components, on biological and physical aspects of the environment, and on new research approaches to understanding the role of marine mammals. The symposium was organised in four theme session, each session starting with an invited key-note speaker and followed by both contributed oral and poster presentations from participants.

Session 1: Biological and environmental factors affecting life history traits, included a key-note talk given by Dr Mark Hindell (University of Tasmania, Australia) who examined the complex interplay between phylogenetic history and environmental factors in shaping life history traits in marine mammals. The session included 6 oral and 2 poster presentations that addressed issues related to the reproduction, recruitment and mortality in seal and whale populations. The influence of contaminants and environmental factors were also discussed.

Session 2: Foraging strategies and energetic requirements, began with a key-note talk by Dr Dan Costa (University of Santa Cruz, USA) who addressed the issue by asking what would be the management and conservation implications of species specific foraging strategies and energetic requirements. The session included 10 oral and 2 poster presentations. Issues addressed in this session included foraging behavior, strategies and ecology of baleen whales and dolphins, and habitat use and seasonal changes in energy intake and body condition in seals.

Session 3: Theoretical considerations on apex predators and multispecies models. In his key-note address, Dr Andrew Trites (University of British Columbia, Canada) suggested that, although it is evident that the interaction between marine mammals and their prey influence the structure and dynamics of marine ecosystems and, similarly, that predators and prey have shaped each other's behavior and life history traits, there is little empirical evidence of these influences. However, ecosystem models are valuable tools to better understand these problems. The session included 9 oral and 5 poster presentations. Issues addressed included methods of estimating diets, prey selection, spatial distribution, uncertainty in abundance estimation and multispecies modeling.

Session 4: Marine mammal – fisheries interactions. The key-note speaker was Dr John Harwood (University of St Andrews, UK) who used his talk to quantify direct and indirect marine mammal – fisheries interactions and to discuss how such interactions can be incorporated into the ecosystem approach to fisheries. The session included 7 oraland 5 poster presentations. These addressed various bycatch issues, direct interactions between seals/whales and particular fisheries, and the consumption of resources of interest to fishers by marine mammals.

The symposium ended with a general discussion where the participants identified the progress that had been made in the past 13 years and discussed future research that will advance our understanding of the role of marine mammals in the ecosystem.

After the symposium all contributors were invited to submit final papers which, if accepted after peer review, will be published in a special symposium issue of the *Journal of Northwest Atlantic Fishery Science* (sponsored by NAFO). The issue will also include a more comprehensive summary of the entire symposium. The conveners wish to thanks the participants for their contributions and in making this a most informative and enjoyable three days. We also wish to thank the sponsors and the on-site support given by the NAFO Secretariat.

6 Symposium on the Ocean in a High-CO_2 World

Conveners:

James Orr (Chair) – IAEA Marine Environment Laboratories, Monaco; Ken Caldeira – Carnegie Institute of Washington, Stanford University, USA; Victoria Fabry – California State University, USA; Jean-Pierre Gattuso – Laboratory of Oceanography, Villefranche, France; Peter Haugan – University of Bergen, Norway; Patrick Lehodey – Collecte Localisation Satellites, France; Silvio Pantoja – University of Concepcion, Chile; Hans-Otto Poertner – Alfred Wegener Institute, Germany; Ulf Riebesell – IfM-GEOMAR, Germany; Tom Trull – CSIRO Antarctic Climate and Ecosystems Cooperative, Australia.

Venue and dates: Monaco, 6–9 October 2008

Introduction

Fossil-fuel combustion releases carbon dioxide (CO_2) to the atmosphere, leading to a warmer climate. But there is another direct impact of increasing CO_2 in the atmosphere. It is changing the chemistry of the ocean.

The ocean absorbs CO_2 from the atmosphere at a rate of more than 20 million tons a day, thus removing one-fourth of the anthropogenic CO_2 emitted to the atmosphere each year (Canadell, 2007; GCP, 2008) and thereby reducing climate-change impacts of this "greenhouse gas". But this benefit to humanity does not come without a cost to the ocean. When CO_2 dissolves in seawater, it forms carbonic acid. As this ocean acidification continues, it decreases both ocean pH and the concentration of carbonate ion, the basic building block of the shells and skeletons of many marine organisms.

Since the beginning of the Industrial Revolution, ocean acidity (defined here as the hydrogen ion concentration) has increased by 30%. This change is about 100 times faster than any change in acidity experienced during the last many millions of years. Within only a few decades, surface waters in the coldest parts of the ocean are projected to start becoming corrosive to the calcium carbonate shells of some marine organisms. But large unknowns, including the potential for organisms to adapt and the propagation of effects through ecosystems, need to be studied in order to evaluate ecological and economical impacts.

In May 2004, the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission of UNESCO (UNESCO-IOC) co-hosted an international symposium, "The Ocean in a High-CO_2 World", to evaluate what is known about these issues, as well as the potential benefits and impacts associated with proposed strategies to mitigate increasing atmospheric CO_2 concentrations by sequestering carbon in the ocean. This symposium brought together 120 of the world's leading scientists from 18 countries with expertise in marine biology, chemistry, and physics in order to piece together what was known about the impacts of ocean acidification on marine ecosystems and to identify the research priorities needed to understand the mechanisms, magnitude, and time scale of these impacts. The journal *Nature* recently referred to this symposium as "a turning point in expanding awareness among scientists about acidification" (Goldston, 2008). Following this symposium, several national and international organizations requested SCOR and the IOC to keep this issue under review, and their governing bodies agreed to make this symposium a regular event to be held every 4 years.

The 2nd symposium on *The Ocean in a High-CO_2 World* was held during 6–9 October 2008 at the Oceanography Museum of Monaco under the High Patronage of His Serene Highness Prince Albert II. The symposium was again sponsored by SCOR and IOC-UNESCO as well as the International Atomic Energy Agency's Marine Environment Laboratories and the International Geosphere-Biosphere Programme. Additionally, it was supported financially by the Prince Albert II Foundation, the Centre Scientifique de Monaco, the U.S. National Science Foundation, the International Council for the Exploration of the Sea, the North Pacific Marine Science Organization, the Oceanography Museum, and the Monaco Government.

The meeting brought together 220 scientists from 32 countries to assess what is known about the impacts of ocean acidification on marine chemistry and ecosystems, covering 9 themes:

future scenarios of ocean acidification, effects of changes in seawater chemistry on nutrient and metal speciation, paleo-oceanographic perspectives, mechanisms of calcification, impacts on benthic and pelagic calcifiers, physiological effects from microbes to fish, adaptation and micro evolution, fisheries and food webs, and impacts on biogeochemical cycling and feedbacks to the climate systems. The symposium also addressed acidification issues related to intentional subseabed storage of CO_2, impacts on economics, and links with policy. The symposium included invited and contributed talks, posters, and three discussion sessions: 1) natural and artificial perturbation experiments to assess acidification; 2) observation networks for tracking acidification and its impacts; and 3) scaling organism-to-ecosystem acidification effects and feedbacks on climate.

As a follow-up, results from this 2nd symposium are being disseminated via four documents: (1) a Research Priorities Report, (2) a Summary for Policymakers; (3) a Conference Declaration; and (4) a special issue of the peer-reviewed journal Biogeosciences, offering a subset of the contributed research papers. This document is the Research Priorities Report, which highlights the new findings and documents the research priorities that were identified by the symposium participants during the discussion sessions. It was prepared by the symposium's international planning committee, and it is intended for ocean scientists and research program managers throughout the world.

Science Summary

Anthropogenic ocean acidification is rapid in the context of past natural changes. Surface ocean pH has already dropped by 0.1 units since the beginning of the Industrial Revolution, which is equivalent to a 30% increase in hydrogen ion concentration (referred to here as acidity). This rate of acidification has not been experienced by marine organisms, including reef-building corals, for many millions of years. The future chemical changes that will occur in the ocean as a result of increasing atmospheric CO_2 are highly predictable. Across the range of IPCC SRES scenarios, surface ocean pH is projected to decrease by 0.4 ± 0.1 pH units by 2100 relative to preindustrial conditions (Meehl *et al*, 2007). A previous natural ocean acidification event that occurred approximately 55 million years ago at the Paleocene-Eocene Thermal Maximum (PETM) is linked to mass extinctions of some calcareous marine organisms (Zachos *et al*., 2004). After the PETM's relatively rapid onset of acidification, which could have lasted for many centuries or millennia, it exhibited a slow recovery period that spanned millions of years. Today's anthropogenic "acidification event" differs because it is human-induced and because it may be occurring much more rapidly. Previous natural acidification events may have been associated with the five major coral mass extinction events that are known to have occurred during Earth's history (Veron, 2008). Recovery from the current large, rapid, humaninduced perturbation, if left unchecked, will require thousands of years for the Earth system to reestablish even roughly similar ocean chemistry (Archer, 2005; Montenegro *et al*, 2007; Tyrrell *et al*., 2007; Archer and Brovkin, 2008), and from hundreds of thousands to millions of years for coral reefs to be reestablished, based on past records of natural coral-reef extinction events (Veron, 2008).

Ocean acidification is already detectable. Time-series records of ocean carbon chemistry over the last 25 years show clear trends of increasing ocean carbon and increasing acidity (decreasing pH) that follow increasing atmospheric CO_2 (Bates *et al*., 2007). These trends correspond precisely with what is expected from basic marine chemistry (Caldeira *et al*., 2007). Over the last two decades, there have also been measurable decreases in the shell weights of Southern Ocean pteropods (Roberts *et al*., 2008) and foraminifera (Moy *et al*., 2008) while corals on the Great Barrier Reef have shown a recent decline in calcification (Cooper *et al*., 2006). However, more studies are needed to verify that these declines in shell weights are due to ocean acidification.

Severe biological impacts may occur within decades. Projections of the saturation levels of aragonite (a metastable form of calcium carbonate used by many marine organisms) indicate that calcification rates in warm-water corals may decrease by 30% over the next century (Gattuso *et al*., 1999; Langdon and Atkinson, 2005). By the middle of this century, calcification rates of many warm-water corals are expected to drop to the point that they will be outpaced by erosion (Erez, 2008; Gattuso, 2008a; Kleypas, 2008, Langdon, 2008), which would have serious impacts on coral reef ecosystems. Cold-water corals, which are found in deep waters, may also be in danger. These corals serve as habitat for many commercial fish stocks, and today virtually all of them are bathed in waters that are supersaturated with respect to aragonite. Yet by 2100, it is projected under the IS92a scenario that about 70% of these cold-water corals will be exposed to waters that are undersaturated with respect to aragonite, which would be chemically corrosive to their skeletal material (Guinotte *et al*., 2006). In manipulative experiments with coldwater corals, when ambient pH was reduced by 0.15 and 0.3 units, calcification rates declined by 30 and 56% (Maier *et al*., 2008). Some coastal waters in the Northeast Pacific have recently become undersaturated with respect to aragonite during spring due to upwelling onto the continental shelf of intermediate waters enriched in anthropogenic CO_2 (Feely *et al*., 2008). Off Iceland, invasion of anthropogenic CO_2 into deep waters is causing deep waters to undergo this same transition to "corrosive" conditions, from being saturated with respect to aragonite to being undersaturated: every day, 1 km^2 more of seafloor is exposed to these conditions, as are associated bottom-dwelling organisms (Olafsson *et al*., 2008). This transition to undersaturated conditions is projected to occur within decades in surface waters over much of the polar oceans (Caldeira and Wickett, 2005; Orr *et al*., 2005; McNeil and Matear, 2008; Orr *et al*., 2008).

Marine organisms exhibit a range of responses to ocean acidification. Studies of marine calcifiers indicate that most but not all of them exhibit reduced calcification with increased ocean acidification (Fabry *et al*., 2008). Marine calcifiers differ because they have different mechanisms that control their internal microenvironment where calcification takes place. Also, different life stages of marine calcifiers respond differently. These differences need to be taken into account when designing experiments to evaluate likely future changes in calcification rates due to ocean acidification. The majority of sensitivity experiments have been carried out on adults of a limited number of species using short-term experiments. Studies are now examining the different life-cycle stages of organisms to identify which ones will be affected most severely. Early life stages may be particularly sensitive to acidification. For example, ocean acidification negatively affects sea urchin reproduction by reducing sperm motility and swimming ability, lowering fertilization success, and impeding embryo and larval development (Havenhand *et al*., 2008). One oyster species that was selectively bred to resist disease has been shown to be more resistant to acidification impacts (Parker *et al*, 2008), which raises the hope that under the right circumstances some organisms might be able to adapt to some degree. In contrast, longer experiments with calcifying phytoplankton, coccolithophores, indicate no adaptation to high CO_2 after even after 150 generations (Müller *et al*., 2008). Meanwhile, there is an open debate about the potential effects of acidification on coccolithophores (Riebesell *et al*., 2008; Iglesias-Rodriguez *et al*., 2008). Elevated CO_2 from ocean acidification affects a suite of physiological mechanisms (Pörtner, 2008). Effects of ocean acidification on ecosystems may occur first and be strongest where marine species are already stressed by effects from anthropogenic warming. Physiological studies support the development of a cause and effect understanding for phenomena ranging from performance changes in individual species to changes in species interactions and phenologies at the ecosystem level (Pörtner and Farrel, 2008).

Naturally low pH environments provide a glimpse of ecosystems in a high-CO_2 world. Insights into how ecosystems may adapt to a high-CO_2 environment have been gained from natural environments near seafloor vents that emit CO_2 at ambient temperature as well as in regions with naturally varying pH gradients such as coastal upwelling systems. The high-CO_2, shallow, seafloor vent areas around Ischia, Italy, in the Bay of Naples show that when mean pH conditions reach values that are expected for the end of the century, there is a total absence of some species, generally reduced biodiversity, and regime shifts to completely different ecosystems, where sea grasses and invasive species thrive (Hall-Spencer *et al*., 2008). Living gastropods also show severe eroding and pitting of shells in areas when average pH declines to 7.4 or less. There is a substantial decrease in species abundance in this area before mean pH drops below 7.8. Another case is the warm-water coral reefs that are found in naturally high-CO_2, low pH waters of the eastern tropical Pacific, which are less cemented and more prone to bioerosion (Manzello *et al*., 2008).

Socioeconomic and policy perspectives

Ocean acidification may affect fisheries, tourism, and stabilization of atmospheric CO_2. Effects of ocean acidification may propagate from individual organisms up through marine food webs, which could affect the multi-billion dollar commercial fisheries and shellfish industries as well as threaten protein supply and food security for millions of the world's poorest people.

Coral reefs generate billions of dollars through tourism each year and serve as habitat for onefourth of the world's fish species during at least part of their lifetime. Unfortunately, coral reefs appear particularly vulnerable because of the combined impacts of coral bleaching, caused by increased water temperatures, and ocean acidification, which will reduce calcification and weaken reef structure. With the development of carbon markets and international agreements to cap CO_2 emissions, a price tag can now be assigned to the acidification-driven degradation of the ocean's large capacity to absorb CO_2. With the carbon market price range of US$20 to $200 per ton of carbon, the ocean's current annual capacity of 2 gigatons of anthropogenic carbon per year represents an annual subsidy to the global economy of 40 to 400 billion dollars, which is about 0.1 to 1% of the global gross domestic product (Held, 2008). The ocean's capacity to take up anthropogenic CO_2 is being degraded by ocean acidification, which will make it more difficult to stabilize atmospheric CO_2 concentrations.

Costs of stabilizing atmospheric CO_2 much lower than inaction. Conventional wisdom of climate economics held that it would be too costly to mitigate greenhouse gas emissions to reach a target of 450-ppm CO_2 equivalents (CO_2e) (Nordhaus and Boyer, 2000). Unfortunately, stabilizing atmospheric CO_2 at that level still runs a 54% chance that the anthropogenic increase in global-mean temperature will surpass 2°C (Mei n-shausen, 2006). However, more recent economic analyses are more optimistic about how innovation spurred by investments in lowcarbon technologies will reduce costs. A suite of carbon cycle-economy models predict the cost of pursuing the 450-ppm CO_2e target to be about 0.5% of the world GDP (Edenhofer *et al*., 2006). Sir Nicholas Stern estimates that the cost to attain the same 450-ppm level would be about 2% of GDP (Stern [2006] estimates updated in June 2008). Similar estimates also are provided by the recent report to the Australian government (Garnaut, 2008). These costs are considered tolerable by most economists and are much smaller than would be those associated with inaction.

Achieving stabilization will require urgent, unprecedented cuts in global emissions. Although economically feasible when viewed over several decades, stabilising at even 650 ppmv CO_2e (roughly 530 ppm CO_2) would require that CO_2 emissions peak by 2020 and that they be reduced at a rate of 3% per year, which is equivalent in magnitude to the present rate of increase (Anderson and Bows, 2008). Such unprecedented cuts in global emissions will require swift implementation of ambitious international agreements complemented by local, regional, and national initiatives that lead the effort to meet this challenge early on and then go beyond.

Decision-makers need science-based policy advice. Scientific research formulates and answers scientific questions. But these answers may be far removed from what is needed by policymakers. In order to ensure the relevance, usefulness, and dissemination of results from acidification research, it needs to be formulated while considering policymakers as critical endusers. For ocean acidification research projects, the associated user groups should include policy experts with interests that span the relevant environmental, industry, and conservation sectors. These users should advise research scientists about what types of analyses and products would be most useful to managers and decision-makers, what format and nature the policy-related messages should take, and what are the best ways to disseminate results. These special users should also strive to integrate the resulting scientific findings into their own sector and organizations. An example of this type of group is the Reference Users Group of the European Project on Ocean Acidification (see http://www.epoca-project.eu).

Discussion Group Reports

Following the invited and contributed oral presentations, which were all held in plenary session, symposium participants divided themselves into three separate discussion groups. Each group met for 2 ½ hours and then returned to the final plenary sessions to report back on group discussions, to make recommendations, and to promote questions and further discussion.

These three groups addressed perturbation studies, observational networks, and scaling up results and climate feedbacks.

Group 1: Natural and artificial perturbation experiments to assess acidification.

Chair: Ulf Riebesell (IFM-GEOMAR, Kiel, Germany)

Rapporteur: Steve Widdicombe (Plymouth Marine Laboratory, UK)

Charge to Group 1:

a) What experiments have been most useful to understand the potential effects of ocean acidification?

b) What have been the limitations in previous perturbation experiments?

c) How can these limitations be overcome?

d) What new perturbation experiments would help us better understand ocean acidification and its effects on fisheries and ecosystems?

Approaches

The group discussed the range of natural and artificial perturbation approaches that have been used to assess ocean acidification impacts. The discussion covered a range of paleoceanography studies, spatial variability studies, and use of mesocosms and modeling.

These studies include

- Highly (or fully) controlled single-species laboratory experiments to look at species responses, to improve understanding of physiological mechanisms, and to identify longer-term, multi-generational, adaptation responses;
- Microcosms and mesocosms to elucidate community responses and to validate and upscale single-species responses;
- Natural perturbation studies from CO_2 venting sites and naturally low pH regions such as upwelling regions, which provide insights to ecosystem responses, long-term effects, and adaptation mechanisms in low-pH environments;
- Manipulative field experiments; and
- Mining the paleo-record to develop and test hypotheses.

While many of these approaches for ocean acidification research are new and there are currently no common guidelines for best practices, scientists agreed that even "mistakes" in applying these approaches have increased our understanding of the mechanisms of organism and community response.

Limitations

One of the greatest current limitations is the lack of comparability among experiments. There is often insufficient description of the carbonate system parameters or other environmental conditions. Experiments use different pH scales, and the scale that is used is often undocumented. There is inadequate information about animal condition and there are problems when experiments are carried out with stressed animals. There are discrepancies between the use of wild and cultured specimens, and differences in practices of pre-acclimation, where an organism is slowly acclimated to the stressor rather than responding to sudden exposure. For paleo-studies, a significant limitation is the mismatch between paleo and modern ecosystems.

Other limitations include difficulties with experimental approaches and lack of coordination or agreement on methods, protocols, and data reporting, such as

- Problems with reproducibility of observations;
- Organisms that have been kept in culture for many years have been used for experiments, but may no longer be representative of natural populations, a problem that is well-known in human cell cultures;
- Experiments are limited to those species that are easy to maintain in the laboratory, thus ignoring many sensitive species;
- Studies have examined a single process (e.g., respiration, calcification, growth, etc.) without considering the integration of changes in multiple processes into the wholeorganism response to high CO_2;
- Ecological processes are not sufficiently studied, including the importance of vulnerability at different life stages of the organisms, competition, and trophic interactions;
- Difficulties with maintaining natural conditions (e.g., food supply, densities) are prevalent;
- Investigators often report observations rather than try to identify the mechanisms responsible;
- Differences in perception of what makes a good or publishable result affects what is published, whereas the community also needs to hear about "mistakes" and conditions that produced no significant effects, so that we can learn from them;
- Dissemination of results and conclusions has been slow; and
- Communication among disciplines has been limited at best.

Overcoming limitations

To overcome many of these limitations, the group highlighted the importance of three key aspects: improved collaboration, increased funding, and greater public awareness.

Collaboration is needed to optimize limited resources, highlight common priorities, and facilitate greater data and information sharing. Several current technological limitations may be overcome through closer collaboration with engineers. Material from experiments, such as tissue or shell samples, should be shared more readily. Agreements on standards and best practices are needed, including the type of metadata that must be reported. Facilities and groups with expertise in mesocosms, laboratory manipulations, or particular analytical techniques should be identified to facilitate sharing of both expertise and facilities. Working groups on key organisms should be organized to review current knowledge and develop best practices for experiments. Communication is a key tool for overcoming many of the current limitations, and an effort should be made to announce experiments long in advance in order to encourage collaboration and ensure that other researchers from different disciplines can benefit from experimental material or data. A calendar of upcoming acidification experiments should be developed and maintained; associated Web sites should be improved to provide comprehensive information on ocean acidification activities.

Efforts to improve public awareness are crucial to overcoming limitations in ocean acidification research as well as funding. One suggestion is to identify several charismatic species that could serve as "acidification ambassadors" in museums, aquaria and schools, with experiments and videos explaining ocean acidification and its potential impacts on marine life.

New and improved experiments

Group 1 discussed needs for new types of experiments and approaches as well as the needs for improving and enhancing current approaches. Suggestions include

- Develop an approach to link pelagic and benthic mesocosm studies;
- Improve the links between physiologists, ecologists and fisheries scientists to begin to look at integrated food webs;
- Enhance benthic and pelagic mesocosms and Free-Ocean CO_2 Enrichment-type systems to scale up and validate laboratory experiments;
- Carry out long-term perturbation studies to look at adaptation and micro-evolution;
- Apply a whole-organism approach with multiple end points, both physiological and behavioral;
- Improve methods to understand underlying mechanisms of calcification for different species;
- Study simple assembled "ecosystems" with multiple trophic levels to assess biological interactions and fluxes among organisms and across trophic levels;
- Develop an approach to study community-level responses by identifying simple communities that could be manipulated ;
- Assess what makes some species more tolerant to low-pH, high-CO_2 environments, and identify indicators of vulnerability and tolerance; and
- Develop and enhance the use of open-ocean mesocosms.

The group also discussed the potential for carrying out mesoscale, *in situ* CO_2 enrichment experiments, but repeatedly questioned the scientific value and data return of this approach relative to the large amount of funding that would be required to implement it. Finally, the group discussed the trade-off between the desire for perfect experimental results and the urgency of informing society and policymakers in order to influence CO_2 mitigation efforts.

Group 2: Observational networks for tracking acidification and its impacts.

Chair: Toby Tyrrell (National Oceanography Centre, Southampton, UK)

Rapporteur: Chris Sabine (NOAA/PMEL, USA)

Charge to the group:

a) How can we monitor changing chemistry (environments, sensors, networks, etc.)?

b) How can we detect impacts on calcifiers (techniques, variables, environments, etc.)?

c) How can we detect impacts on other organisms, ecosystems, and fisheries?

d) How do we optimize monitoring efforts to enhance our understanding of ocean acidification?

Tracking acidification and its impacts requires large-scale and sustained programs of *in-situ* measurements. Participants stressed the need for early international cooperation to develop a coordinated, global network of ocean observations that could leverage existing infrastructure and programs as far as possible, while noting the need for additional sites for monitoring and process studies aimed explicitly at ocean acidification.

Key recommendations include

- Develop new instrumentation for autonomous measurements of CO_2 system parameters, particulate inorganic (PIC) and particulate organic carbon (POC), and other indicators of impacts on organisms and ecosystems;
- Maintain, enhance, and extend existing long-term time series that are relevant for ocean acidification;
- Establish new monitoring sites and repeat surveys in key areas that are likely to be vulnerable to ocean acidification;
- Develop relaxed carbon measurement methods and appropriate instrumentation that are cheaper and easier, if possible, for high-variability areas that may not need the highest measurement precision;
- Establish a high-quality ocean carbon measurement service for those unable to develop their own measurement capabilities;
- Establish international collaborations to create a data management and synthesis program for new ocean acidification data as well as data mining and archival for relevant historical data sets;
- Work on developing an ocean acidification index (perhaps saturometry using a standard carbonate material); and
- Initiate specific activities for education, training, and outreach.

One of the key questions regarding responses to ocean acidification is resolving the distinction between "tipping points" and adaptation. Are there geochemical thresholds for ocean acidification (e.g., $CaCO_3$ mineral solubility) that, if crossed, will lead to irreversible deleterious effects on species or ecosystems (i.e., tipping points)? Or are organisms or ecosystems sufficiently elastic that adaptations to changing seawater chemistry will occur that will reduce potential negative impacts of ocean acidification? Ocean acidification-relevant indicators beyond basic water-column carbonate chemistry have yet to be adequately developed. Routinely measurable parameters that reliably detect biotic effects of ocean acidification, such as indicator-species abundance, calcification per cell, biochemical signatures of physiological stress, or ecosystem species composition, do not yet exist but need to be developed and incorporated into a global monitoring network.

Technical Needs

Workshop participants agreed that it is essential to promote the use of standardized measurement protocols and data reporting guidelines for ocean acidification research. An internationally agreed upon guide to best practices for carbon measurements was recently published (Dickson *et al.*, 2007), but other ocean acidification measurements also need to be standardized. The group also thought that a set of relaxed criteria could be developed for making carbon measurements easier and cheaper, for cases that do not require the currently recommended high precision and accuracy. However, it was agreed that the uninformed use of cheap, 'off-the-shelf' pH sensors should be discouraged for most ocean acidification-related purposes, because high-quality results are unlikely to be obtained. Group 2 recommends that for shipboard measurements of the inorganic carbonate system, the two parameters that should be measured are total dissolved inorganic carbon and total alkalinity because certified reference materials (CRMs) currently exist for both (http://andrew.ucsd.edu/co2qc/), whereas no CRMs exist for the other parameters.

Currently, pCO_2 and pH sensors are available for stationary platforms and underway shipboard measurements. Workshop participants emphasized the vital importance of developing autonomous systems for measurement of additional parameters of the seawater CO_2 system, particularly total dissolved inorganic carbon and total alkalinity. Because pCO_2 and pH strongly co-vary, they are not the ideal pair of parameters to measure. Additionally, experimentalists voiced a strong need to develop new methods to quantify the inorganic carbon system in seawater using small-volume samples (5 to 20 ml).

Field Observations

Existing infrastructure and monitoring programs should be leveraged as far as possible. Programs that already monitor organisms or ecosystems could be expanded to also monitor ocean acidification by adding carbonate chemistry measurements. For example, additional measurements and process studies could be conducted at Long-Term Ecological Research sites such as those in the California Current or near Palmer Station in the Western Antarctic Peninsula. Although ship-board surveys will likely be the primary approach for making coordinated multi-disciplinary ocean acidification studies, autonomous sensors on moored buoys and gliders should be used extensively to enhance the global network. For example, carbon sensors should be mounted on the OceanSITES network of moorings. Yet new monitoring sites, process study sites, and surveys, will still be needed in high-sensitivity regions that are critical for understanding ocean acidification. This may be accomplished through the development of regional networks. Satellite algorithms should be examined as a way of assessing ocean acidification in ocean surface waters in conjunction with *in situ* measurements (e.g., LIDAR to detect structural changes in coral reefs).

Attempts should be made to initiate measuring programs that are designed to discern impacts of acidification on calcifying and other marine organisms. Ocean acidification may lead to decreases in size-normalised (1) foraminifera and pteropod shell weight and thickness, (2) average PIC per coccolith, (3) proportions of malformed coccoliths and shells, (4) volumetric calcification rates (rate of uptake of radio-labeled carbon into CaCO3), (5) abundances of calcifying organisms, and (6) average PIC concentration in open-ocean waters. Biological parameters such as these should be measured at time-series sites and on repeat surveys to allow detection of changes over time. After several decades, large-scale inhibition of calcification would also lead to a measurable increase in surface seawater alkalinity. Therefore, repeat surveys that include alkalinity as a measured variable should be encouraged, particularly into areas having high calcification rates, such as the low-latitude Pacific Ocean. Also, archiving of present-day organisms collected on cruises may prove useful for later comparisons.

Data Management

Data management and dissemination must be a part of the ocean acidification research that is planned from the beginning. Data must be reported and archived such that they are readily accessible now and in future decades. Likewise, data mining and archival of historical data may provide useful insights into the evolution of ocean acidification over time. This effort needs to be approached carefully, as there are many historical data that are not of sufficient quality to address these issues. A quality assessment effort should be conducted in conjunction with each data mining effort in order to confirm that data are useful.

Education and Outreach

Workshop participants recognized the necessity for interdisciplinary training of graduate students, post-doctoral investigators, and principal investigators to enhance observation networks, both regionally and globally. Suggestions included holding multi-disciplinary summer schools for experimentalists and modelers, involving national and international scientists.

Initiatives for public outreach and education were also recommended. Meetings with coral-reef managers, fisheries managers and other stakeholders should be held to engage specific communities to develop ideas for monitoring strategies. Participants recommended tapping into existing programs to advance public education at the national and international level. Readily accessible presentations and fact sheets on ocean acidification and its effects on marine life should be created for the public and schools. Additional information should be made available via Web sites.

Group 3: Scaling organisms to ecosystem acidification effects and feedbacks on climate.

Chair: Hans-Otto Pörtner (Alfred-Wegener Institute, Germany)

Rapporteur: Ken Caldeira (Carnegie Institute, USA)

Charge to the group:

a) How can effects occurring on single organisms and small experimental populations be scaled up to ecosystem effects over time?

b) Can genetic changes be detected over experimental or observational periods and, if so, how can genetic changes occurring over these periods be extrapolated in order to evaluate potential effects over longer periods of time?

c) How can known changes in populations of organisms that are expected to be affected by ocean acidification (due currently to forcing from other than ocean acidification) be used to predict the potential future effects of ocean acidification?

Group 3 sub-divided the questions into 5 main topics and addressed the major research questions and key approaches as well as the methods and tools for addressing them.

Scaling up from organisms to ecosystems

Major Research Questions

A set of major research questions was identified to understand how we can scale up from single organisms to ecosystems:

1) Which ecosystems are at the greatest risk from ocean acidification and which of these are most important?

2) Are there clear ecological tipping points that can be defined in terms of pH or carbonate ion concentration?

3) What is the impact of ocean acidification on marine biodiversity?

4) What are impacts of ocean acidification on fisheries, food production, and other human uses or benefits [ecosystem services]?

5) What physiological processes are most important to the scaling issue?

6) What are the impacts of ocean acidification on population levels (consider typical population properties)?

7) How are impacts of ocean acidification on different life stages of individuals reflected at the ecosystem level?

8) How are organism responses and species interactions related?

9) What are the ecosystem-ecosystem linkages (e.g., how will changes in depth of remineralization affect ecosystems below the zone of remineralization) ?

10) What is the potential for migration and avoidance behavior to adjust to pH and carbonate ion changes?

Research Approaches

Scaling up from black-box experimental results on individuals and populations to the ecosystem level requires mechanistic understanding of the physiology and genetics of organisms and how these interact to affect energy flows and ecosystem structures. Several different research and analysis approaches could be used to understand scaling better, including laboratory experiments, mesocosm studies, observations of ocean ecosystems, and ecosystem perturbation experiments. It may be possible to examine analogues from other kinds of environmental disturbance (e.g., overfishing can lead to explosion of sea urchins) to understand food-web effects.

First, it will be helpful to produce a matrix of key physiological processes related to calcification, acid-base control, and other processes affected by changes in pH and carbonate ion concentrations; identify sensitive organisms; and evaluate the role of these organisms in various ecosystems. Some long-term studies show impacts of various factors on ecosystems.

Using these sensitive organisms, laboratory experiments should focus initially on sensitivity indicators such as mortality, stress, and changes in performance to try to understand the mechanistic basis for sensitivity. Experimental conditions should include high- to low-level exposures, short- to long-term exposures, and various stages in the life history of sensitive organisms. Multiple natural populations (in addition to standardized laboratory strains) should be used in such experiments.

The genetics of the effects of changes in pH and carbonate ion concentrations are relatively unknown. It will be necessary to evaluate the plasticity in responses to changes in pH and carbonate ion concentrations, genetic diversity, and the relationship of genetics to sensitivity at population level. Physiological processes will need to be related to gene regulation, diversity, etc. (environmental genomics).

Ultimately, it will be important to model individual species to understand ecosystem-scale adaptation in terms of nutrient cycling, energy transfer through trophic levels, fecundity, etc.

Ocean acidification versus other ongoing changes in the marine environment

Major Research Questions

Because ocean acidification occurs simultaneously with other changes in the global ocean,

Group 3 identified major research questions and associated uncertainties concerning interactions:

1) How do we isolate ocean acidification impacts from other causes of change in the observational context?

2) How do changes in temperature, salinity, light, nutrients, oxygen levels, human behavior (overfishing, pollution) etc, interact with ocean acidification? This includes

   a) Changes in weather and its variability.

   b) Changes in ocean circulation, large-scale cycles

   c) Changes in seasonal patterns, El Niño, etc.

3) Does ocean acidification make sensitive organisms more susceptible to disease?

4) How does ocean acidification affect the success of invasive species?

5) What are the relevant regimes of changes in temperature, pH, etc. that should be used by experimentalists interested in "realistic" scenarios?

Research Approaches:

Developing good observing systems in key areas will be fundamental for understanding how ocean acidification and other global changes interact. These systems should include measurements of ocean carbon system parameters as well as temperature, salinity, winds, nutrients, etc. In addition to good observations, it will be necessary to improve our understanding of the background state of sensitive organisms, including their physiological state (health, reproduction), as well as their burden of parasites and other disease. Multi-factorial experiments, both in the laboratory and in mesocosms, should be conducted. These experiments should rely on standardized protocols while including effective data management, sharing, and archiving. With results from these activities, modeling can be integrated with experiments to provide better understanding of how the systems work, as well as potentially developing predictive capabilities. Modelling efforts can also benefit by integrating results from the research activities related to the scaling up issue.

Scaling in time: adaptation and evolution

Major research questions:

Major research questions related to understanding how sensitive organisms may adapt and evolve over time include the following:

1) To what extent will organisms be able to adapt (or evolve) to deal with ocean acidification?

   a) How fast can this adaptation or evolution occur and how does this compare with anticipated rates of change?

2) To what extent does gene flow and dispersal [life history, generation time] influence adaptability to ocean acidification?

3) Is there evidence of ongoing adaptation or evolution?

   a) What are the key gene regulatory networks for processes relating to ocean acidification?

   b) Are these gene abundances changing in the field?

4) How can changes from ocean acidification be distinguished from the effects of other global changes?

5) What are the relative roles of plasticity, acclimatization, and evolutionary adaptation?

   a) What are differences among closely related populations living in different environmental conditions?

  b) What are the relationships among generation time, plasticity, and adaptation?

6) How will the evolutionary adaptation of species affect species interaction?

7) What are time scales for ecosystem change and recovery?

Approaches:

The first approach would be to compare individuals and populations of the same species living in different areas with different natural pH values, for example, observing natural analogues such as CO_2 vents, understanding that this approach has some limitations. After they are identified, key genes should be monitored in natural populations to determine whether they are changing. An examination and analysis of the paleo-record may provide insights. Long-term laboratory and mesocosm experiments will be needed to study changes at the genetic level over the long-term under environmentally relevant conditions (seasonal cycles, nutrient conditions, variability, etc.), including experiments that slowly ramp up CO_2 concentration to more closely mimic progressive change. Commitment to long-term studies is essential, which is difficult with 2-3 year funding cycles. Finally, selective breeding experiments can help provide information about the adaptability of organisms to changing pH and carbonate ion concentrations.

Feedbacks on climate and the carbon cycle

Major research questions:

Major research questions that should be addressed to understand how ocean acidification could feed back on climate and the carbon cycle include the following:

1) How will ocean acidification affect production of dimethylsulfide (DMS) and other climatically important gases (and therefore climate)?

  a) How will the effects of ocean acidification on gas production interact with climate change?

  b) Are there other important radiative effects of ocean acidification (e.g., ocean albedo)?

2) How will the impact of ocean acidification on the microbial loop affect climatically important fluxes (DMS, other trace gases, carbon export)?

  a. How will the effects of ocean acidification on the microbial loop interact with climate change?

3) What are the long-term climate consequences of effects of ocean acidification on biogeochemical cycles?

  a) How will increased CO_2 content affect sediment dissolution?

  b) Will the effect of CO_2 fertilization significantly impact biogeochemical fluxes?

4) How will ocean acidification affect production of trace gases (e.g., halogen containing gases) that affect the ozone levels?

5) What are time scales for geochemical recovery?

Approaches:

The approaches to study how ocean acidification feeds back on climate and the carbon cycle include modeling, large-scale open-ocean perturbation experiments with CO_2 or a mineral acid, for which both legal and logistical concerns remain, and observation of natural analogues (e.g., upwelling systems).

Other questions to consider include the following:

1) Would intentional or unintentional perturbations to the sulfur cycle affect response to ocean acidification?
2) What is the relationship between proposed carbon sequestration approaches and ocean acidification?
    a) Ocean fertilization
    b) Direct injection
    c) Accelerated carbonate weathering
3) To what extent and at what scale are direct mitigation approaches possible?

The Next Four Years

The first symposium on *The Ocean in a High-CO_2 World* (2004) proved to be a landmark event, even though it brought together only about half the number of scientists as attended the second symposium in Monaco. In 2004, the term "ocean acidification" was not in wide use, and only a small group of specialists had been studying how increasing marine concentrations of CO_2 and corresponding reductions in pH and carbonate ion concentrations were affecting marine organisms, mostly corals. At that time, ocean scientists were primarily studying the beneficial effects of the ocean's great capacity to take up CO_2, thereby moderating the increase in atmospheric CO_2 from fossil-fuel burning. But as the meeting progressed, there was a growing awareness of problems associated with corresponding changes in ocean chemistry and potential impacts on marine organisms.

The first symposium marked a turning point for many scientists, who suddenly understood that the impacts of ocean uptake of CO_2 were as important as assessing the air-sea CO_2 flux. The media also picked up on these growing concerns and interest increased rapidly as papers from the symposium were published in high-profile science journals (Feely *et al.*, 2004; Sabine *et al.*, 2004; Orr *et al.*, 2005) and as scientific reviews were released by the UK Royal Society (Raven *et al.*, 2005), by OSPAR Commission (Haugan *et al.*, 2006), by NSF, NOAA, and the U.S. Geological Survey (Kleypas *et al.*, 2006), and by the German Advisory Council (Schubert *et al.*, 2006).

Four years later, under heightened concern, the scientific community was reunited for a Second Symposium on The Ocean in a High-CO_2 World. The interest in ocean acidification has grown, as demonstrated by the 220 scientists from 32 countries that came to Monaco to participate during October 6-9, 2008. During just the 4 years that elapsed between the two symposia (2005-2008), there have been 168 scientific papers on the topic of ocean acidification, whereas during the preceding 55 years (1949-2004) there were 158 papers (Gattuso, 2008b). Ocean acidification is now widely cited in the press in conjunction with climate change, often being referred to as "the other CO_2 problem". Highlights of some of the recent results that were presented at the second symposium include

- New studies focusing on the polar oceans and when their surface waters will start to become undersaturated with respect to aragonite, leading some scientists to suggest stabilizing atmospheric CO_2 at no more than 450 ppmv to limit these severe conditions;
- New studies indicating that shell weights of Southern Ocean foraminifera and pteropods are decreasing, which may be due to ocean acidification;

- New perturbation experiments showing that the rate of calcification of an Arctic pteropod declines at lower pH
- A new study demonstrating that cold-water coral calcification decreases under high-CO_2 conditions;
- A new study of the impact of increased ocean CO_2 and temperature on larval stages of oysters revealing negative effects from ocean acidification, but also that these effects are much less severe in oysters that have been bred selectively to be more resilient to disease;
- New perturbation experiments revealing deleterious effects of ocean acidification on invertebrate reproduction and larval stages;
- New studies showing how ecosystems react to naturally high-CO_2 conditions near seafloor vents, where ecosystem changes generally follow expected trends based on previous understanding gained from laboratory perturbation experiments; and
- New studies revealing that ocean acidification is affecting sound propagation and noise in the ocean.

Scientists also identified new research priorities, based on needs for further investigation and current limitations for observations, methods, and technology (Section 4). Participants stressed the importance of improving international coordination to facilitate agreements on protocols, methods, and data reporting and to optimize our limited resources by greater sharing of materials, facilities, expertise, and data.

Symposium participants recognized the importance of developing strong links with end-users of ocean acidification research results, in order to guide information and product development and to better disseminate this information to appropriate audiences. Despite major uncertainties, the research community must prioritize finding ways to scale-up understanding of biological responses of individual organisms to provide meaningful predictions of how ocean acidification will affect food webs, fisheries, and tourism. Researchers will also need to develop easy-to-understand information that would be particularly useful to end-users, such as simple indicators of change and thresholds beyond which the ecosystem will not recover.

Increasing atmospheric CO_2 concentrations drive both ocean acidification and climate change, but they are separate issues involving different research communities. Scientists emphasized that there must be a greater effort to integrate results from ocean acidification research, which is still in its infancy, into the IPCC process and post-Kyoto negotiations that are aimed at reducing CO_2 emissions.

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7 World Conference on Marine Biodiversity

Conveners: Carlo Heip (The Netherlands), Carlos Duarte (Spain),

Venue and dates: Valencia, Spain, 11–15 November 2008

Session Highlights by Jake Rice – Conserving Biodiversity – Making Policy, Management Tools, and Scientific Knowledge Work Together

Over 500 scientists from more than 40 countries and 20 international organisations participated in this Conference. The co-convenors, Carlo Heip of the Netherlands and Carlos Duarte of Spain were supported by a scientific steering committee including an ICES representative (Jake Rice) and several members from MarBEF with ties to ICES. MarBEF was the overall motivating group behind the congress, and ICES joined 23 other international bodies with mandates for marine science, conservation of biodiversity, or related themes, as sponsors. ICES was the sponsor of one of the 24 theme sessions entitled "Conserving Biodiversity – Making Policy, Management Tools, and Scientific Knowledge Work Together". The session comprised 12 oral presentations and several related posters, with over 150 participants present for some of the oral presentations.

The session brought out a number of advances in the linkages between advances in scientific knowledge about biodiversity and developments in policy, management strategies and tools, and implementation. The major new policy development on the international stage are the criteria and guidelines for identifying marine – especially seafloor – areas in need of enhanced protection from human activities, in particular the UN FAO Technical Guidelines for Deep-Sea Fisheries on the High Seas, and the CBD Marine and Coastal Resolution IX/20. Application of these criteria to marine ecosystems will be very challenging to the scientific community, but successful efforts may contribute greatly to improved conservation of marine biodiversity.

Presentations from Australia, Canada, and Spain highlighted new efforts at national scales to advance both knowledge about of marine biodiversity and the uptake of that knowledge by policy makers, managers, and society. All stressed the importance of public outreach in such initiatives. With regard to tools and strategies, marine protected areas remain the popular tool for protection of marine biodiversity. Several presentations reviewed benefits arising from various types of MPAs implemented in a variety of ways and with a variety of objectives. Viewed together, the messages from these presentations was that the features of an MPA and particularly the provisions of its management plans really need to determined on a case by case basis, taking account of both the ecological benefits desired from the MPA and the social, cultural and economic context in which the MPA will be managed. Other tools than MPAs are available for conservation of marine biodiversity, including economic tools for ecological valuation and analytical tools such as neural network theory.

The message emerging from the session was that the science community is responding to the urgent need for stronger policies for conservation and sustainable use of, more and better tools, and improved implementation. However, the work has only begun and much more is needed. There is a possibility that threats are increasing faster than knowledge is, and an ever greater possibility that knowledge is increasing much faster than it is being implemented. More research is needed, but there is an even greater need for more communication about marine biodiversity among the research community, policy makers, and managers.