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# IOC Contributions to Science Synthesis

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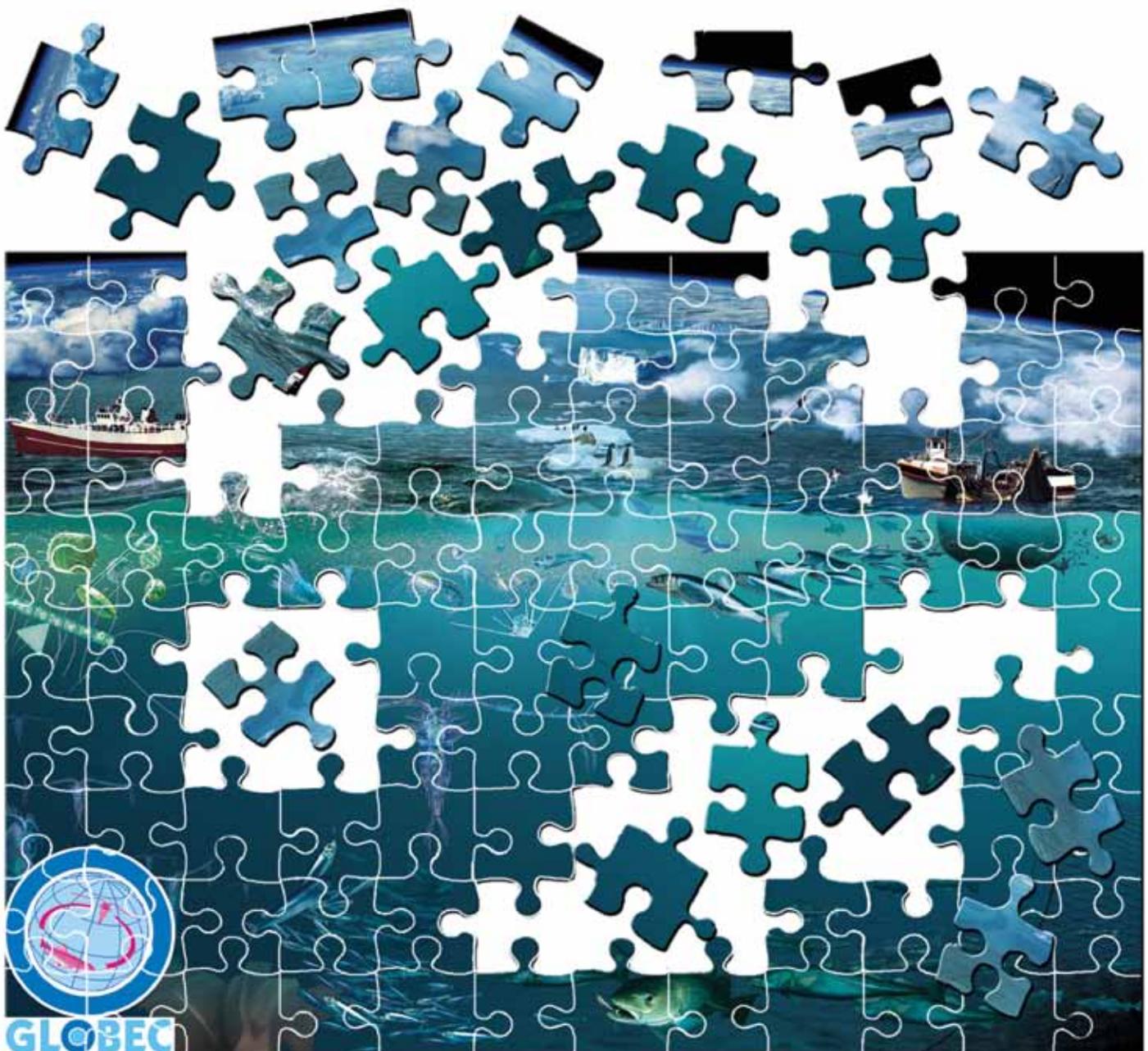
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CELEBRATING 50 YEARS OF THE  
INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

BY EILEEN E. HOFMANN AND ELIZABETH GROSS

# IOC CONTRIBUTIONS TO SCIENCE SYNTHESIS



**ABSTRACT.** Over the past 50 years, the Intergovernmental Oceanographic Commission has significantly influenced the direction and advancement of ocean science by using its unique position to encourage synthesis and integration across diverse activities and disciplines. International oceanographic programs focused on marine ecosystems, ecology, and living resources (Global Ocean Ecosystems Dynamics project), ocean carbon (International Ocean Carbon Coordination Project), and harmful algal blooms (Global Ecology and Oceanography of Harmful Algal Blooms program) are used to illustrate IOC's role in synthesis activities. Results of these projects, including fundamental changes in how the marine science community approaches measurement protocols, data availability, and data sharing, along with IOC publications and periodic assessments of the status of ocean science enabled synthesis activities that engaged the wider community and extended across disciplines. Ensuring informed development and application of marine science and technology is an important role for IOC as issues related to climate change, resource extraction, and the use of the marine environment become more pressing and the need for informed ocean management increases.

## INTRODUCTION

In the 50 years since its inception, the Intergovernmental Oceanographic Commission (IOC) has played an important role in directing and facilitating the advancement of ocean science, as shown by the overviews and summaries of IOC activities given in other articles in this issue (e.g., Anderson et al., 2010; Glover et al., 2010; McGillicuddy et al., 2010; Peterson and Cyr, 2010; Sabine et al., 2010). An additional important IOC role has been to encourage synthesis and integration across these many activities to provide the basis for better management of the environment and resources of the ocean and coastal areas. Through synthesis, new understanding is gained, and integration pulls together this new understanding to produce a new interpretation (Steffen, 2004; Figure 1).

IOC's intergovernmental status (see Box 1) places it in a strong position to use synthesis to develop new standards and methodologies that are needed to advance ocean science across many disciplines and to ensure distribution and adoption by government agencies of its Member States.

IOC has effectively used its position to periodically undertake comprehensive assessments of the important science and societal issues likely to arise in marine science and ocean management (SCOR, 1969; IOC, 1984; Field et al., 2002). These assessments (Box 2) represent important syntheses of ocean research, and the visioning approach used has provided guidance and recommendations for areas to be developed in ocean science research that extend 10–20 years into the future (see Valdés et al., 2010).

These assessments also reflect changes in approaches and priorities in ocean science research. For example, the most recent assessment highlighted the need for multidisciplinary ocean science that has relevance to societal needs and promotes sustainability of marine resources (Field et al., 2002).

Since its early involvement with the International Indian Ocean Expedition in the 1960s, IOC has played an important role in coordinating exchange of information and data between its Member States and the broader marine sciences community. The International Oceanographic Data and Information Exchange (IODE) is an example of an IOC program that facilitated the exchange of oceanographic data and provided the infrastructure to meet the needs of the science community for data and information, an important and necessary component for synthesis and integration (see Glover et al., 2010). Through its participation in the development and implementation of observing programs, such as the Tropical Ocean-Global Atmosphere Program (TOGA, McPhaden et al., 2010), the Global Ocean Observing System (GOOS), and the Pacific Tsunami Warning System (now expanded to global coverage), IOC has provided infrastructure and expertise that represents a synthesis of many years of research on observing the ocean.

Marine resource management and improvement of marine ecosystem sustainability are areas where IOC has taken a lead. For example, the Global Coral Reef Monitoring Network provides an infrastructure for coordination of information, data, and training. This network informs the global community about the status of coral reefs and

Figure 1 (opposite page). This commissioned illustration of GLOBEC science provides a view of integration and synthesis showing that integration can only be built from pieces that actually fit together. The result of the integration is a new vision of the structure and function of the marine ecosystem. This view of synthesis and integration is appropriate for the activities of IOC and its partner organizations. Details of the figure and the GLOBEC approach to integration and synthesis are given in Barange and Werner (2004).

## BOX 1. INTERGOVERNMENTAL AND NONGOVERNMENTAL ORGANIZATIONS

Scientific advice and management is accomplished on an international level through two parallel structures, one intergovernmental and the other nongovernmental. Intergovernmental organizations (IGOs) are made up of Member States. The individuals who attend meetings of IGOs represent national governments and present positions worked out in advance in accordance with national policies and priorities. Decisions made by IGOs may result from long discussions that consider issues beyond science, and deliberations may seem ponderous and bureaucratic, but the resulting resolutions have force behind them because they are binding on Member States.

Nongovernmental organizations (NGOs) are made up of scientists serving in their individual capacities, sometimes represented through national committees based in an academy of sciences, royal society, or similar body. NGOs can respond rapidly to new science problems, and can be flexible because national governments and interests are not involved. Although the structure and operation of IGOs and NGOs differ, cooperation between the two is sometimes needed to implement aspects of some programs.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) is the primary intergovernmental organization (within the United Nations system) with responsibility for science, and the International Council for Science (ICSU) is the primary nongovernmental organization for science. Both UNESCO and ICSU have different units that handle different scientific topic areas. For marine science, UNESCO's organization is the Intergovernmental Oceanographic Commission (IOC) and that for ICSU is the Scientific Committee on Oceanic Research (SCOR). IOC and SCOR offer complementary inputs to their joint activities. IOC often provides expert staff related to the subject area of a joint project and can bring the input of national governments into deliberations. Outputs of joint activities can be disseminated through national governments of the IOC Member States. NGOs, such as SCOR, provide financial support from various sources and independent input from the worldwide ocean science community, unfiltered by national and international governmental processes. Outputs of joint activities are subject to the peer-review process that is the norm for the global academic community. Partnerships between IOC and NGOs make it possible to tackle issues that would be difficult for either to handle alone.

enables development of cooperative programs to improve coral reef conservation. Recent joint initiatives directed at understanding and assessing the consequences of climate change and human activities on the health of coral reefs and their sustainable ecosystem services in the Western Pacific Region represents such an effort.

The programs mentioned above provide an indication of the range of activities undertaken by IOC, all of which include a component of synthesis and integration. IOC has also played an important role in developing large international multidisciplinary research programs, which have changed the approach used in marine ecosystem research. Three example science programs were focused on marine ecosystems, ecology, and living resources (Global Ocean Ecosystems Dynamics Project–GLOBEC); ocean carbon (International Ocean Carbon Coordination Project–IOCCP); and harmful algal blooms (Global Ecology and Oceanography of Harmful Algal Blooms Project–GEOHAB). Other articles in this issue discuss details of these programs (GLOBEC–Peterson and Cyr, 2010; IOCCP–Sabine et al., 2010; GEOHAB–Anderson et al., 2010); the discussion that follows is intended to illustrate IOC's role in moving these programs from initial stages to

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developed and integrated research activities. From the outset, the US ocean science community has had substantial involvement in these projects. Through these international projects, the direction of US ocean science was influenced, and equally important, these projects helped build expertise and train the US ocean science community. An important aspect of advancing the science in these programs has been IOC involvement with partner organizations, such as the Scientific Committee on Oceanic Research (SCOR), the International Geosphere-Biosphere Programme (IGBP), and the World Climate Research Programme (WCRP). Thus, a discussion of IOC and its partner organizations is given first to provide context for the development of these programs.

### IOC AND ITS PARTNER ORGANIZATIONS

The international marine research community has contributed expertise that has influenced the development of IOC's programs in many ways. These include the important mechanism of SCOR working groups (WGs). The partnership with IOC has benefited several SCOR WGs, and the WGs have, in turn, assisted IOC's own scientific activities in relation to marine ecosystems and fisheries. For example, SCOR WG 67 on Oceanography, Marine Ecology, and Living Resources developed and prepared an initial science plan focused on recruitment processes and presented it to IOC in 1983 as a basis for the establishment of the IOC Ocean Science and Living Resources (OSLR) program. For many years, this program was one of the four key components of IOC's science activities.

## BOX 2. IOC AND OCEAN SCIENCE ASSESSMENTS

IOC, in partnership with SCOR, undertook two assessments of the status of ocean science; a third assessment included an additional partner, the Scientific Committee on Problems of the Environment (SCOPE). These assessments involved members of the ocean science community who represented a range of disciplines and expertise. The goal of the assessments was to identify new opportunities that could take advantage of developing technologies and new understanding and to identify knowledge gaps and hence new areas of research.

SCOR WG 30 on Scientific Aspects of International Ocean Research, which existed in the mid 1960s, undertook the first assessment of ocean science, publishing its findings in SCOR (1969). This report, also referred to as the "Ponza Report," emphasized understanding marine pollution, which was a research area in chemical oceanography in the subsequent decade. This report was used by IOC to develop its long-term plan on ocean research and exploration.

The second assessment was intended to provide a study of "...expected major trends in ocean research up to 2000" and resulted in an effort known as the Future of Ocean Research (FORE). The results of this assessment (IOC, 1984) provided a discipline-oriented view of ocean research. Each of the traditional oceanographic disciplines (physics, chemistry, biology, geology/geophysics) was asked to address three questions that were focused on important ocean research problems that should receive attention in the next decade, the expected major advances and needed research for them, and the principal impediments to achieving these advances. Crosscutting issues such as climate and fisheries were considered within the discipline-based approach used for the assessment. The assessment highlighted areas of research that were significantly developed in the subsequent 20 years, such as forecasting of ocean responses to atmospheric forcing (e.g., El Niño/Southern Oscillation) and elucidating the importance of microorganisms in marine food webs (e.g., the microbial loop). The need for research on basic oceanography of coastal regions was recognized in each of the discipline-oriented assessments. Many of the research areas highlighted in the assessment were incorporated into large international research programs, such as GLOBEC, the World Ocean Circulation Experiment (WOCE), and the Ocean Drilling Program (ODP).

The third assessment recognized the interdisciplinary nature of ocean science and the importance of science that is relevant to societal needs. This assessment also departed from the two previous in that it had a goal of identifying "...directions for ocean science in support of sustainable development for the next twenty years." In addition to assessments of ocean science in the coastal zone, fisheries, and climate, the third assessment (Field et al., 2002) considered operational oceanography, industrial and commercial uses of the ocean, and the need for social and institutional frameworks that will allow cooperative research, informed ocean governance, and capacity building. The vision for 2020 set forth in the third assessment highlighted 12 areas of ocean science that were predicted to be important in meeting the needs of society in the first two decades of the twenty-first century. Whether these are indeed priorities for research will be determined as ocean science moves forward. However, the prediction from the third assessment that marine scientists and technologists must work closely with those in the social, economic, and political sciences is sure to be realized.

The OSLR program also included IOC's harmful algal bloom activities. Other fruitful WGs co-sponsored by IOC and SCOR include WG 97 on Physiological Ecology of Harmful Algal Blooms, WG 98 on Sardine and Anchovy Fluctuations, WG 105 on the Impact of World Fisheries on the Stability and Biodiversity of Marine Ecosystems, and WG 119 on Quantitative Ecosystem Indicators for Fisheries Management. Results of these WGs have provided the foundation for subsequent international science programs.

The International Council for Exploration of the Sea (ICES) has been an important partner with IOC in various activities. The ICES/IOC Working Group on Harmful Algal Bloom Dynamics and the ICES/IOC Study Group on Development of Marine Data Exchange Systems Using XML (SGXML) provided inputs to primary IOC activities, especially in terms of enhancement of databases, such as those for harmful algal blooms. Similarly, the ICES/IOC Steering Group on GOOS has enhanced collaboration between the two organizations and helped to expand the capabilities of the observing system.

Through co-organization of international symposia with ICES and the North Pacific Marine Science Organization (PICES), IOC has advanced its agenda of supporting study and synthesis of research on climate change and its effects on marine ecosystems and society.

### EXAMPLE PROGRAMS

The science questions and program goals for GLOBEC, ocean carbon, and harmful algal blooms had their origins in the international science community. The international GLOBEC program

grew out of emerging scientific plans in the United States and the recognition that international cooperation would be needed for the program to be successful. IOC was a key sponsor of GLOBEC from its inception, creating a beneficial partnership between the intergovernmental and nongovernmental science communities. IOCCP developed as a follow-up to a previous IOC-SCOR activity, the Advisory Panel on Ocean CO<sub>2</sub>. For GEOHAB, a SCOR WG provided the forum for discussion and development of scientific plans that were then embraced by the wider community, including IOC.

### Marine Ecosystems and Fisheries

By early 1990, the US GLOBEC program was well underway, with several planning workshops having taken place (NAS, 1987; USGLOBEC, 1988). There was a growing recognition that, in order to tackle the problems confronting the scientific community, an internationally coordinated GLOBEC program would be needed, especially because other national programs with a focus on marine ecosystem dynamics were emerging at the same time. There was also a strong feeling that there was a gap in existing oceanic global change research programs, none of which was addressing the linkages between physical processes in the ocean and its biological variability, especially in such processes as secondary production and recruitment, which are critical to the maintenance of populations of economically important resource species.

At this time, IOC had significant interests in GLOBEC-type science through its long-standing OSLR program. Concurrently, the international community approached SCOR to take a role in

developing an international GLOBEC program. These activities resulted in IOC and SCOR co-sponsoring an international workshop on Global Ocean Ecosystems Dynamics Research and Monitoring in order to assess the state of understanding of this topic and whether it could be advanced through an international research program (IOC, 1991). As a result, IOC and SCOR officially established the international program in 1991 (GLOBEC, 1992), and it became an IGBP project in 1995 (IGBP/GLOBEC, 1997). The partnership between IOC and SCOR continued through the conclusion of International GLOBEC in March 2010. In March 1998, IOC hosted the first GLOBEC Open Science Meeting in Paris which led to completion of the GLOBEC Implementation Plan (IGBP/GLOBEC, 1999). This meeting was critical to the development of the GLOBEC project and set the direction that was followed throughout the lifetime of the project.

The recent synthesis of GLOBEC results (Barange et al., 2010) shows clearly that this program substantially advanced understanding of the relationship between physical variability in the upper ocean and changes in biological processes such as growth, reproduction, and mortality; the availability of prey; and predation rates. IOC staff supported the GLOBEC project and played a strong role in its evolution, nominating and approving members of the steering committee, hosting several major GLOBEC meetings, attending some science steering committee meetings, and supporting the move toward synthesis in the latter phase of the project.

## BOX 3. IOC PUBLICATIONS

### Ocean Carbon

IOC has been a major contributor to activities related to ocean carbon since recognition of the ocean's major role in the global carbon cycle. IOC, SCOR, and other organizations were interested in global carbon cycle science, as well as the societal impacts of perturbations of the carbon cycle, and recognized the need for many international organizations to contribute to the study and observation of carbon dioxide in the atmosphere and the ocean. A significant IOC contribution to carbon cycle science was increasing the impact of carbon science results coming from the activities of working groups (convened by SCOR and others) through publication of the results and recommendations. The reports from these working groups (Box 3) were instrumental in developing measurement systems and programs for assessing ocean carbon inventories and distributions, and quantifying their control and regulatory processes.

IOC and SCOR have co-sponsored activities related to the ocean's role in global climate change since 1979, when the first joint Committee on Climate Change and the Ocean (CCCCO) was formed. In 1984, CCCC formed a CO<sub>2</sub> Advisory Panel, which was later transformed into a Joint Global Ocean Flux Study (JGOFS)-CCCCO group and, subsequently, a JGOFS-IOC group. IOC contributions to the JGOFS project were important, especially publication of the protocols manual (Box 3), which provided a common basis for making measurements that allowed JGOFS data collected by scientists from many nations to be used in multiship intercalibration exercises at sea, and in numerous synthesis studies following the

An important IOC role has been to publish and disseminate scientific information brought together both by IOC groups and other organizations through the UNESCO Technical Papers in Marine Science, which are scientific papers and publications; Monographs on Oceanography Methodology and IOC Manuals and Guides, which describe methodologies; and IOC Workshop Reports, which report the discussions and recommendations from IOC-sponsored workshops. Publications from these series have often been developed through cooperation with external organizations, such as the World Meteorological Organization (WMO) and the Scientific Committee on Oceanic Research (SCOR).

Example publications representing important synthesis products that provided clear benefits and contributions to the international ocean sciences community are:

- *Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements* (Knap et al., 1994), which describes the protocols approved by the international Scientific Steering Committee for the Joint Global Ocean Flux Study (JGOFS) for most JGOFS core measurements
- *Phytoplankton Pigments in Oceanography: Guidelines to Modern Methods* (Jeffrey et al., 1997), which provides protocols for measurement of pigments
- *Guide to Best Practices for Ocean CO<sub>2</sub> Measurements* (Dickson et al., 2007), which provides protocols for measurement of carbon dioxide in marine systems (joint publication of PICES and IOCCP)
- *The International Thermodynamic Equation of Seawater – 2010: Calculation and Use of Thermodynamic Properties*, which provides uniform standards for the thermodynamics and equation of state of seawater (IOC, SCOR, and IAPSO, 2010; see Millero, 2010)

UNESCO/IOC Technical Papers in Marine Science that provided important contributions to development of ocean carbon research programs are:

- *The Carbon Budget of the Ocean* (UNESCO, 1980)
- *Methodology for Oceanic CO<sub>2</sub> Measurements* (UNESCO, 1992)

Other important publications have provided outlines and strategies for major ocean programs, such as the Global Ocean Observing System (Baker, 2010).



completion of the field activities.

With the completion of JGOFS, this cooperative activity was reformed as the IOC-SCOR Ocean CO<sub>2</sub> Advisory Panel. This panel was superseded by the IOC-SCOR International Ocean Carbon Coordination Project (IOCCP), which promotes the implementation of a global network of ocean carbon observations through development of international agreements on standards, methods, and databases. IOCCP works with the Global Ocean Observing System, the Joint World Meteorological Organization (WMO)-IOC Technical Commission on Oceanography and Marine Meteorology (JCOMM), international research projects such as the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) project, and the Surface Ocean–Lower Atmosphere Study (SOLAS), and with scientists working in government agencies and research institutions who make ocean carbon measurements and are developing new measurement methods. IOCCP convenes workshops and helps develop manuals on ocean carbon measurement methods and systems (Box 3) and will soon release a manual from the Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP), which will provide guidelines and protocols for repeat hydrography sampling. As with JGOFS, IOCCP facilitates synthesis activities, especially those that involve biogeochemical modeling studies.

In 2004, IOC and SCOR convened the first symposium on *The Ocean in a High-CO<sub>2</sub> World* to bring together ocean scientists for an interdisciplinary examination of science related to the ocean in the context of increasing atmospheric carbon dioxide concentrations,

including potential effectiveness, risks, and unknowns of activities designed to sequester atmospheric carbon dioxide in the ocean. The first symposium and associated publications were widely disseminated within both the ocean science and policy communities worldwide, and included information about the implications of ocean acidification and the urgent need for more research on this issue. IOC and SCOR decided after the first symposium to hold an international symposium on this topic every four years. The second symposium was held in Monaco in 2008 and the third symposium is being planned for 2012. Other partner organizations joined IOC and SCOR in this effort in 2008. These symposia foster synthesis and integration of research on ocean acidification.

### Harmful Algal Blooms

The international program on harmful algal blooms emerged from SCOR WG 97 on Physical Ecology of Harmful Algal Blooms, which conducted its work through a NATO Advanced Study Institute in 1996, the results of which are given in Anderson et al. (1998). Also, the ICES-IOC Working Group on Harmful Algal Bloom Dynamics was established in 1994 to provide research directions on the physical, chemical, and biological interactions associated with harmful algal blooms. IOC and SCOR worked together to convene an exploratory workshop in 1998 and eventually to form the joint GEOHAB program. IOC played a strong role in this program, providing financial support, supplying a staff member to assist in program management, suggesting and approving steering committee members, and hosting meetings. The results that have emerged

from the GEOHAB program provide a synthesis of observational and modeling studies conducted through harmful algal bloom research programs.

### IOC AND SYNTHESIS

The support provided by IOC for the projects mentioned above, as well as others, was critical to their development. These projects represent fundamental changes in how the marine science community approaches measurement protocols, data availability, and data sharing, for example. These changes permit synthesis to proceed in a manner that engages a wider community, which enhances what can be gained from synthesis. Similarly, the GLOBEC and JGOFS projects clearly showed the importance of including coupled biogeochemical-ecosystem-circulation modeling as an integral part of the science activities (McGillicuddy et al., 2010). The GLOBEC project in particular used modeling in advance of field programs to synthesize ideas and data to inform development of field activities. Although these are not strictly formal synthesis activities, they do represent a philosophical legacy that allows synthesis to move forward, and they indicate where IOC has had the most influence in encouraging synthesis.

The lessons learned from the international projects sponsored and co-sponsored by IOC are now having an effect in setting up linkages among ocean observation systems, such as GOOS, the science user community, and management and policy communities. IOC is well positioned to take a lead role in ensuring that the products of these activities will continue to enhance synthesis to further understanding of

ocean science. Through its activities and network of Member States, IOC is in a position to ensure informed development and application of marine science and technology and can provide an essential source of information for policymakers, government officials, resource managers, scientists, the media, and the general public.

This IOC role is now more important than ever as issues related to climate change, resource extraction, and the use of the marine environment become more pressing and the need for informed ocean management increases.

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