4.0 OCEAN CARBON AND OTHER ACTIVITIES

4.1 IOC/SCOR International Ocean Carbon Coordination Project (IOCCP) *Fennel*

Terms of Reference

- To develop an international communication centre on ocean carbon activities through the development and maintenance of Web-based compilations and syntheses of ocean carbon observation and research activities, and through e-mail and/or Web-based newsletters and other publications;
- To provide an international forum for initiatives to promote high-quality observations to understand the ocean component of the global carbon cycle, through international agreements on standards, including:
    - Methods/Best Practices
    - Quality Control and Quality Assurance Procedures
    - Data and Meta-data Formats
    - Use of Certified Reference Materials
- To facilitate data collection, management (consistent with data exchange policies of the World Data Centres), data product development, and archival of ocean carbon and related data by:
    - Aiding regional and global data syntheses being developed through ocean carbon research programmes, as requested;
    - Facilitating and aiding the development of historical data bases for ocean carbon, including data recovery activities, as necessary;
    - Ensuring long-term data availability by working with data management groups and World Data Centres to archive data sets beyond the lifetime of the individual projects.
- To work with global research and observation programmes to promote and document the development and status of a sustained ocean carbon observing system;
- To liaise with integrated programmes (IGCO, GCP) to promote the integration of ocean carbon into earth system studies.

SSG Members (2011-2013)

Co-Chair: Chris Sabine, NOAA / PMEL, (USA)
Co-Chair: Toste Tanhua, IfM-Geomar, (Germany)
Repeat Hydrography: Bernadette Sloyan, CSIRO, (Australia)
Surface Ocean CO2 Data: Are Olsen, Univ. Bergen, (Norway)
Underway pCO2 Measurements: Pedro Monteiro, CSIR, (South Africa)
Time Series Stations: Melchor Gonzalez, U. Las Palmas, (Spain)
Surface Flux Maps / Data Assimilation: Ute Schuster, UEA, (UK)
Ocean Interior Data: Masao Ishii, MRI-JMA, (Japan)
Data and Information Management: Alex Kozyr, CDIAC, (USA)
Integrated Greenhouse Gas Monitoring Networks: Yukihiro Nojiri, NIES, (Japan)

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Ocean Acidification: Jean-Pierre Gattuso, CNRS-UPMC, (France)
SOLAS/IMBER carbon coordination group focal points: Nicolas Gruber, ETH-Zurich (Switzerland) and Nicolas Metzl, LOCEAN-IPSL, CNRS (France).

PROJECT COORDINATORS

- **Dr. Kathy Tedesco, UNESCO-IOC**
  k.tedesco(at)unesco.org

  Dr. Maciej Telszewski, UNESCO-IOC
  m.telszewski(at)unesco.org

SPONSORS

- **UNESCO - Intergovernmental Oceanographic Commission**
  Dr. Kathy Tedesco, UNESCO - IOC
- **Scientific Committee on Oceanic Research**
  Dr. Ed Urban, SCOR

IOCCP has been a successful cooperative venture between SCOR and IOC since 2005. In the past year, IOCCP activities have been focused on the Surface Ocean CO_2 Atlas Project, the Global Ocean Ship-based Hydrographic Investigations Panel, Best Practices for Ocean Acidification Research and Data Reporting, Time Series Stations, and the Joint IOC-ICES Study Group on Nutrient Standards.

I. The Surface Ocean CO_2 Atlas Project (SOCAT)
The goal of SOCAT is to assemble a global surface CO_2 data set of all publicly available ocean surface date for fugacity[1] of CO_2 (fCO_2) in a common format, using identical quality control (QC) procedures, with no interpolation. SOCAT will produce two distinct data products:

1. a 2nd level quality-controlled global surface ocean fCO_2 data set following agreed procedures and regional review, and
2. a gridded SOCAT product of monthly surface water fCO_2 means on a 1° x 1° grid with no temporal or spatial interpolation, using the 2nd level quality-controlled global surface ocean fCO_2 data set.

Five regional groups have been developed to carry out the 2nd level quality control and regional scientific syntheses. The regional groups and chairs are

- Atlantic and Arctic Ocean – Schuster, Lefèvre
- Indian Ocean – VVSS Sarma
- Pacific Ocean – Feely, Nojiri

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[1] The fugacity of a gas is related to its partial pressure, but takes into account the non-ideal nature of the gas.

- Southern Ocean – Tilbrook, Metzl
- Coastal seas – Borges, Chen
- Global group – Bakker, Olsen, Sabine, Pfeil, Metzl

The regional groups met in 2010 to review progress on SOCAT quality, revisit live access server (LAS) tools developed for SOCAT, and discuss science issues to be conducted in the following months. The Equatorial Pacific, North Pacific, and Indian Ocean Regional Workshop was on held 8-11 February 2010 in Tokyo, Japan with financial support from IOCCP, the Japanese Institute for Environmental Studies (NIES), and the Japan Agency for Marine Earth Science and Technology (JAMSTEC). The Southern and Indian Ocean Workshop was held on 16-18 June 2010 in Hobart, Tasmania, sponsored by the IOCCP, SOLAS/IMBER, and Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), and national support from Japan and France.

This compilation currently includes data from more than 10 countries, producing an initial database composed of more than 1,859 cruises conducted from 1968 to 2007, with approximately 8.8 million measurements of various carbon parameters, available in a common format, 2nd level quality-controlled data set. This data set will serve as a foundation upon which the community will build as new surface fCO_2 data become available.

The QC procedures were finished and Version 1.4 of the data set was closed at the end of May 2011. At the same time the data set was internally released to several associated scientists who will test it for coherence and consistency. Version 1.4 is due for public release in September 2011. Several peer-reviewed publications describing the technical aspects of the data treatment, LAS functionalities and gridding procedures are in preparation. These are planned to be submitted prior to the public release of the data set in September 2011. A network of interlinked Web sites (IOCCP, PMEL, CDIAC, www.socat.info) has been created to allow for the easiest possible data access and to increase the exposure of the data set.

II. The Global Ocean Ship-based Hydrographic Investigations Panel

Both the CLIVAR community and the ocean carbon community recognize the urgent need for better coordination of planning, implementation, standardization, data synthesis, and interpretation efforts for hydrography. The hydrography community also recognizes that today’s hydrography programs address different issues than were addressed during the WOCE era; issues that require a more integrated approach in terms of variables measured, sampling strategy, and integration of ship-based sampling with other platforms, such as Argo and time-series stations. IOCCP and CLIVAR, in collaboration with the joint SOLAS-IMBER carbon working group, developed the Global Ocean Ship-based Hydrographic Investigations Panel (GO-SHIP) to bring together interests from physical hydrography, carbon, biogeochemistry, Argo, OceanSITES, and other users and collectors of survey data to consider how future global ship-based hydrography can build on the foundations established by the global surveys of GEOTRACES, WOCE, JGOFS, and CLIVAR.

A draft strategy was developed by GO-SHIP for the OceanObs09 conference in Venice, Italy on 21-25 September 2009. The full strategy document "Ship-based Repeat Hydrography: A Strategy for a Sustained Global Program" (Hood et al., 2010) was published in electronic form in 2010 (http://www.go-ship.org/Documents.html).

The hydrographic manual was published in August 2010 (http://www.go-ship.org/HydroMan.html). The manual provides detailed instructions for the high-quality collection and analysis techniques of numerous ocean parameters, both physical and biogeochemical. Sixteen chapters covering CTD methods, discrete samples, and underway measurements have been reviewed and revised by more than 50 experts.

III. Best Practices for Ocean Acidification Research and Data Reporting

The need for standardized protocols and reporting of data has been highlighted at numerous ocean acidification workshops over the past few years. Common methods are critical to identify differences/similarities in calcification among various taxa, regions, and over time. It is also imperative that data be reported in a manner that will be comprehensible and accessible to scientists several decades from now if changes are to be detected. Specifically, the international research community needs to establish agreed protocols for calcification rate measurements and mesocosm/perturbation experiments, as well as for protocols for data reporting. The IOCCP and the European Project on Ocean Acidification (EPOCA) co-sponsored a workshop in November 2008 to reach international agreements on best practices for ocean acidification research.

The workshop produced a guide for "Best Practices in Ocean Acidification Research and Data Reporting" (U. Riebesell, V. Fabry, J.-P. Gattuso (Eds.), 2010) as a reference to provide guidance for research in the rapidly growing field of ocean acidification. The guide is available in print form from the EPOCA, IOCCP, and SCOR offices and electronic form at http://www.epoca-project.eu/index.php/guide-to-best-practices-for-ocean-acidification-research-and-data-reporting.html.

IV. Time-Series Stations

A priority of IOCCP is the improved understanding of the processes controlling the exchange of carbon between the atmosphere, the surface ocean, and the ocean interior. Ocean time series are one of the most valuable tools oceanographers have at the present time to observe trends, to understand carbon fluxes and processes, and to demonstrate the crucial role the carbon cycle plays in climate regulation and feedbacks. A table of Carbon Time Series Stations from 2007 is available at http://www.ioccp.org/Time%20series/TablePDFs/TSGlobal.pdf. The table is divided into ship-operated and mooring-operated sites by ocean basin. It is critical to keep this list updated in order to improve synergies among sites and scientific coordinators, to facilitate research proposals utilizing the facilities, and to involve as many researchers and institutions as possible in sites where on-going ship activities are being reduced due to decreased resources. Time-series sites, especially those that require ship operations, are expensive and require long-term national and international commitments. Showing that these time-series sites contribute to a larger international network of time-series stations can help justify the investments that nations are making in these projects.

The IOCCP SSG is currently updating the 2007 list of stations where carbon variables are being measured or are expected to be measured in the near future, including contact information for the principle investigator or time-series administrator, as well as current and future operational concerns.

V. Joint IOC-ICES Study Group on Nutrient Standards

The International Nutrient Scale System Workshop participants agreed that by establishing the International Nutrients Scale System (INSS), the comparability and traceability of nutrient data in seawater can be ensured. Results from the INSS international workshop were published in 2010 as "Comparability of nutrients in the world's ocean' (Aoyama, M. (Ed.), 2010).

In addition, the organizers established a Joint IOC-ICES Study Group on Nutrient Standards (SGONS) to carry out the INSS work. The first SGONS workshop was hosted by IOCCP and held in Paris, France on 22-23 March 2010 with 32 participants from 11 countries (http://www.ioccp.org/Workshops.html). The meeting focused on the ongoing activities of the Study Group on Nutrient Standards (SGONS) and future international collaborations to establish global comparability of nutrient data from the world's ocean. Thirty-two participants from 11 countries attended the meeting organized by Michio Aoyama, SGONS chair, and David Hydes, co-Chair.

The Terms of References of SGONS are to

- Develop and establish reference materials for nutrients in seawater (RMNS) collaborating with producers of currently available RMNS. Primary determinands are nitrate, nitrite, phosphate and silicate.
- Collaborate with and encourage the National Metrology Institute of Japan to complete certification of RMNS for nitrate, nitrite, phosphate and silicate.
- Develop new sampling and measurement protocols using the RMNS.
- Carry out an international collaboration exercise to verify the stability of the reference materials and test the proficiency of the new protocols.
- Complete a revised nutrients analysis manual.
- Distribute 10,000 bottles of reference material for nutrients to laboratories measuring nutrients as part of the CLIVAR Repeat Hydrography Programme to construct a global nutrient dataset referenced to the new RMNS.
- Promote the use of RMNS to aim for global acceptance in order to enable reliable comparability between global nutrient data sets, and to investigate the feasibility of expanding RMNS to include ammonium and dissolved organic matter.
- Collaborate with the ocean science community that uses chemical reference materials, including carbonate system reference material for dissolved inorganic carbon, total alkalinity and pH, and dissolved oxygen in seawater.

Discussions included developing and establishing reference materials for nutrients in seawater (RMNS), collaborating with producers of currently available RMNS, the background and history of SGONS and international nutrients scale system, the International Nutrient Scale System

(INSS), progress with the production and certification of RMNS materials, and the status of the nutrient analysis chapter for the revised GO-SHIP manual.

Results of RMNS used on hydrographic cruise P6 in 2009/2010 by Scripps Institution of Oceanography showed considerable improvement of internal comparability and external comparability among the stations and between the 2009/2010 and the 2003 cruises, the latter of which was conducted by JAMSTEC with RMNS. The group also agreed to hold the next inter-laboratory comparison study in early 2011 and expand the number of laboratories participating.

VI. The Ocean in a High-CO_2 World Symposium

IOC funding and activity related to the Third Symposium on The Ocean in a High-CO_2 World is included as part of IOCCP. Details of the symposium status are given in the next section.

4.2 Symposia on The Ocean in a High-CO_2 World ***Volkman***

This is a joint project of SCOR, IOC, and IGBP. The primarily activities in the past year have been related to planning for the symposium, in five areas:

1. Design of symposium, including designing the structure, selecting plenary speakers and chairs of parallel sessions, and creation of subcommittees for the early-career scientist activities and the communications/Policy Day. The international planning committee met on 2-3 December 2010 in Monterey, California (site of the symposium) to carry out these tasks. The structure of the symposium was designed as follows.

Sept. 23 (Sunday)	**Sept. 24 (Monday)**	**Sept. 25 (Tuesday)**	**Sept. 26 (Wednesday)**	**Sept. 27 (Thursday) Policy Day**
	Plenary	Plenary	Plenary	Plenary
	Break	Break	Break	Break
	Parallel Sessions	Parallel Sessions	Parallel Sessions	Plenary
	Lunch	Lunch	Lunch	Lunch
Registration, poster set up and ice- breaker reception	Parallel Sessions	Parallel Sessions	Parallel Sessions	
	Break	Break	Break	
	Parallel Sessions	Parallel Sessions	Parallel Sessions	
	Poster Session	Poster Session	Dinner at Aquarium	

The plenary presentations and additional parallel sessions are as follows. All of the individuals identified have agreed to serve in the roles for which we have invited them.

	PLENARY TOPIC	**CHAIRS & REVIEWERS**	**SPEAKER**
Opening			Julie Packard (US)
Opening	The history of ocean acidification science		Peter Brewer (US)
1	Changes in ocean carbonate chemistry since the Industrial Revolution	Daniela Schmidt, J. Orr, R. Feely	Richard Zeebe (US)
2	Rates of change of ocean acidification: Insights from the paleorecord	Daniela Schmidt, CE de Rezende, J. Orr	Daniela Schmidt (UK), F
3	Interactions of ocean acidification with physical climate change	Anya Waite, Y. Nojiri, P. Brewer	Laurent Bopp (FR)
4	Responses of marine organisms and ecosystems to multiple	Kunshan Gao, Ulf Riebesell, J-P Gattuso, H.	Hans-Otto Poertner (DE)

	environmental stressors (ocean acidification, hypoxia, temperature, UV, etc.)	Poertner	
5	Acclimation and adaption to ocean acidification: Genomics, physiology, and behavior	Kunshan Gao, H. Poertner, Jim Barry	Gretchen Hofmann (US), F
6	Ecosystem change and resilience in response to ocean acidification	A. Waite, Jim Barry, Ulf Riebesell	Steve Widdicombe (UK)
7	Biogeochemical consequences of ocean acidification and feedbacks to the Earth system	Ken Denman, Ulf Riebesell, J-P Gattuso, CE de Rezende	Richard Matear (Aus)
8	Understanding the economics of ocean acidification	C. Armstrong, J. Orr, Daniela Schmidt	Luke Brander (HK)
9	Policy and governance in the context of ocean acidification: Implications, solutions, and barriers	Owen Gaffney, Dan Laffoley, et al. TBD	Victor Galaz (Sweden)
10	Impacts of ocean acidification on foodwebs and fisheries	Anya Waite, J. Barry, Ken Denman	Beth Fulton (Aus), F
	PARALLEL		
1	Detection and attribution of ocean acidification changes	Anya Waite, J. Orr, R. Feely	
2	Effects of ocean acidification on nutrient and metal speciation	CE de Rezende, Ulf Riebesell, P. Brewer	
3	New developments in measuring and observing ocean acidification and its effects	K. Denman, P. Brewer, Y. Nojiri	
4	Regional impacts of ocean acidification	Anya Waite, J-P Gattuso, Meg Caldwell (LOC)	
5	Effects of ocean acidification on calcifying organisms	Kunshan Gao, Daniela Schmidt, J-P Gattuso	
6	New concerns in ocean acidification research	P. Brewer, Y. Nojiri, H. Poertner, Jim Barry	

2. Policy Day planning—The first three days of the symposium will be a traditional science meeting, giving an opportunity for the global community of scientists doing research on ocean acidification to report on their work through oral and poster presentations. On the fourth day, based on experience from the second symposium (in Monaco), we will shift the focus to the implications of ocean acidification science for policy. Planning for the Policy Day is being conducted by a subcommittee led by Dan Lafolley, the chair of the Reference User Group of the European Project on Ocean Acidification. At this point, the

plan will be to start the Policy Day with a scientific summary from the first three days of the symposium. This presentation would be followed by two panels of high-profile policymakers and a news conference.

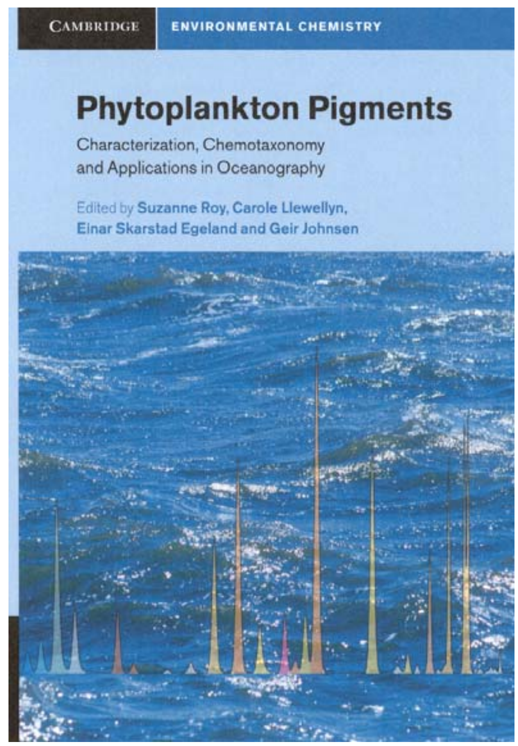
3. Planning for Early-Career Scientist Activities—The subcommittee that is working on the program for early-career scientists at the symposium is chaired by Ken Denman (Canada). The group must complete the first part of its work before September 2011, when registration for the meeting will open. The subcommittee recommended the following:
   - Eligibility for Travel Grants and Mentoring—Individuals eligible for early-career travel grants and mentoring will be those who are Ph.D. students and Ph.D. graduates who have received their Ph.D.s within 5 years of the beginning of the symposium. We will also have some support available for developing country scientists who are more than 5 tears beyond their Ph.D.
   - Applications will Web-based, requiring an abstract to present a poster or an oral presentation in a parallel session, a letter expressing the applicant's research interests and interest in participating in the symposium, and a supporting letter from their advisor, supervisor, or organization official. Individuals whose abstracts are not accepted for presentation at the symposium will not be eligible to receive a travel grant or mentoring.
   - Two "tracks" will be available for early-career scientists, recognizing that different individuals will have different needs. The "networking track" (see below) will be made available to all early-career scientists and developing country scientists, whether they apply for a travel grant or not, and should include those opting for the "mentoring track" also. The "mentoring track" (see below) will be provided for travel grant recipients who request it. However, mentoring will not be compulsory for successful applicants.
   - The "networking track" will include one or more special events that will help early-career and developing country scientists attending the event to get to know each other and learn about common research interests. An ice-breaker event will be held before the symposium. In may also be possible to make available cruises into the Monterey Bay National Marine Sanctuary, beach/dune walks with local experts, etc.
   - A flyer will be created to reach early-career scientists and distributed through the email lists of participating organizations and at related meetings.
   - A timeline for applications and the review process needs to be developed.
   - A process for identifying mentors, including a job description and background materials, needs to be developed.
   - Changes to the meeting Web site need to be proposed. May include a tick box on the registration page to indicate those willing to serve as a mentor, a separate page for mentors, and a separate page for early-career and developing country scientists who want to apply for a travel grant. The latter would include a tick box for the applicants to specify if they want to be assigned a mentor.
   - Will wait on arranging next Skype call to see how things progress by email.

4. Creation of the symposium Web site—The Web site for registration and for information about the symposium is available at www.highco2-iii.org. Information is being put there as it becomes available.
5. Ed Urban attended the OA Principal Investigators meeting hosted by the Ocean Carbon and Biogeochemistry Program on 22-24 March 2011 to update other PIs about the status of planning for the symposium and to learn about the range of research being conducted by PIs in the program.

4.3 Other Activities

4.3.1 Phytoplankton Pigments in Oceanography *Urban*

SCOR WG 78 on Determination of Photosynthetic Pigments in Seawater published a book entitled *Phytoplankton Pigments in Oceanography* in 1993, which became the de facto standard reference on phytoplankton pigments. In 2005, a group representing the editors of the WG 78 book and scientists made the case for the need for a new book that would pick up with the 1993 book left off, and a scoping meeting was held in 2006. SCOR provided additional support based on the report from the scoping meeting.



The book *Phytoplankton Pigments: Characterization, Chemotaxonomy and Applications in Oceanography* will be published by Cambridge University Press in September 2011. The editors of the book are Suzanne Roy (Université du Québec, Rimouski, Canada), Carole Llewellyn (Plymouth Marine Laboratory, UK), Einar Skarstad Egeland (Bodø University College, Norway), and Geir Johnsen (Norwegian University of Science and Technology, Trondheim, Norway). The editors raised funding from their institutions and other sources to make it possible for SCOR to purchase 100 copies, which will be distributed to the editors' institutions and to libraries in developing countries.

4.3.2 SCOR/IODE Data Publication Activity *Costello*

What was to become the SCOR/IODE initiative on data publication started in December 2006 at the Second SCOR Summit of International Marine Research Projects (see http://www.scor-int.org/Project_Summit_2/ProjCoord2.htm). The meeting brought together representatives of most large-scale international ocean research projects (e.g. SOLAS, GEOTRACES, IMBER, GLOBEC, etc.). The meeting considered what constituted the major barriers to data sharing and greater data submission to national and global databases and identified a need to create a formal process to ensure that scientists get credit for releasing their data and for every time the data are used by others. To this aim, the meeting recommended that SCOR form a Panel on Ocean Data Publication and Incentives.

In 2008, SCOR and IODE began to work together on this issue and the "SCOR/IODE Workshop on Data Publishing" (17-18 June 2008, IOC Project Office for IODE) was organised. The objectives of the meeting were to

1. Describe current status of data citation and publication in oceanography;
2. Identify problem areas;
3. Identify interoperability issues of current data citation and publication practices; and
4. Formulate suggestions to address problem areas.

The meeting concluded that the following actions were needed:

1. Build new infrastructure and new approaches to data publication;
2. Increase the availability of the data used for figures, tables and statistical analyses in traditional journal articles;
3. Encourage the expansion of journals which specialize in “data publications” or “data briefs”; that is, journals where data/datasets are described rather than interpreted. Requirement for data repositories to serve as archive of data related to journal articles;
4. Use persistent identifiers to anchor data in repositories to be used/published in publications; and
5. SCOR and IODE to work with existing data centers to promote the development of data repositories at the institutional, national and/or regional level.

The report of the meeting is available as IOC Workshop Report No. 207 at http://www.iode.org/wr207.

In December 2008, a meeting was organized with ocean science journal editors in San Francisco, USA with representatives present from *Earth System Science Data* (ESSD), *Fisheries Oceanography*, *Earth and Planetary Science Letters*, *Journal of Geophysical Research-Oceans*, *Biogeosciences* and *Progress in Oceanography*. Written input was received also from the *Journal of Plankton Research*, *Oceanography* magazine, and *Palaeoceanography*. The meeting came to the following conclusions:

1. The effort was worthwhile and many of the editors consulted want to stay involved in the discussions and participate in the development of the ideas.
2. The idea of the peer review of datasets requires more discussion and careful consideration.
3. The process of publication of data briefs or other stand-alone papers describing data sets is being tested by *Earth System Science Data*. The SCOR/IODE effort should focus for now on issues related to providing the digital backbone for data related to traditional publications.
4. More attention needs to be given to how digital object identifiers (DOIs) can best be used to link journal articles and datasets.

5. It is important to know whether fields outside ocean sciences are pursuing data publishing.

In March 2009, a meeting was held to develop use cases (IOC Project Office for IODE, Oostende, Belgium, 9-11 March 2009). The meeting included participants from BCO-DMO, BODC, WDC-MARE, IODE, and Elsevier. The use cases identified were:

- Use Case 1: Creating data publications from existing and future holdings at national data centers.
- Use Case 2: Providing the "digital backbone" for traditional journal publications.

Pilot projects were chosen to test the processes for data publication in the two cases. While BODC worked on developing Use Case 1, a meeting was organized by the MBLWHOI Library in Woods Hole, Massachusetts, USA to further develop the pilot project for Use Case 2.

A meeting was convened by SCOR and IODE, plus the Marine Biological Laboratory/Woods Hole Oceanographic Institution Library (MBLWHOI Library) on 2 April 2010 to advance the two use cases that had been developed over the past two years. The meeting noted progress in the two use cases and made plans for future cooperation between data centers and libraries. A plan was developed for a "challenge" to data centers and libraries to test the role of libraries as the "digital backbone" for archiving of data underlying the tables and figures in traditional journal publications. The results of this challenge were reported to the data management community at the ICSU Committee on Data for Science and Technology's 22nd International Conference in October 2010 and to the ocean science community at the AGU Fall Meeting in December 2010. The report from the 2 April meeting is available at http://www.scor-int.org/Publications/wr230.pdf.

The next meeting of the group of sponsors of this activity will take place in Liverpool, UK, in November 2011.

4.3.4 International Quiet Ocean Experiment *Urban*

The International Quiet Ocean Experiment (IQOE) workshop in October 2010 concluded that there was sufficient interest in this topic to hold an open science meeting (OSM) to gauge community interest. A planning meeting for the OSM was held in February 2011, at which the sessions and plenary speakers, and discussion chairs and rapporteurs were selected. The OSM will be hosted by IOC at UNESCO Headquarters in Paris, France on 30 August-1 September 2011. The OSM will be focused around five discussion sessions that were designed to produce the project science plan:

1. Observing Systems, including technology development
2. Scientific knowledge needed for industry and regulators
3. Ocean soundscapes
4. Designing research relating soundscapes to effects on organisms
5. Experimental approaches to understanding responses of organisms to specific sources

The chairs, rapporteurs, planning committee members, and staff will work on the first draft of the science plan on 2 September. A meeting Web site has been set up (see http://www.iqoe-2011.org/) and a related Web site has been developed as a portal to literature and other information about sound in the ocean (see http://aquaticacousticarchive.com/). The work of the group was presented at the American Acoustical Society meeting in May 2011 and in an article that appeared in *Oceanography* magazine early June 2011 (see following).

International Quiet Ocean Experiment
Open Science Meeting

UNESCO Headquarters
Paris, France
30 August-1 September 2011

<u>30 August (Tuesday)</u>

9:00 Welcome – *Wendy Watson-Wright*, IOC Executive Secretary and Assistant (?) Director General., UNESCO

9:15 IQOE history and concept - *Ian Boyd*, University of St. Andrews

9:45 The future industrialization of the oceans – TBA

10:15 What is a soundscape and how should soundscapes be quantified and characterized? - *Christine Erbe*, JASCO Australia

10:45 Coffee break

Existing technologies that could be useful for characterizing soundscapes

11:15 Global Ocean Acoustical Observation System – *Brian Dushaw*, University of Washington

11:35 Autonomous Observation Systems - *Doug Cato*, Defence Science and Technology Organisation, Australia

11:55 Underwater naval acoustic systems - *David Moretti*, U.S. Naval Undersea Warfare Center

12:15 Modeling and Prediction of Soundscapes - *Mike Porter*, Heat, Light, and Sound Research

12:35 Comprehensive Test Ban Treaty Organization - *Mark Prior*

13:00 Lunch

14:30 Introduction to Breakout Groups – *Ian Boyd and George Frisk*

1. **Observing Systems, including technology development**
   Co-chairs: *Brandon Southall* (SEA, Inc.) and *Brian Dushaw* (University of Washington)
   Co-rapporteurs: *Jennifer Miksis-Olds* (Penn State University) and *Rex Andrew* (University of Washington)
2. **Scientific knowledge needed for industry and regulators**
   Co-chairs: *John Young* (Resource Access International, USA) and *Frank Thomsen* (DHI Water and Environment, Denmark)
   Co-rapporteurs: *René Dekeling* (Defence Materiel Organisation, Netherlands) and *Jason Gedamke* (NOAA)
3. **Ocean soundscapes**
   Co-chairs: *Manell Zakharia* (NURC, Italy) and *Doug Cato* (University of Sydney)
   Co-rapporteurs: *Christine Erbe* (JASCO Australia) and *Tony Hawkins* (Loughine)
4. **Designing research relating soundscapes to effects on organisms**
   Co-chairs: *Christopher Clark* (Cornell University) and *Jakob Tougaard* (Aarhus University)
   Co-rapporteurs: *Peter Evans* (Sea Watch Foundation) and *Roger Gentry* (ProScience Consulting)
5. **Experimental approaches to understanding responses of organisms to specific sources**
   Co-chairs: *Vincent Janik* (University of St. Andrews) and *Robert Gisiner* (U.S. Navy)
   Co-rapporteurs: *Patrick Miller* (University of St. Andrews) and *Sophie Brasseur* (IMARES)

15:00 Begin discussion groups

16:00 Coffee break

16:30 Continue discussion groups

18:00 Adjourn for Day

Reception at UNESCO

31 August (Wednesday)

9:00	What is known about the physics of acoustics in the ocean? – *George Frisk*, Florida Atlantic University
9:30	What is known about the biological effects of sound?- *Peter Tyack*, Woods Hole Oceanographic Institution
10:00	Continue discussion groups
11:00	Coffee break
11:30	Continue discussion groups
13:00	Lunch
14:30	Continue discussion groups
16:00	Coffee Break
18:00	Adjourn Meeting for the Day

1 September (Thursday)

9:00	Reports back from discussion groups and plenary discussion
11:00	Coffee break
11:30	Continue discussion groups
13:00	Lunch
14:30	Continue discussion groups
16:00	Coffee Break
16:30	Plenary to discuss completion of science plan and implementation of IQOE
18:00	Adjourn Meeting for the Day

Open Science Meeting for an International Quiet Ocean Experiment

30 August – 1 September 2011

UNESCO Headquarters - Paris, France

The Scientific Committee on Oceanic Research (SCOR) and Partnership for Observation of the Global Oceans (POGO) announce an open science meeting for an International Quiet Ocean Experiment (IQOE). The purpose of the open science meeting is to develop a Science Plan for the IQOE, a focused international research effort that may last a decade or so. This plan will include background information to document the importance of the issue of sound in the ocean and its effects on marine organisms; identify information gaps; and describe research, observations, and modeling activities needed to fill these gaps.

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Plenary Presentation Topics

- IQOE history and concept
- What is known about the physics of acoustics in the ocean?
- The future industrialization of the oceans
- What is known about the biological effects of sound exposure? Biologically significant effects? What is already possible using existing technologies? How could existing technologies be added to existing observing systems?
- What is a soundscape and how should soundscapes be quantified and characterized?
- Modeling and prediction of soundscapes

Themes for discussion sessions

- Observing systems, including technology development
- Scientific knowledge needed for government agencies, industry and regulators
- Ocean soundscapes
- Designing research relating soundscapes (cumulative effects of many sources) to biologically significant effects on organisms
- Experimental approaches to understanding responses of organisms to specific sources

Important Dates

31 March:	Registration opens *(see www.IQOE-2011.org)*
15 July:	One pagers due for input to discussion sessions
31 July:	Early registration deadline

Registration Fees

Early registration: *(until 31 July)*	$200 for regular scientists $100 for students
Regular registration: *(1-30 August)*	$300 for regular scientists $150 for students

An International Quiet Ocean Experiment

BY IAN L. BOYD, GEORGE FRISK, ED URBAN, PETER TYACK, JESSE AUSUBEL, SOPHIE SEEYAVE, DOUG CATO, BRANDON SOUTHALL, MICHAEL WEISE, REX ANDREW, TOMONARI AKAMATSU, RENÉ DEKELING, CHRISTINE ERBE, DAVID FARMER, ROGER GENTRY, TOM GROSS, ANTHONY HAWKINS, FENGHUA LI, KATHY METCALF, JAMES H. MILLER, DAVID MORETTI, CRISTIAN RODRIGO, AND TOMIO SHINKE[1]

ABSTRACT. The effect of noise on marine life is one of the big unknowns of current marine science. Considerable evidence exists that the human contribution to ocean noise has increased during the past few decades: human noise has become the dominant component of marine noise in some regions, and noise is directly correlated with the increasing industrialization of the ocean. Sound is an important factor in the lives of many marine organisms, and theory and increasing observations suggest that human noise could be approaching levels at which negative effects on marine life may be occurring. Certain species already show symptoms of the effects of sound. Although some of these effects are acute and rare, chronic sublethal effects may be more prevalent, but are difficult to measure. We need to identify the thresholds of such effects for different species and be in a position to predict how increasing anthropogenic sound will add to the effects. To achieve such predictive capabilities, the Scientific Committee on Oceanic Research (SCOR) and the Partnership for Observation of the Global Oceans (POGO) are developing an International Quiet Ocean Experiment (IQOE), with the objective of coordinating the international research community to both quantify the ocean soundscape and examine the functional relationship between sound and the viability of key marine organisms. SCOR and POGO will convene an open science meeting to gather community input on the important research, observations, and modeling activities that should be included in IQOE.

INTRODUCTION

Does the noise made by humans harm marine life? At present, we can offer only preliminary answers to this important question, for only a few species. We know that the ocean has become more industrialized and that the noise levels associated with human activities have increased (NRC, 2003). For example, in areas where measurements have been made, anthropogenic noise in the ocean has been increasing across much of the frequency spectrum (Andrew et al., 2002; McDonald et al., 2008), and especially at lower frequencies (< 500 Hz; Frisk, 2007). Increases in noise from human activities add to the many natural sources of sound in the ocean, such as waves breaking, rain, and ice movement, and the sounds of the marine animals themselves (Figure 1). Given the spatial and temporal complexity and variability in all sound sources, the relative contribution of anthropogenic noise is not always readily distinguishable.

The combined effects of temperature and pressure in the deep ocean create a sound channel by which acoustic waves can be transmitted over large distances, sometimes hundreds of kilometers, and often much further. The complex pathways taken by this sound affect the final received levels, but if they are averaged through time at the receiver, they provide an integrated signal defined by the relative locations of all the sound

[1]The authors of this article were the attendees at a meeting, held at the University of Rhode Island from October 27–29, 2010, to discuss the feasibility of conducting an experiment to examine the effects of sound on life in the ocean.

producers, the architecture of the ocean basin, and the properties of the water through which the sound has passed. It is sometimes possible to distinguish among different sound sources based on sound characteristics.

Humans introduce noise to the ocean through many different activities. Each source may have different effects, depending upon the frequency range, its intensity, and whether it is an intermittent, pulsed, or continuous sound. Some anthropogenic sounds—such as some military sonars, seismic air guns used extensively for oil and gas exploration, and pile driving—are both impulsive and high intensity. Such sounds can elicit strong negative reactions, or even physical injury, in some species, a concern that has led to higher levels of scrutiny for many of those sources. Recently, military sonars have been a particular focus of attention because of their association with the stranding of beaked whales (Cox et al., 2006). Nevertheless, the acute effects of sonars upon beaked whales probably occur only rarely because the effects of sonars themselves co-vary with other factors, such as context of the exposure (i.e., bathymetry, presence of surface temperature ducts, behavior, and number of naval vessels). Animal strandings are probably the most easily observed end point of a syndrome of behavioral responses to sound (Boyd et al., 2007), leading through some unknown progression to physical harm and/or mortality. There is a strong suspicion, supported by increasing evidence, that a similar syndrome of reduced capacity to perform normal life functions is present across a wide range of marine fauna, including fish (Slabbekoorn et al., 2010) and marine mammals (Southall et al., 2007; Tyack, 2008).

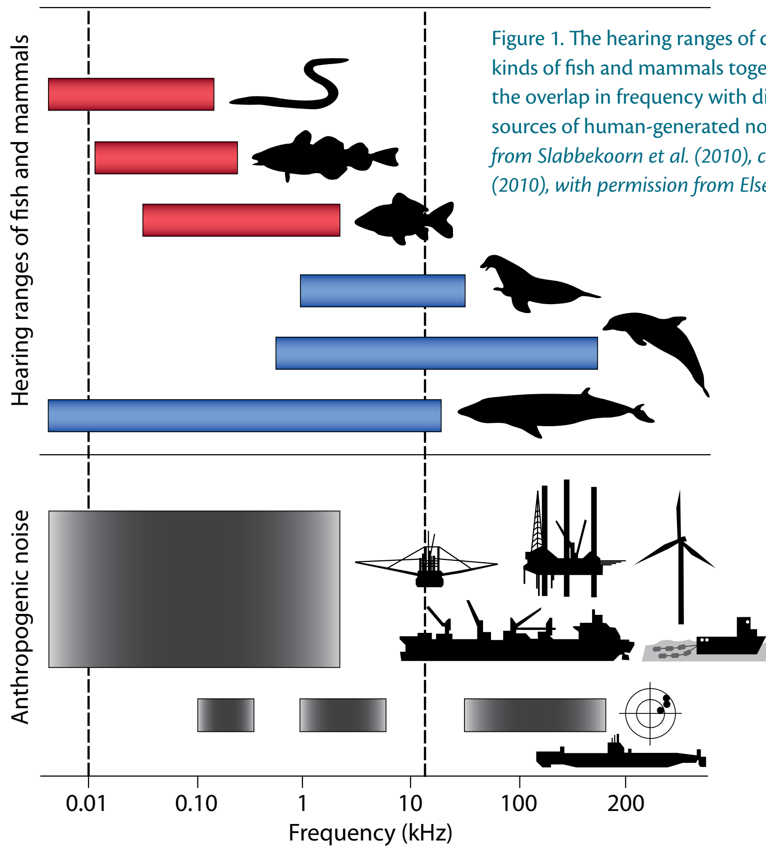

Figure 1. The hearing ranges of different kinds of fish and mammals together with the overlap in frequency with different sources of human-generated noise. *Modified from Slabbekoorn et al. (2010), copyright (2010), with permission from Elsevier*

A major unanswered question is whether anthropogenic noise has a significant impact on the fitness of individuals within populations that jeopardizes the viability of those populations. The US National Research Council addressed this question in its 2005 report on marine mammal populations and ocean noise (NRC, 2005), but the principles apply equally to all forms of marine life. We reflect this issue diagrammatically in Figure 2. The NRC report developed an approach known as Population Consequences of Acoustic Disturbance (PCAD), which defined a rationale for developing assessments of the significance of sublethal effects and for identifying the most important gaps in our knowledge. Our problem now is to define the functional relationships between behavioral or physiological responses to sound and population effects that are required for this assessment process to work.

Shipping is an important anthropogenic sound source (Wenz, 1962). The volume of cargo transported by sea has been doubling approximately every 20 years (http://www.marisec.org/shippingfacts/worldtrade/volume-world-trade-sea.php), resulting in an increase in anthropogenic sound. Although the systematic measurement of sound in relation to these changes is incomplete, the current estimate is that expanded shipping, which is directly correlated with increased global economic activity, has been accompanied by an increase in anthropogenic sound for frequencies below 500 Hz (Frisk, 2007). Over the past few decades, the shipping contribution to ambient noise has increased by as much as 12 dB above the natural background level in some locations (Andrew et al., 2002; Hildebrand, 2009). We also know that offshore oil and gas exploration and production, as well as development of renewable energy, have expanded during the same period, as has the fishing industry.

DEFINING THE QUESTIONS

Many animals use sound in the ocean, either passively to listen and orient relative to their surroundings, or actively as they produce sound to communicate or to search for prey or for objects; in some cases, their use of sound is a byproduct of other activity. Active use of sound is relatively easy to detect, but passive use is not. It is likely that most multicellular marine organisms use sound passively as a way of sensing the environment, including listening for prey and predators, and changing behavior in relation to weather and obstacles (including moving ships or static propellers such as are proposed for tidal turbines). The idea that animals may use something analogous to "acoustic daylight" (Buckingham et al., 1992) to gain an image of their surroundings is gaining momentum, even if it is difficult to demonstrate empirically. The properties of sound in water and the low levels of light penetration below the surface in many circumstances mean that, for some species, sound is more important than light as the principal source of environmental information. Much evidence points to sound in the low frequencies (< 1 kHz) being most important, except in the cases of some invertebrates (e.g., snapping shrimp) and marine mammals (dolphins, some whales, and seals) that have developed the capacity to both hear and, in some cases, produce complex sounds at much higher frequencies (up to > 200 kHz in smaller cetaceans). Our basic knowledge of the way in which the majority of marine organisms sense sound and then respond behaviorally to different sound stimuli is quite rudimentary for most species and groups. Similarly, the extent to which the introduction of higher background sound levels masks the ability of marine animals to interpret sound signals from the environment is largely unknown, as is their reaction to acute anthropogenic sounds in their vicinity.

For example, we now know that several species of whales have adjusted their communication calls in a manner that suggests they are "raising their voices" or otherwise changing their calls in order to be heard (e.g., Holt et al.,

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2008; Parks et al., 2010). This "Lombard effect" (Lombard, 1911) was originally reported for humans, but it is also seen in terrestrial species such as birds that use sound in social activities (Lengagne, 2008; Slabbekoorn et al., 2010). There is evidence that, in the presence of high levels of background sound, some species simply stop vocalizing, either because they are being disturbed or because, like humans trying to talk in the presence of loud background noise, they give up because communication becomes ineffective. Acoustic masking of marine mammal sounds by increased ambient noise is of particular concern in low-frequency specialists, such as the large baleen whales (Clark et al., 2009). Although it is possible that whales could be especially sensitive (and we know that not all whale species share the same sensitivities), the presence of masking and the Lombard effect leads to two additional questions: (1) are these general effects widespread among marine organisms and, (2) even if they are widespread, are they important to the function and survival of viable populations?

WHY SHOULD WE BE BOTHERED WITH NOISE IMPACTS ON MARINE ORGANISMS?

This question is important for two main reasons. The first is that the industrialization of the ocean is likely to increase in the next few decades. A very large proportion of the manufactured goods and raw materials needed by a growing global economy is being shipped around the world on the ocean. The demand for hydrocarbons is also pushing exploration and production further offshore into deep waters at continental shelf edges. Energy extraction from the ocean, although relatively small at present, is expected to expand rapidly over the next few decades. In coastal areas, recreation is also bringing with it increasing noise levels from pleasure boats. There are real concerns that this process of expanding industrialization and recreation will lead us in small steps toward an intolerable acoustic environment for many marine organisms.

It is vital that "industrialists" engage with solving the problem. If they are not involved, the inexorable march of the *precautionary principle* will slowly but progressively constrain their ability to operate (Gillespie, 2007). Environmental nongovernmental organizations with missions to protect the marine environment will drive the regulatory process. But, while precautionary approaches may be inconvenient to many who have narrow commercial interests, precaution in the face of uncertainty is rational and is an approach that is now deeply embedded in the way that society operates. Reducing uncertainty by increasing

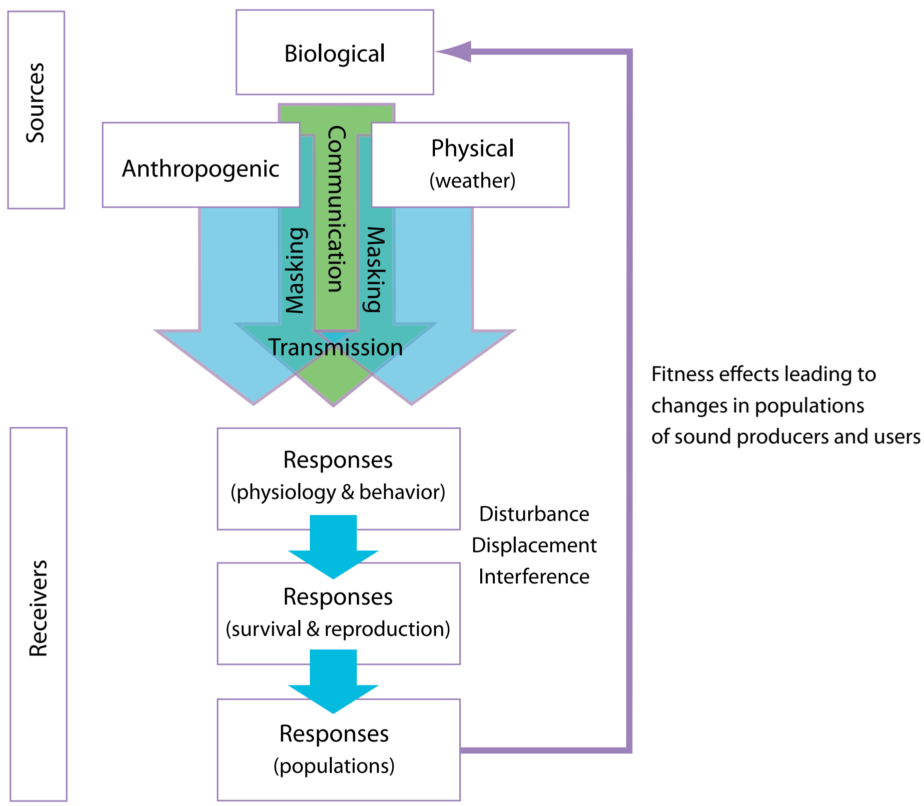

Figure 2. A diagrammatic view of the problem being investigated by the International Quiet Ocean Experiment (IQOE), which defines three major sources of sound in the ocean: physical, biological, and anthropogenic. The sounds involved in marine animal communication and echolocation can be "masked" by physical and other biological sound sources. Communication is likely to have evolved to cope with this type of masking. However, overlaid on this soundscape is new noise added by humans, and marine animals may not be able to handle the additional masking to the same extent. The characteristics of the sound received by organisms ("receivers") will determine responses that could cascade through physiological or behavioral effects that affect an animal's ability to feed, migrate, and breed and that, in turn, may lead to changes in reproduction and survival of the individual. Relatively few physiological and behavioral responses will have a direct effect on populations, but increasing effects of sound could accumulate across individuals, thus pushing these effects gradually to population-level effects.

our knowledge and understanding of the noise problem will be the best guard against excessive precaution and over-regulation.

The second reason for paying attention to the issue of sound in the ocean is even more profound. It is that we are slow to learn from the negative impacts of past industrialization of the ocean. The dangers of causing irreversible declines in the quality of the planet's self-regulating environment are tangible and real. We know that the nonlinear, complex nature of the homeostatic Earth system means that collapses could happen quickly and without much warning. At some point, small changes could lead to very large shifts in the state of the system. Noise may interact with other stressors (e.g., fishing, climate change, pollution) to yield synergistic and/or cumulative impacts. Although there is some evidence that many parts of the ocean show remarkable resilience to the direct exploitation of fish, whales, plankton, and other forms of biological productivity, there is increasing evidence that there are definite limits. *Ecological collapse* is an emotive and poorly defined term. However, if we view it from a human perspective, as ecosystems that can no longer support normal goods and services, local collapse has already occurred as a result of direct exploitation (Bakun and Weeks, 2006; Thurstan and Roberts, 2010). The danger we face is that the uncontrolled introduction of increasing noise, some of which could be avoided with appropriate design, planning, and technological innovation, could add significant further stress to already-stressed oceanic biota. Unless we improve our knowledge of the consequences of noise pollution, we may be cruising blindly toward consequences that, in terms of a simple cost-benefit trade-off, could cost us much more than we will ever gain from ignoring them.

AN EXPERIMENTAL APPROACH

To address the challenging questions posed by the effects of increasing ocean noise, we need to ensure that there is coordination of research, observation, and modeling activities across international boundaries and across disciplines. This need for coordination has stimulated the development of the International Quiet Ocean Experiment (IQOE). This project will employ two methods to help increase understanding of sound in the ocean and its effects. One method will be an *experimental approach* involving the active manipulation of anthropogenic sound sources, either through directed, temporary reductions of anthropogenic sound sources at regional scales, or through planned lulls in noise production (e.g., planned shutdown of offshore construction, diversion of shipping lanes, or temporary presence and absence of sound sources). The second method will be a *comparative approach* through identification of sites that have similar characteristics but differ in terms of their levels of anthropogenic sound.

OCEAN SOUNDSCAPES

A first step in the process of documenting effects of human-produced noise on marine organisms will be to define what we call *ocean soundscapes.* Although we have identified at least 30 sites or networks globally from which current or recent data about ocean noise are available, in almost all cases, the monitoring stations involved have been established to perform specific functions. This lack of coordinated design is reflected in the disparity of sensor designs and of data collection and transmission protocols. We need to find ways to use these data in a unified framework and to establish other measurement systems in order to understand the complex global sound field in the ocean. Building a picture of this global sound field, even in a relatively unrefined form, is a high priority as a baseline for other studies. Sound propagation modeling—based on ship position and activity (from Automatic Identification System data), data for wind and rainfall, and data for seismic surveying, sonars, and pile driving—may provide a general view of the sound fields across the global ocean. The biggest "unknown" in estimating the global soundscape will be the contribution of biological sound, which will require better understanding of animal vocal behavior, particularly when species vocalize in large numbers to produce "choruses." Refinement of this model will be possible with increasing knowledge of sound production from ships and other human activities, many of which are currently poorly characterized.

Ultimately, IQOE would encourage the establishment of a Global Ocean Acoustical Observing System (e.g., Dushaw et al., 2009). Such a system could build on the existing and planned capability of the Global Ocean Observing System and on local and regional systems, such as the US Integrated Ocean Observing System and the Australia Integrated Marine Observing System, by helping to define standards and protocols for sensors and for the analysis, storage, and distribution of data across a global research community.

PREDICTING SOUND FIELDS AND MANAGING NOISE BUDGETS

Establishing the global ocean soundscape, with appropriate statistical consideration of spatial and temporal variance, is a necessary step toward predicting ocean sound fields in particular locations. Sound field predictions can then be challenged with in situ measurements from existing data collection sites, and a process of tuning the sound field models to maximize the fit to the empirical observations will eventually refine ocean soundscape descriptions.

Predicting sound fields in this way should also feed directly into the emerging processes for regulation of offshore human activities and general industrial development. In both the United States and Europe, for example, legislation is moving rapidly to embrace marine spatial planning and to set standards for noise production, principally on a precautionary basis. But, available information is insufficient to build the rationale for spatial management of industrial activities to reduce potential noise impacts on sensitive species or habitats. Characterization of soundscapes on the global scale will enable regional administrations to downscale the soundscapes to reflect their own needs at regional and local scales and to help define the kinds of threshold values that managers often need in order to be able to set legally binding conditions on ocean use. This nested approach to model development and validation is necessary because noise is a problem that needs to be tackled initially at large scales because of the long-range propagation of low-frequency sound. Even local models need to have boundary conditions specified in order to build local noise budgets; it is hoped that IQOE will provide this capability.

EXPLORATION IN DEEP TIME

So, what was the global ocean like before humans arrived? Many have explored this question with respect to the removal of marine mammals and fish, in particular, but we also want to know how noisy the ocean was in the past. In other words, can we back-cast the ocean soundscape to a preindustrial era? Similarly, can we predict the ocean soundscape in the future if current trends continue? Can we create a kind of "Keeling curve" for ocean noise (Keeling et al., 1976)? What is the cost-benefit trade-off if regulations are set to reduce the sound produced by human activities? Questions such as these, though interesting in their own right, have most relevance if they are accompanied by robust functional relationships between sound and the growth or decline of populations of marine organisms.

The challenge and opportunity of IQOE is to coordinate scientific activities on the effects of ocean noise on marine organisms internationally, whether conducted in the academic, governmental, or industry (e.g., Joint Industry Program) sectors. Development of a body of knowledge that begins to illuminate types of responses to different levels of noise in the life functions of individual organisms—such as changes in reproductive rate, growth rate, use of habitat, survival rate, and social structure—is an essential part of the strategy being adopted for this experiment. The species that need to be included vary across the full range of marine organisms, but perhaps could focus principally on some of the keystone or indicator species within major, or important, ecological systems, as well as species already recognized as endangered. Many of the resulting "effects" studies will be small scale and in situ, and some may be possible in controlled conditions in the laboratory. However, all will need to be designed carefully, with controls and also with a view to ensuring that the effects observed can be built into larger-scale strategic models of effects at population and ecological levels, such as the PCAD model referred to previously.

WHERE, WHEN, WHO, AND HOW?

IQOE is being developed under the sponsorship of the Scientific Committee on Oceanic Research (SCOR) and the Partnership for Observation of the Global Oceans (POGO) as a potential joint project, with exploratory funding from the Alfred P. Sloan Foundation and other sources. Through this cooperation, IQOE aims to engage with the global oceanographic community. The intent of IQOE is to combine the talents of physical oceanographers, acousticians, behavioral biologists, ecosystem modelers, and population biologists.

Although IQOE should have a global outreach, we foresee that specific sites or regions will be used, either because they provide extreme examples of locations where sound is likely to have large impacts, or because they are particularly quiet and undisturbed by sound. We propose paying specific attention to areas where relatively rapid changes in industrial activity are occurring or are likely, in order to assess and identify changes in both the soundscapes and responses in marine biota in a comparative way.

IQOE provides a mechanism for focusing and coordinating existing activity. We recognize, for example, that the plans for construction of offshore wind farms in the North Sea represent an opportunity to observe and possibly to carry out experiments on the effects of percussive noise from pile driving. These types of in situ studies could be an important part of the IQOE approach. In some circumstances, planned shutdown of sound sources will add to the knowledge gained from studies that examine animal distribution and abundance before, during, and after disturbance events. There are also some very capable deep ocean laboratories available for conducting experiments on the effects of sound, mainly in the form of naval underwater test ranges that have extensive arrays of acoustic sensors. Some of these facilities have already been used for innovative experimental studies on the effects of sound on beaked whales.

The idea of experimentally shutting down anthropogenic sound sources and observing the effects was a central driver for IQOE development (Ausubel, 2009). Recognizing that marine noise has been increasing, experimental approaches to examining the effects of sound need to involve the reduction, or removal, of anthropogenic sound as well as the introduction of increased sound. However, as the space and time scales get larger, the idea of reducing anthropogenic sound sources gets increasingly difficult. Figure 3 depicts this trade-off between the capacity to carry out experimental manipulations and the size of the temporal and spatial scales involved, and it shows the matrix of different experimental designs and time scales along a gradient of increasing difficulty. In fact, to shut down all human activity in the ocean for only one day—which would be barely long enough for the sound ringing around on the ocean to dissipate—could have a financial cost of more than $10 billion. So, IQOE will focus upon more modest objectives for experimental

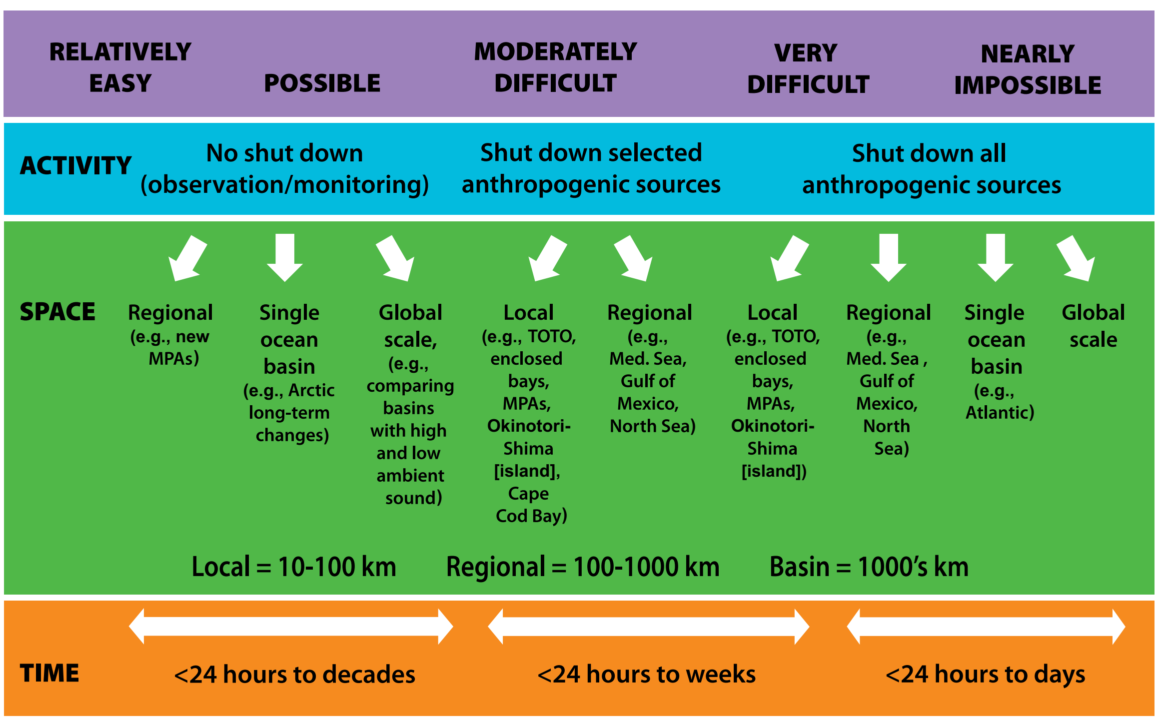

Figure 3. Matrix of quieting feasibility. The difficulty and financial cost of a shutdown of noise sources increases from left to right in the matrix. The feasible time that a noise shutdown could be accomplished decreases from left to right (orange row). Different experimental activities (blue row) might be possible at different spatial scales (green row). The goal of IQOE would be to conduct activities at many different scales. The relationship of the different temporal and spatial scales means that the most feasible approaches are likely to be several experiments carried out over long durations at small scales (i.e., toward the left of the diagram). Two roles that IQOE will play will be (1) to help reduce the difficulty of experiments from left to right in this diagram, and (2) to coordinate experiments of the type defined to the left of the diagram so that they will combine to deliver some of the benefits that would emerge if we were able to carry out experiments lying to the right of the diagram.

manipulation. These objectives will carry even more weight if the results can find general application through the parameterization and/or validation of the global sound field model.

IQOE should also drive technology innovation. Smaller instruments with greater data storage and transmission capacity would allow sound measurement to become more routine and available to a broader range of researchers at affordable prices. In addition, properly promoted, investigation of the five-dimensional world of ocean sound—the three spatial dimensions plus time and the frequency dimension (pitch)—will bring a new depth of understanding to the lives of people who may never have looked at the ocean in this way before.

SCOR and POGO will continue to develop the IQOE idea with an August 30–September 1, 2011, open science meeting (see http://www.IQOE-2011.org) to ensure broad input from the acoustic and oceanographic communities and to enable creation of a science plan for an international research project on sound in the ocean. This plan will build on the work reported in Boyd et al. (2008) and NRC (2003, 2005). The issue of sound in the ocean deserves to be added to the list of global changes that are monitored and studied.

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