Chapter 30. Marine Scientific Research

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1. Introduction

A scientific understanding of the ocean is fundamental to carry out an effective management of the human activities that affect the marine environment and the biota that it contains. This scientific understanding is also essential to predict or forecast, mitigate and guide the adaptation of societies to cope with the many ways the ocean affects human lives and infrastructures at different spatial and temporal scales.

Ideally, in order to manage human activities so as to achieve sustainable use of the marine environment and its resources, we need to know the geology and geophysics of ocean basins, the physical processes at work as the waters of the world's different oceans and seas move around, the input, distribution and fate of substances (both natural and artificial), the occurrence and distribution of flora and fauna (including the assemblages and habitat dependencies that control the different ecosystems), the biological processes that regulate and sustain the productivity of ecosystems and the way in which all these elements interact. Marine scientific research is the main way in which we can move towards this goal.

From a more fundamental perspective, the ocean is still one of the least known areas of the world. Humanity in its search of understanding has reached beyond our solar system and seeks fundamental answers in the infinitely distant and in the infinitely small. It has been said that we know more about the morphological features on the surface of other planets than of our own ocean. A significant effort of ocean exploration, using the most advanced techniques available today, is still probably one of the most rewarding collective efforts for humanity, as is attested to by the series of achievements of major international scientific programmes of the past..

Sustainability has to do with the mode by which humanity make use of nature. The increasing pressures that we impose on natural systems leave no room for complacency. At any point in time it is possible to extract the best advice that science can provide to completely or partially remove uncertainties around a phenomenon. From a scientific point of view, the need for better information always exists, therefore unresolved uncertainties are not a valid ground for delaying action. There are many improvements that can be made to managing human impacts on the ocean on the basis of current scientific knowledge. However, it is not long since the need to effectively communicate scientific results to policy makers has been recognized and is being systematically addressed through internationally validated efforts. At the national level, it is becoming common practice among institutions funding research to request those receiving their grants to undertake explicit initiatives of outreach towards the general public or to summarize the result of publicly funded research for policy makers. From a more basic perspective, publicly funded projects in data intensive sciences, like earth sciences, geophysics, and genomics are requested to deposit and disseminate the raw data collected through open access repositories.

The traditional knowledge of those who work with the sea has, in many cases, built up over millennia an understanding of many of these elements. It is essential that this traditional knowledge also be incorporated in our overall understanding of the ocean. Marine scientific research has an important role in validating traditional knowledge and identifying emerging issues. Marine scientific research is therefore fundamental to achieving sustainable use of the oceans.

2. The scale and extent of marine scientific research

The scale and extent of marine scientific research are as wide as the scope of the World Ocean Assessment: every field that needs to be covered in an assessment of the state of the world's marine environment needs to be explored scientifically. This Assessment therefore shows the results of the work that is being done in all these fields and assesses the major gaps in information, thus pointing the way to judgements on priorities for further scientific research.

In order to obtain a full picture, it is necessary to consider where, by whom and how the scientific research is being done. This is not an easy task, because until now no systematic collection of this information has occurred, although the Intergovernmental Oceanographic Commission of UNESCO (IOC/UNESCO) has initiated a process to produce regularly a Global Ocean Science Report (GOSR) aiming to conduct a global and regional assessment of capacity development needs in the field of marine science research and ocean observations.

One starting point is the question of who is doing this research. The IOC/UNESCO maintains a database of "ocean and freshwater experts", which can be analysed to help answer this question. The IOC/UNESCO database is compiled on the basis of voluntary self-recording by experts without any independent validation procedure (http://www.oceanexpert.net). There is therefore no reason to think that it is comprehensive, and the status and experience of the experts listed may vary. Examination suggests that it contains practically no experts whose expertise is solely in fresh water, and that nearly all experts have chosen to declare a geographic area of study. It therefore enables an initial understanding of research demographics for the various parts of the ocean. Table 1 shows the information on geographic areas of study derived from an analysis of this database. As this information is provided individually by the experts without any independent validation procedure, any analysis based on it may well be affected by biases or incompleteness in the database, and as much of the detail of the information provided is determined by the experts themselves, any analysis is bound to be fairly broad-brush, but this database is the best comprehensive basis available for examining the question of the spread of interests of marine scientists. This appears as a gap of information that needs to be addressed.

Table 1. Regions of study of IOC experts

Area of Study declared by experts	Experts located in a coastal State of Area of Study	Experts located elsewhere	Total number of experts declaring an interest in the Area of Study
Arctic Ocean	59	78	137
North Atlantic Ocean	519	208	807
Baltic Sea	91	7	98
Black Sea	135	11	146
Mediterranean Sea	393	71	464
North Sea	117	4	121
Wider Caribbean	314	12	326
South Atlantic Ocean	169	562	731
Indian Ocean	588	137	625
Red Sea	61	18	79
The Persian Gulf	49	16	65
North Pacific Ocean	375	102	477
- West Pacific ocean and fringing seas	100	34	134
South Pacific Ocean	157	102	259
Southern Ocean	142[1]	6	148

Source: Analysis of IOC, 2014.

Subject to the reservations explained above about the nature of the evidence, the main conclusions are that:

(a) Significantly more marine scientific researchers regard themselves as experts on the Atlantic Ocean than on the Pacific Ocean

(b) The Indian Ocean is relatively well served by marine scientific researchers; and

(c) The two main Southern hemisphere ocean basins (South Atlantic and Pacific and the Southern Ocean) attract relatively fewer marine scientific researchers.

[1] For the Southern Ocean, the coastal States have been taken to be those States that maintain research stations on Antarctica.

3. Status and trends of scientific output by regions

3.1 Status and trends relating to personnel

An alternative approach to assessing the capacities for marine scientific research by region is to review the number of scientific papers published about each region. This approach also suffers from limitations, and care must be exerted in using it. Some of the issues in assessing the numbers of scientific papers published about the different regions lie with the language of publication and the cost per publication. Although most of the international scientific literature is published today in English, a large potential bias remains with regard to scientific papers and reports published in other languages, or in local journals not reported to international data bases. Although some data bases containing full-text articles address these issues, for example, SciELO (Scientific Electronic Library Online; http://www.scielo.org) for several geographic areas and CNKI (China Knowledge Resource Integrated Database; http://www.cnki.net) for China, the risk of under-reporting of certain countries, languages and regions exists. Another issue is the attribution of the origin of papers. Usually, the attribution is assigned according to the location of the principal, first or corresponding author. This means that the attribution of where work has been done will exclude the location of junior authors in the multi-authored papers, which are now very common.

The analysis below shows the global results analyzed by region of scientific papers published on oceanography from one database for scientific papers which has a wide coverage – ScImago (http://www.scimagojr.com/). Although the papers used are classified *sensu lato* as "oceanography", the data base lists articles in 122 journals with a broader scope than what is usually understood as "oceanography" in the strict sense (Appendix). The journals covered are those that were regularly published in 209 distinct jurisdictions, national or otherwise (described as "countries and territories" in the data base) over the 17 years between 1996 and 2013.

During the 19 years of the data base, a healthy, clear, positive trend of increasing scientific contributions on oceanography each year from around 7,000 to nearly 14,000 altogether is shown (Figure 1). On the other hand, the number of countries from which contributors are drawn has shown only a slight increase of about 20 new countries in 17 years, probably due to the fact that the database is reaching the upper limit of the number of countries.

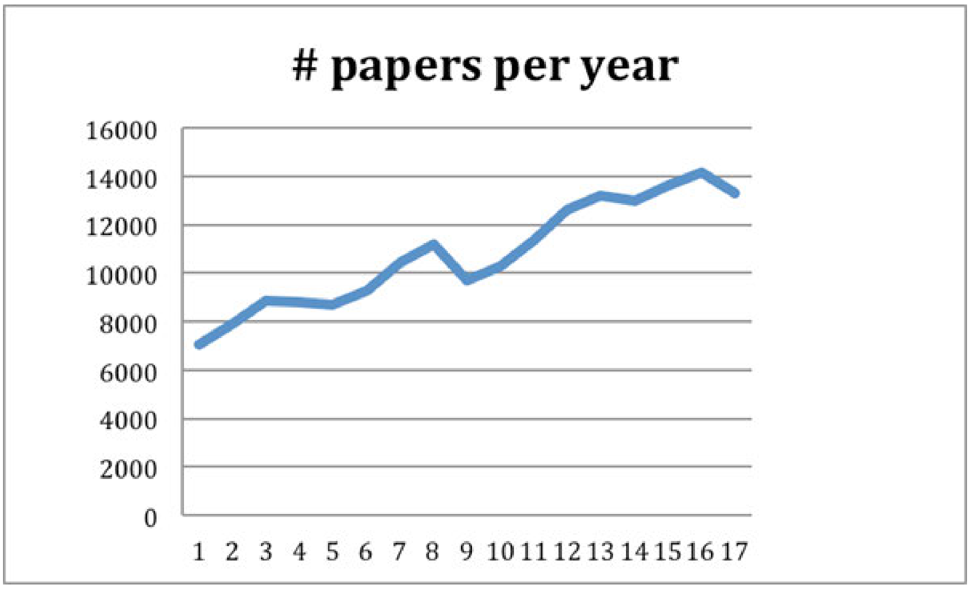

Figure 1. Increase in number of scientific papers on oceanography. Adapted from Analysis of ScImago, 2014.

When the countries and territories are grouped into eight regions, the following breakdown emerges of the origins of the 213,760 articles published between 1996 and 2013 (Figure 2).

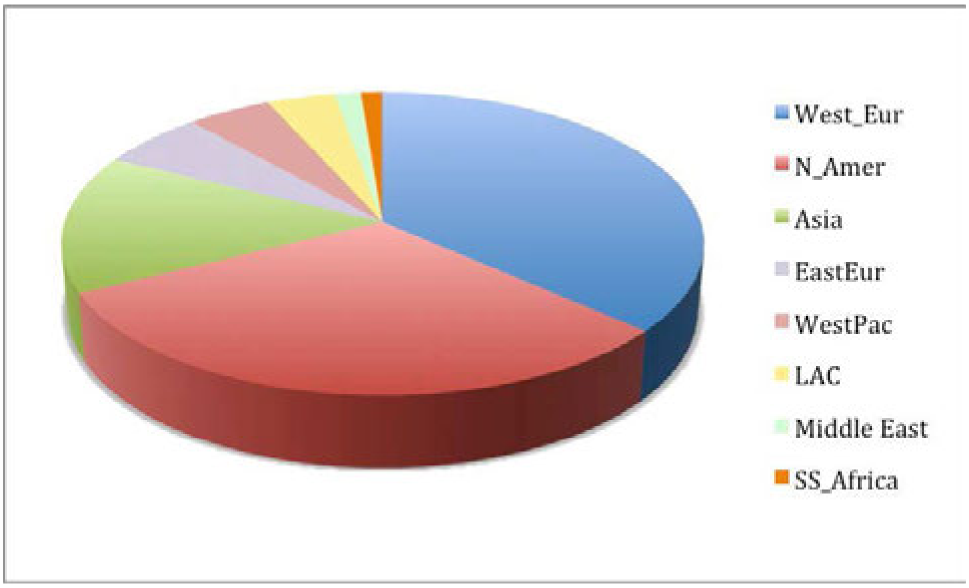

Figure 2. Geographic areas of origin of scientific papers on oceanography 1996 – 2013. Source: Analysis of ScImago 2014.

These proportions per region, with North America and Western Europe having the highest number, do not differ significantly from those obtained when analyzing papers from other scientific disciplines. This suggests that they accurately reflect the level of scientific activity in general, not merely a situation specific to the marine sciences, and therefore that this analysis may reflect common, broad issues on available research infrastructure, investment and institutional development that, together with appropriate national policies, do control the development of scientific research in general.

3.2 Status and trends relating to equipment

Almost as important as the personnel involved in marine scientific research are the facilities available to them. It is even more difficult than with the personnel to gain an overall view of how far researchers studying the marine environment have adequate equipment. Nevertheless, one indication can be gained from the available information about research vessels. The University of Delaware in the USA maintains an online catalogue of research vessels, including both surface and submersible vessels, and their cruise schedules (www.researchvessels.org). This covers 836 research vessels based in 59 countries, including both publicly owned and commercial research vessels. Again, given that it relies on voluntary recording, it is not comprehensive, but gives a general impression of the distribution of research vessels. Judging by their size, many of these vessels are for coastal operations: 224 are less than 20 m length, while only 138 larger than 80 m. Of those with ocean going capabilities 179 are clustered between 40 and 60 m and 139 between 60 and 80 m. The different capabilities of the vessels can be roughly assessed by the type of equipment they have. All vessels in the database have echo-sounding capabilities, while only 187 are equipped with Conductivity, Temperature and Depth probes (CTDs), 124 with Acoustic Doppler Current Profilers (ADCP), 116 with multi-beam mapping systems and 57 with dynamic positioning systems. Of all the reported fleet 129 have icebreaker capabilities and 103 can berth and deploy remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs) or submersibles. It is likely that many members of the modal classes (40-80 m length) are fisheries R/V or multipurpose platforms capable of fisheries survey capabilities (acoustic or standard trawling). Table 2 shows an analysis of the areas in which these research vessels are based.

Table 2. Marine Research Vessels

Geographic Area of the World	Number of Research Vessels reported	Largest number recorded in the Geographic Area by one State
Africa	6	4 (South Africa)
Asia	179	108 (Japan)
Eastern Europe	153	116 (Russian Federation)
Western Europe	184	39 (United Kingdom)
North America	288	230 (USA)
Oceania	10	7 (Australia)
Latin America and Caribbean	29	7 (Argentina)
Total	849	

Source: Analysis of IRVSI 2014.

Even with the limited information available, this analysis shows a preponderance of research vessels based in the northern hemisphere. Closer analysis suggests that the vessel capacities for research in the Indian Ocean, in other parts of the waters around Africa and in much of the Pacific Ocean are also limited. Anecdotal information suggests that this imbalance is also applicable to other equipment needed for marine scientific research.

4. Collaboration in Marine Scientific Research

One way of overcoming imbalances in national capabilities to undertake marine scientific research is through international joint activities.

Oceanography has always been considered as an international endeavour. The organizers of the Challenger Expedition, that conventionally marks the origin of modern oceanography, took every step necessary to secure the contribution of the best international specialists of the time to produce the fifty volumes of the Challenger Report, containing the results of the Expedition. The first efforts in the study of the North Sea, North Atlantic and the Arctic were also international, and gave rise to the creation in 1902 of the International Council for the Exploration of the Sea (ICES), which plays a fundamental role in codifying the methodologies that enable progress in physical and chemical oceanography.

After the Second World War, the main event that brought together international scientific cooperation was the International Geophysical Year (IGY) of 1957-58. Although the IGY included some oceanographic research, this was not its main focus and the oceanographic community reacted to this situation by planning a major international expedition to the least-known ocean basin at the time: the Indian

Ocean.

These initiatives gave rise to two international institutions: first, the Scientific Committee of Ocean Research (SCOR) under the International Council of Scientific Unions (ICSU) in 1957 to coordinate ocean research in the IGY, and then the IOC/UNESCO in December 1960, following a recommendation of the First Oceanographic Congress held in July 1960 in the Danish Parliament. During the International Indian Ocean Expedition, the IOC coordinated the efforts of 27 nations employing over 40 oceanographic research vessels in more than 70 cruises in the Indian Ocean during 1962-1965.

Later SCOR and IOC, through the regular organization of the Joint Oceanographic Assemblies, kept the focus of the community on the design of international research programmes. For example, the Committee on Climatic Changes and the Ocean, sponsored by SCOR and IOC, is at the origin of two global research projects of primarily physical studies: the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean-Global Atmosphere Study (TOGA) also co-sponsored by the World Climate Research Programme (WCRP). WCRP was established in 1980 under the joint sponsorship of ICSU and the World Meteorological Organization (WMO) and since 1993 the IOC has also sponsored it.

In the 1980s two major international programmes requiring ocean going capabilities were co-sponsored by SCOR, the International Geosphere-Biosphere Programme (IGBP) and jointly with IOC: first the Joint Global Ocean Flux Study (JGOFS), focusing on the role of the ocean in the global carbon cycle, and second the Global Ocean Ecosystem Dynamics (GLOBEC) programme. Over ten years GLOBEC developed seven regional comparative studies to understand marine ecosystem responses to global changes, including both environmental and human pressures, and produced over 3,500 publications, including 30 special issues of primary journals. The Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) programme has followed GLOBEC.

SCOR and IOC/UNESCO have also developed the Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) Programme with a focus on obtaining an understanding of the ecological and oceanographic conditions that cause harmful algal blooms and promote their development. Other international programmes are the Global Coral Reef Monitoring Network and the Census of Marine Life, a ten year effort focusing on the biology of the ocean that mobilized more than 2,700 scientists, published 3,100 scientific papers and described 1,200 new species for science, leaving as one of its legacies the Ocean Biodiversity Information System (OBIS), the largest repository of marine biodiversity to date.

In the domain of marine geology and geophysics, the Integrated Ocean Drilling Programme, that initially built and operated the R/V *"Glomar Challenger"* in the seventies, was followed after October 2013 by the International Ocean Discovery Programme (IODP) currently operating the R/V *"JOIDES Resolution".* These international programmes were instrumental in developing the technology to drill the sea floor and to obtain the long cores that provide a wealth of research activities expanding our knowledge in different areas, including plate tectonics and seismology.

In geochemistry, the Geochemical Ocean Sections Study, GEOSECS, obtained very accurate sections and profiles of the distribution of chemical, isotopic, and radiochemical tracers in the ocean, building a global three-dimensional view of the chemical composition, including alkalinity, of the ocean, enabling the establishment of a solid baseline to measure acidification worldwide. GEOSECS is now being followed by GEOTRACES, which is measuring the distributions of trace elements in the sea.

4.1 The development of a permanent infrastructure to observe the Ocean.

Perhaps one of the most fundamental changes in marine scientific research was the realization that what was needed to underpin many of the more focused or local research efforts was a common infrastructure to observe the oceans at the global but also at other relevant temporal and spatial scales. In the late 1980s, oceanographers had come to realise that the ocean played a tremendously important role in the climate system through its ability to store large amounts of heat and to move this source of energy for the atmosphere slowly around the globe. Accordingly, understanding and forecasting climate change was seen to require observations over much longer periods of time, than the time-limited experiments such as the ocean observations done during the First GARP[2] Global Experiment (FGGE) during 1978-79 or the TOGA study, which ran from January 1985 to December 1994.

In 1989 IOC's Technical Committee for Ocean Processes and Climate (TC/OPC) recommended the design and implementation of a global operational observing system. The WMO Executive Council endorsed that call in June 1989, as did the 15th IOC Assembly in July 1989. Finally, in June of 1990, the Intergovernmental Panel for Climate Change (IPCC) called for a Global Ocean Observing System (GOOS) which was endorsed by the Second World Climate Conference in September 1990, that saw GOOS as a major component of the proposed Global Climate Observing System (GCOS). In February 1991, the TC/OPC agreed that the concept of GOOS should be broadened to include physical, chemical and biological coastal ocean monitoring; climate was no longer to be the sole focus. In May 1991, WMO's 11th Congress accepted to co-sponsor the GOOS.

Existing physical oceanographic observing systems developed over the years by UNESCO/IOC became fundamental building blocks of GOOS. For example, the IOC's global sea-level observing system (GLOSS) and the joint IOC/WMO Integrated Global Ocean Services System (IGOSS), which included the Ship-of Opportunity Programme and the drifting and other buoys of the Data Buoy Cooperation Panel.

The creation of GOOS reflected the desire of many nations to establish systems of ocean observations dealing with environmental, biological and pollution aspects of the ocean and coastal seas, to raise the capacity of developing nations to acquire and use ocean data effectively and to integrate existing systems of observation and data management within a coherent framework.

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[2] GARP is the Global Atmosphere Research Programme

That desire was reflected in the call made in Rio de Janeiro from the United Nations Conference on Environment and Development in June 1992 to develop GOOS as one of the mechanisms required to support sustainable development. This required that the initial focus on climate research had to be enlarged to include other aspects, like the impact of pollution and the status of marine living resources. The Health of the Ocean (HOTO) Panel was established as an *ad hoc* group in 1993, and became a formal advisory group to J-GOOS in 1994. An *ad hoc* Living Marine Resources (LMR) Panel met in 1993 and in 1996, and an *ad hoc* Coastal Panel met in 1997.

IOC/UNESCO and WMO gave first priority to the implementation of the physical oceanographic component of GOOS, as the ocean component of the climate observing system GCOS. This part of GOOS has been successfully in operation since 2005; however the development of the other parts of GOOS has continued as new technologies emerge and mature, enabling the automatic long-term measurements of chemical and biological variables.

4.2 Operating Systems of GOOS

Although fundamentally underpinning most of the research conducted to understand the role of the ocean in climate change, strictly speaking GOOS is not a research project. GOOS should be better recognized as a *large and distributed scientific facility* or infrastructure, equivalent to the large observatories of astrophysics or the big accelerators of particles of physics. This section describes its components (IOC/GOOS, 2015).

4.2.1 Surface moorings

Surface moorings are large fixed buoys, moored to the bottom of the ocean, mostly deployed in the Equatorial region. They measure surface winds, air temperature, relative humidity, sea-surface temperature and subsurface temperatures from a 500-m-long thermistor chain hanging below the buoy. Daily data are broadcast to shore through satellite links (TAO, 2015).

4.2.2 Argo Profiling Floats Programme

The Argo floats are autonomous observation systems which drift with ocean currents making detailed physical measurements of the upper 2 kilometres of the water column. Floating along at a depth of 2,000 metres, every 10 days an Argo float awakens and increases its buoyancy by pumping fluid into an external bladder. During its journey upward through the water column, it records the conductivity (salinity) of the seawater, its temperature, and pressure. Once at the surface, the Argo float finds its geographical position via global positioning systems (GPS) and transmits its data by satellite to Argo data centres. After completing the upward profile it decreases its buoyancy and sinks again, collecting a similar record on the trip down to 2000 m. The information is joined with data from over 3,000 other Argo floats to form a synoptic 3-D view of the ocean in near real time (http://www.argo.ucsd.edu/index.html).

About 800 profiling floats are deployed on a yearly basis by a number of States. Between 2004 and 2009, 26 States deployed at least one float to maintain a global array of 3,200 units, spaced 3° by 3° of latitude and longitude. Profiling float technology has evolved to reach the initial desired five-year lifetime, and a float deployed today will probably last between 5 and 10 years. Argo floats spend 90 per cent of their time at 2,000-m depth and on average rise to the surface every ten days to transmit their data.

This system has revolutionized oceanography since its inception in 1998 through the Climate Variability and Predictability (CLIVAR) programme and the Global Ocean Data Assimilation Experiment (GODAE).

Argo floats take more than 100,000 salinity and temperature profiles each year, more than 20 times the number of annual hydrography profiles taken from research ships. The Argo array is maintained by the active engagement of 30 countries that contribute floats and ship-time for the deployments. The original engineering specifications of the floats were made available to many research institutions around the world and floats are now made in several countries. The International Argo Steering Team oversees technically the project and operations are monitored at the Argo Information Centre, a part of the IOC – WMO, Joint Technical Commission of Oceanography and Marine Meteorology - operational centre (JCOMMOPS).

Argo data have transformed ocean circulation studies. Today Argo data are routinely assimilated into global circulation models, giving accurate and timely global views of the circulation patterns and heat distribution of the ocean. This product has become an essential element of atmospheric forecast models and greatly improves seasonal climate, monsoon, El Niño forecasts, as well as tropical cyclone simulations. The value of subsurface heat content measurements to the study of global warming and climate change has made the Argo an invaluable component of 21st-century environmental observation systems.

4.2.3 The Ship-of-Opportunity Programme (SOOP).

Ships of opportunity are usually ordinary cargo ships on regular routes, whose owners and crew agree to carry and, where necessary, operate oceanographic equipment during their regular voyages. Other types of vessel are also used. The Ship-of-Opportunity Programme (SOOP) and its Implementation Panel (SOOPIP) is an operational programme under the intergovernmental governance of the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). The primary goal of SOOP is to satisfy upper-ocean data requirements which have been established by GOOS and GCOS, and which can be met at present by measurements from ships of opportunity (SOO).

SOOP operates a global network of Expendable Bathythermograph (XBT) and ThermoSalinoGraphs (TSG) systems on board of merchant ships, from which data are transmitted in real time and made available to the oceanographic and meteorological communities for operational use in ocean models and for other scientific purposes. Around 14,000 XBT probes are launched every year and more than 30,000 TSG observations are collected annually. Other types of measurements are also made. The following devices are commonly used:

(a) *XBT (Expendable BathyThermograph)* is an expendable (disposable) temperature- and depth-profiling system;

(b) *TSG (ThermoSalinoGraph)* is an automated sea-surface temperature and salinity measurement system for making continuous underway measurements from the ship's water intake;

(c) *CTD* is an electronic set of instruments to make precise conductivity, temperature, and depth measurements. The instrument is connected to the ship by a conducting cable; Accuracies better than 0.005 mS/cm are usually achieved for conductivity, better than 0.002^{o} C for temperature, and better than 0.1 per cent of full-scale range for depth;

(d) *XCTD* is an expendable (disposable) conductivity, temperature and depth profiling system.

(e) *ADCP (Acoustic Doppler Current Profiler).* A beam of sound of known frequency is reflected from small particles moving with the water. Adequate sampling of this backscattering beam allows current measurements by the Doppler effect at different depths. ADCPs can, for example, be installed on the hull of the ship "looking downwards" or lowered from a ship to different depths to measure a wider range of current profiles. An accurate GPS positioning system can then be used on a moving ship to subtract the ship's speed from the measured current vector;

(f) *pCO2*. Measurements of the "partial pressure of CO_2" (pCO_2) on the ocean surface indicate whether the local ocean is acting as a source or a sink of CO_2. Measurements use a standardized infrared analyzer or a gas chromatograph to determine the concentration of CO_2. The probe is installed in the hull of a ship, and measurements can be made while the ship is under way. Partial pressure of CO_2 in the air can also be measured. Accuracies in the order of 0.2 parts per million can be achieved.

4.2.4 Hydrography

The direct sampling of ocean water by lowering bottles from a ship and bringing water samples up on board ship for analysis remains one of the fundamental tools of ocean observations. A CTD rosette, equipped with Niskin bottles, is lowered to its deepest point and then as it is winched up to the ship the bottles are closed, one at a time, capturing a CTD profile of the water column along the way. The water can be sampled for CO_2, chlorophyll, microorganisms, biogeochemistry, and a wide variety of other uses. The International Ocean Carbon Coordinating Programme and the CLIVAR Programme organize and coordinate major hydrography cruises and maintain databases of tens of thousands of hydrography profiles taken throughout the world's ocean. These programmes provide essential data streams for GOOS, as they provide precise and accurate *in situ* measurements that benchmark observations measuring the penetration of heat in the ocean or the changes in alkalinity, monitoring the ocean's uptake of CO_2 that is changing the ocean acidity levels.

4.2.5 Surface drifting buoys

The Global Drifter Programme manages the deployment of surface drifting buoys around the world. These simple buoys take measurements of seawater-surface temperature, salinity and marine meteorological variables that are telemetered in real time through the WMO's Global Telecommunications System (GTS) to support global meteorological services, climate research and monitoring. The surface drifters are a flexible component of GOOS and can be deployed quickly for such tasks as monitoring an approaching typhoon. The global array is designed to use 1,250 buoys to cover the oceans at a resolution of one per 5° x 5° of latitude and longitude. This array provides over 630,000 sea-surface observations per year. The surface temperature data are used to calibrate satellite temperature imagery, bringing bias errors down from 0.7° Celsius to less than 0.3° C, allowing accurate climate-change monitoring. Along with the Argo profilers, the surface drifter programme has contributed to the success of a real-time monitoring system of the oceans, enabling much more accurate weather and climate forecasts.

4.2.6 Continuous Plankton Recorder

Launched over the side of a research vessel, merchant ship, or other vessel of opportunity, the Continuous Plankton Recorder (CPR) captures plankton from the near-surface waters as the ship tows the instrument during its normal sailing. Since 1946, the CPR has been regularly deployed in the North Atlantic and North Sea on several routes. The CPR is a critical component of GOOS and monitors the near-surface plankton in the North Atlantic and North Sea on a monthly basis from a network of shipping routes. Many other tracks around the world are now covered by the CPR programme. The amounts and types of phytoplankton and zooplankton captured by the CPR are analyzed in a laboratory. After analysis, the counts are checked and added to the CPR database, which contains details of the plankton found in over 170,000 samples taken since 1946 in the North Sea and North Atlantic Ocean, and increasingly elsewhere.

4.2.7 Global Sea Level Observing System (GLOSS)

The Global Sea Level Observing System (GLOSS) is an international programme conducted under the auspices of the JCOMM of the WMO and the IOC. It coordinates a network of sea-level monitoring gauges installed along the coasts of over 70 countries. The main component of GLOSS is the "Global Core Network" (GCN) of 290 sea-level stations around the world for long-term climate-change and oceanographic sea-level monitoring. Each station is capable of accurately monitoring sea-level changes with high accuracy, and many are able to transmit information in real time via satellite links. The GLOSS sub-network that transmits in real time is part of the global tsunami warning systems.

Real-time measurements of water-level changes can provide tsunami warnings for locations surrounding the affected sea basins. Sea-level observations are also useful for local navigation and continual refinement of tide-table predictions. Tide gauges measure rising water levels from storms and extreme tides, which can be responsible for billions of United States dollars in damage and lost productivity every year.

4.3 Ocean Biological Data

As a result of the ten-year-long effort by the Census of Marine Life, a significant increase in biological data took place. This new data was integrated to pre-existing data into the Ocean Biodiversity Information System (OBIS http://www.coml.org/global-marine-life-database-obis). Several of these new data streams are associated to the tagging and tracking of live animals, for example the Tagging of Pacific Pelagics (TOPP) programme in Western North America and the Australian Animal Tracking and Monitoring System (AATAMS). The tagging of marine animals, fish, birds, turtles, sharks, mammals, with electronic sensors is increasingly being undertaken by scientists worldwide to track their movements. Electronic tags such as archival, pop-up archival and satellite positioning tags are revealing when, where and how marine animals travel, and how these movements relate to the ocean environment. (http://www.scor-int.org/observations.htm). An Ocean Tracking Network is being developed. The network will track thousands of marine animals around the world using acoustic tags safely attached to the animals. At the same time, the network will be building a record of data relevant to climate change, through observation of changes in the animals' patterns of movement.

5. Socioeconomic aspects of marine scientific research

Three major points emerge from the foregoing analyses and the material in other chapters on the results of marine scientific research in the fields they cover.

First, the success of the management of human activities that affect the marine environment is conditional upon having reliable information about that environment. If adequate information is not being collected, then management decisions will be less than optimal. Parts of the world that do not have adequate infrastructure for an adequate collection of information about their local marine environment are disadvantaged. Although research based in other parts of the world may provide a good understanding of how the marine ecosystems operate, and of the pressures to which they are subject, such a general understanding must be supplemented by adequate local information. Such collection of local information is always likely to be more efficient, effective and economical.

Second, as the world's marine environment is very much interconnected, sub-optimal management in one part of the world is likely to affect the quality of the marine environment in other parts of the world. This is the case of land-based point-sources of pollution that, depending on circulation, can broadcast their negative impacts across maritime borders; or if stocks of marine living resources are not well managed in one part of the world, diminishing the landings of a certain target-species, this may increase fishing pressure on the same or similar species in other parts of the world.

Third, even though universities and other educational establishments produce good-quality marine experts throughout the world, graduates will experience pressure to move to those parts of the world where they can hope to have access to the best equipment for their further research. It is only in that way that they can hope to develop their careers most successfully. Such a "brain drain" will undermine efforts to establish adequate marine research in all parts of the world until appropriate local conditions for the development of scientific research exist.

6. Environmental impacts of marine scientific research

Any observation of a natural system has the risk that it will disturb that system. Proper design of marine scientific research can reduce, or even eliminate, this risk. It is particularly important that efforts that aim at improving the understanding of marine ecosystems should not damage those ecosystems.

The IOC has an important role in establishing safeguards for marine research projects that risk adversely affecting the marine environment. Efforts have been increasingly made to address this task. The International Ship Operators forum, answering to concerns of the impact of both ship operations and marine scientific research operations, developed a Code of Conduct for Marine Scientific Research Vessels that was approved at the 21st International Ship Operators Meeting (ISUM) in Qingdao, China. The code calls for *"the utilisation of environmentally responsible practices"* (…) and to *"adopt the precautionary approach as the basis for the proposed mitigation measures"*. *"Every vessel conducting marine science should develop a marine environmental management plan"* which *"should be designed to employ the most appropriate tool(s) to collect the scientific information while minimizing the environmental impact."* Among the activities addressed by the code are: dredging, grab & core sampling, lander operations, trawling, mooring deployments, remotely operated vehicle (ROV) sampling, jetting system operations for cable burial, high intensity lighting for camera operations.

Other example can be taken from the Argo floats programme. Every year, about 1 per cent of floats are beached or trapped in fishing nets. These are recovered, secured and redeployed when possible, or recycled through a procedure coordinated by JCOMMOPS. All other floats finish their mission at depth, which is the best compromise found to date to limit the impact on the environment: (1) to avoid energy consumption to recover the instruments at sea by the use of motor vessels, and (2) to avoid having floats drifting at the surface for a long time (after a set of predefined cycles) and becoming a potential issue for navigation. The total mass of float hardware reaching the sea floor every year (less than 30 tons), and more precisely the small fraction of polluting material inside, can be more than fairly compared to old metro trains sunk to provide structure for artificial reefs, merchant ships, fishing vessels, off-shore stations, lost containers and decommissioned offshore oil platforms, that sink to or stay on the sea floor.

Technological improvement now allows the use of a bi-directional telecommunication system, which can "control" the behaviour of the platform by sending new configuration parameters and receiving data. About 30per cent of the Argo array is now equipped with this system. A float can then be asked to stay at surface to await its imminent retrieval. This is already being done today in pilot projects, and is used in particular to recover biogeochemical floats, which are equipped with expensive sensors and require some post-calibration. The involvement of civil society (for example, the yachting community, nongovernmental organizations and foundations) and industry in offering deployment opportunities to cover large ocean areas can be also a way to improve retrieval capacity. This requires a large networking capacity and is encouraged by IOC through its operational Centre JCOMMOPS. The manufacturers of floats are also encouraged, with rest of the world industry, to use environmentally friendly materials, whenever possible. As Argo is the main pillar of the ocean climate warning system, the ratio between advantages and disadvantages for the environment is judged to be more than satisfactory by the marine scientific research community, and at the same time that community continues to develop strategies to mitigate its impact.

Another example of the development of precautions against damage to the marine environment from marine scientific research concerns hydrothermal vents. In the 1990s, an international organization called Interridge was established and is today supported by China, France, Germany, Japan, the United Kingdom and the United States of America, together with Canada, India, Norway, Portugal and the Republic of Korea as associates, to pool resources for the investigation of oceanic ridges. Within this framework, recommendations have been developed on how to protect hydrothermal vents during research (Interridge, 2001). This provides a helpful model for developing protocols to ensure that marine scientific research does not harm the very objects that it wants to study.

7. Conclusions and capacity-building and information gaps

Major disparities exist in the capacities around the world to undertake the marine scientific research necessary for proper management of human activities that can affect the marine environment. The other chapters of this Assessment demonstrate how these disparities constrain the tasks of managing these human impacts. Capacities to undertake marine scientific research exist in most parts of the world.

Although a full assessment of all the existing programmes of capacity development is beyond the scope of this chapter, several long-standing international programmes have addressed these disparities. For example, the Train-Sea-Coast Programme, established in 1993 by the United Nations Division for Ocean Affairs and the Law of the Sea (DOALOS) with initial funding from the United Nations Development Programme and then by the Global Environment Facility, although now closed, aimed to build capabilities to enhance national/regional capabilities on key trans-boundary topics/problems in coastal and ocean-related matters. Topics addressed were quite wide, and ranged from coastal zone management, marine pollution control to marine protected areas and responsible fisheries. On geophysics, the IOC/UNESCO has maintained an annual Training Through Research ocean-going programme for young students to acquire hands-on experience in the operation, use and interpretation of data from current equipment used in marine geology and geophysics. In the area of living marine resources, the Food and Agriculture Organization of the United Nations (FAO) and Norway have developed for the last 40 years the ocean-going Nansen Programme funded by the Norwegian Agency for Development Cooperation (Norad) and executed in a partnership between the

Norwegian Institute of Marine Research (IMR) and FAO. The first R/V *Dr Fridtjof Nansen* was commissioned in October 1974. The third version of the R/V is currently being built and expected to be commissioned in 2016. The International Seabed Authority (ISA) has three active training streams, the *Endowment Fund* supporting the participation of qualified researchers from developing countries in cooperative research on the seabed; the *ISA/Contractors Training programme* aimed at training developing countries' scientists and managers and the *ISA Internship Programme* that, in a twofold approach, receives young scientists and managers from developing countries at ISA headquarters to learn about the goals and functions of ISA, but also receives young, highly qualified personnel to reside and contribute for short periods to ISA activities.

Many other international training initiatives on marine sciences, bi-lateral or multilateral, do exist, especially in the academic/education domain, but no comprehensive global reporting or cataloguing of these important efforts exists to date.

Gaps remain in the abilities to integrate the results of scientific research into the development of policy: capacity-building gaps thus exist in creating an effective science/policy interface first and foremost at the national level, but also at the regional and global levels.

Furthermore, efforts to fill the capacity-building and information gaps identified in other chapters will be much less productive if they are not made against a background of developing a global coverage of systems that can provide adequate integrated management information to global, regional and national authorities. This will be both more efficient and more economical, because a coherent body of scientific information will ensure that unexpected results of human activities and efforts to manage them will not go undetected, and will avoid duplication and overlap.

As this chapter has suggested, systematic information and knowledge about the progress of marine science is lacking. This therefore strengthens the case for supporting within the UN System the IOC's efforts to develop a World Ocean Science Report (see Decision EC-XLVII/6.2) that would eventually complement the existing World Science Report of UNESCO.

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