Global Ocean Science Report

The Current Status of Ocean Science around the World

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

Sustainable Development Goals

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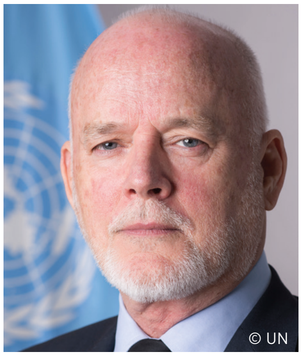
Foreword



Peter Thomson
President of the 71st session of the United Nations General Assembly

Irina Bokova
Director-General of UNESCO

Peter M. Haugan
Chairperson of the Intergovernmental Oceanographic Commission of UNESCO

The world ocean is one, interconnected and vast. It covers 70% of the surface and contains more than 95% of the water of the planet. Grasping such vastness is challenging. Yet we have to realize that the ocean's resistance and resilience are not infinite. We can and should no longer assume that the world ocean can continue absorbing the effects of unsustainable human activities endlessly and still continue providing its vital services.

The ocean is vulnerable. It is our duty to use it sustainably. This is our responsibility to both current and future generations. We must act now to ensure the sustainability of the world ocean.

On 5–9 June 2017, governments and stakeholders from across the world gathered at the United Nations in New York on the occasion of the Ocean Conference, dedicated to the support of Sustainable Development Goal 14 (SDG 14) under the 2030 Agenda.

Today, there is a sense of urgency and responsibility – indeed, a moral imperative – to ensure inter-generational equity in our interaction with the global commons, of which the world ocean is one. We urge the integration of ocean matters, including the social and economic dimensions of how people use and migrate through the world's ocean. Understanding the ocean as a system requires untangling its complexity through research and sustained observations, supported by adequate infrastructures and investments. In short, our understanding of the ocean and its contribution to sustainability largely depends on our capacity to conduct effective ocean science.

The ocean is vulnerable. It is our duty to use it sustainably. This is our responsibility to both current and future generations.

The 2030 Agenda is driven by 17 Sustainable Development Goals that are all interlinked. The Agenda is universal and speaks to both developing and developed countries. The Agenda calls for sustainability of our climate system and biodiversity while promoting food security, health, job creation and prosperity to leave no one behind.

In this context, the world ocean and the related SDG 14 are central to the 2030 Agenda. The ocean will need to continue feeding humankind, support industry and provide solutions to diseases through the discovery and application of new biomolecules. Silently but steadily it will continue stocking 'blue carbon' by absorbing carbon dioxide, and help mitigate the impacts of climate change, both through its coastal ecosystems as well as in the open ocean.

However, this capacity of the ocean is not endless. We now have the obligation to maintain its ecological integrity.

Action starts with vision: the ocean has a central role in supporting life on earth and humankind's well-being. This is the vision of SDG 14, to 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development', and this is the vision guiding all our actions.

The Intergovernmental Oceanographic Commission of UNESCO plays a vital role in promoting, with determination and efficacy, regional and international cooperation on and access to science, technology and innovation. We foresee that the *Global Ocean Science Report* will become the mechanism on which countries and other relevant stakeholders will rely to orient investments in ocean science and related cooperation for the benefit of the ocean and all humanity.

Irina Bokova
Director-General of UNESCO

Peter Thomson
President of the 71st session of the United Nations General Assembly

Peter M. Haugan
Chairperson of the Intergovernmental Oceanographic Commission of UNESCO

Preface

Vladimir Ryabinin

Executive Secretary of the IOC

The Commission bridges ocean science capacity and needs in developed and developing countries, including by mobilizing its Regional Subsidiary Bodies in Africa, Asia and the Pacific, Latin America and the Caribbean, and in the Indian Ocean.

The Intergovernmental Oceanographic Commission (IOC) of UNESCO was founded in 1960 with the aim of promoting cooperation in oceanography for a better understanding of the ocean. From studies focusing on physical properties of the ocean, including in relation to its interaction with the atmosphere, the Commission's work has evolved to encompass studies on pollution and ocean health, the development of sustained observations, including in relation to ocean hazards such as tsunamis, and the provision of platforms for the collection of, and access to, data and information in a freely accessible manner for all.

Nowadays, the 148 Member States of the Commission conduct a rich portfolio of scientific activities aimed at further elucidating the role of the ocean in mitigating climate variability and change, the likely capacity of the ocean to continue delivering a critical food security function through healthy marine food webs, and the contribution of the ocean economy to a prosperous and equitable society. The outputs of IOC's work inform relevant policy processes on the ocean and the law of the sea, and assist countries in sustainable management of their Exclusive Economic Zones.

The work of the Commission is focused on international scientific cooperation and capacity development. The Commission bridges ocean science capacity and needs in developed and developing countries, including by mobilizing its Regional Subsidiary Bodies in Africa, Asia and the Pacific, Latin America and the Caribbean, and in the Indian Ocean.

The Sustainable Development Goal 14 (SDG 14) and its targets explicitly project IOC Member States' priorities on the UN 2030 Agenda for Sustainable Development. IOC has been designated as the custodian agency for the indicators related to Target 14.3, which deals with the need to monitor ocean acidification as a result of increased carbon dioxide in the atmosphere and its absorption by the ocean; and Target 14.a., which focuses on developing adequate capacity in ocean science, including through the transfer of marine technology. This latter target constitutes the focus of this report.

In 2015, the IOC Assembly decided to launch a Global Ocean Science Report (GOSR), the main aim of which was to systematically assess the status and trends in ocean science capacity.

What are the key elements of ocean science, including workforce, research expenditure, infrastructure and publications globally? What is the current level of human capacity, technology, investment and needs of nations in ocean and coastal science, observations and services? How can countries collaborate in ocean science operations in the context of their planned investments in this area?

The GOSR intends to identify and quantify these key elements. The report provides decision-makers with a tool to identify gaps and opportunities to advance international collaboration in ocean science and technology, so as to meet societal needs and to promote the contribution of ocean research to address global challenges related to sustainable development.

In doing so, the GOSR acts as a mechanism for assessing and reporting progress towards the attainment of SDG Target 14.a., for which, until present, no global mechanism has been available. Therefore, the first edition of the GOSR provides the crucial initial baseline.

It is in this context that IOC Member States are discussing the proposal of an International Decade of Ocean Science for Sustainable Development (2021–2030), preferably under the auspices of the UN. The intention is to create a global partnership in ocean science, seek solutions for sustaining benefits from the ocean, share knowledge and enhance interdisciplinary marine research, leading to economic benefits for all Member States, especially Small Island Developing States (SIDS) and Least Developed Countries. Making a step towards comprehensive quantitative knowledge of the world ocean is an absolute must for its sustainable management and achievement of the 2030 Agenda goals.

Vladimir Ryabinin
Executive Secretary of the IOC

Executive summary

Scope and purpose

The ocean is the largest ecosystem on our planet, regulating change and variability in the climate system and supporting the global economy, nutrition, health and well-being, water supply and energy. The coastal zone is home to the majority of the world population; dependency on the ecosystem services provided by the ocean is likely to increase with population growth. The ocean was once thought to be a vast and indefinitely resilient compartment of the Earth system, able to absorb practically all pressures of the human population, from resource exploitation to fisheries and aquaculture development to marine transport. However, according to the First World Ocean Assessment,1 our civilization is running out of time to avoid the detrimental cycle of decline in ocean health that will have dramatic repercussions on the ability of the ocean to keep providing the support we need. To achieve global sustainability and adequate stewardship of the ocean, as called for in the United Nations 2030 Agenda for Sustainable Development (2030 Agenda), ocean science is crucial to understand and monitor the ocean, predict its health status and support decision-making to achieve Sustainable Development Goal 14 (SDG 14) 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'.

Ocean science definition applied in the Global Ocean Science Report[2]

Ocean science, as considered in this report, includes all research disciplines related to the study of the ocean: physical, biological, chemical, geological, hydrographic, health *and social sciences, as well as engineering, the humanities and multidisciplinary research on the relationship between humans and the ocean. Ocean science seeks to understand complex, multiscale socio-ecological systems and services, which requires observations and multidisciplinary and collaborative research.*

The IOC-UNESCO Global Ocean Science Report (GOSR) aims to provide a status report on ocean science. It identifies and quantifies the elements that drive the productivity and performance of ocean science, including workforce, infrastructure, resources, networks and outputs. The report is intended to facilitate international ocean science cooperation and collaboration. It helps to identify gaps in science organization and capacity and develop options to optimize the use of scientific resources and advance ocean science and technology by sharing expertise and facilities, promoting capacity-building and transferring marine technology. As the first consolidated assessment of global ocean science, the GOSR assists the science-policy interface and supports managers, policy-makers, governments and donors, as well as scientists beyond the ocean community. The GOSR offers decision-makers an unprecedented tool to identify gaps and opportunities to advance international collaboration in ocean science and technology and harness its potential to meet societal needs, address global challenges and drive sustainable development for all.

There is no commonly accepted definition of ocean science; the *1982 United Nations Convention on the Law of the Sea* does not provide a definition of marine scientific research. For the purpose of this report, ocean science is considered to be a combination of disciplines classified into eight categories that cover integrative and interdisciplinary strategic research areas often recognized as high-level themes in national and international research strategies and policies (Figure ES1). This classification enables global comparisons and interdisciplinary analyses in line with the 2030 Agenda.

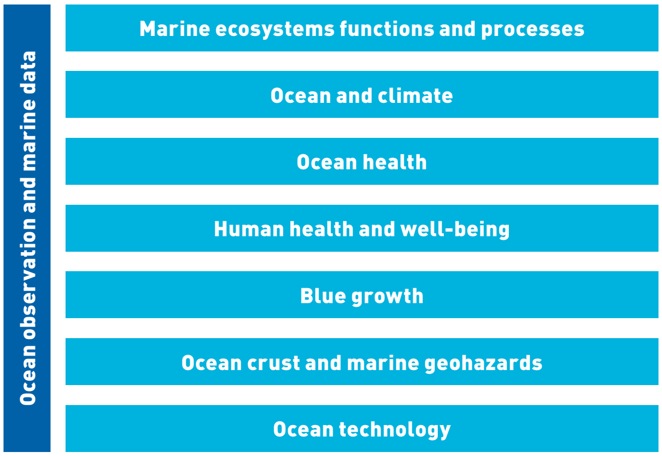


Figure ES1. Ocean science categories considered in the Global Ocean Science Report.

The report draws on a range of information sources. In addition to tailored questionnaires developed for the GOSR, ocean science output data (bibliometrics) by Science-Metrix and supplementary resources (e.g. web-based assessments and reports produced by intergovernmental organizations) were compiled to form the data set for the GOSR analysis

1 Group of Experts of the Regular Process, under the auspices of the United Nations General Assembly and its Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects. 2016. The First Global Integrated Marine Assessment: World Ocean Assessment I. UN.

2 This definition was presented by the Expert Panel on Canadian Ocean Science in the report Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity, Council of Canadian Academies, 2013.

Key findings

1. **Global ocean science is 'big science'**. Conducting ocean science requires numerous staff and large and costly equipment such as ships, ocean installations and laboratories located on the coast. These resources are distributed around the world comprising, for example, 784 marine stations, 325 research vessels and more than 3,800 Argo floats.
2. **Ocean science is multidisciplinary**. Most ocean science facilities work across a broad range of issues (39%), whereas others specialize in observations (35%) or fisheries (26%).
3. **There is more equal gender balance in ocean science than in science overall.** Female scientists represent on average 38% of the researchers in ocean science, about 10% higher than science overall.
4. **Ocean science expenditure is highly variable worldwide**. According to available data, ocean science accounts for between 0.1% and 21% of natural science expenditure and between < 0.04% and 4% of total research and development expenditure. From 2009 to 2013, ocean science expenditure varied among regions and countries; some increased their annual expenditure on ocean science, while others significantly reduced it.
5. **Ocean science benefits from alternative funding**. Private funding, including philanthropy in some cases, provides supplemental support for ocean science and enables the development of new ocean science technologies.
6. **Ocean science productivity is increasing**. Ocean science is expanding in magnitude and scope, resulting in greater scientific output. When comparing the time periods 2000–2004 and 2010–2014, China, Iran, India, Brazil, Republic of Korea, Turkey and Malaysia show the strongest relative growth in scientific output. China has become a major source of new publications, with the USA, Canada, Australia and European nations (UK, Germany, France, Spain and Italy) continuing as top producers of ocean science publications.
7. **International collaboration increases citation rates**. Generally, North American and European countries have a multiplying factor or impact factor (ratio of citations to publications) higher than countries from other parts of the world. The extent to which a country is engaged in international collaboration influences its citation rates. On average, publications that are co-authored by scientists from many countries are cited more often than publications for which all the authors are from the same country.
8. **Ocean data centres serve multiple user communities with a wide array of products**. At the global level, the main type of data archived by ocean data centres is physical data, followed by biological and then chemical data. Less than half of ocean data centres provide data on pollutants or fisheries. The top three ocean data/information products provided by ocean data centres are metadata, geographic information system (GIS) products and raw data access. Ocean data centres provide three main services: data archival, data visualization and data quality control.
9. **Science-policy interactions can occur through many avenues**. Current ocean science policy and science diplomacy focuses on prioritizing scientific research areas and steering the production and use of knowledge to address societal needs and prepare nations for future challenges at national, regional and global scales.
10. **National inventories on ocean science capacity exist only in a few countries.** The multidisciplinary nature of ocean science complicates efforts to establish reporting mechanisms to map ocean science capacities; the organization of national, academic, and federal capacities for marine research varies greatly.

What is true for the ocean, its resources and ecosystem services, is also true for ocean science capacities: you cannot manage what you do not measure.

To foster ocean-based sustainable development, a baseline is needed of where and how existing ocean science capacities are being used to empower society, sustain the environment and generate knowledge to support ocean management and develop useful products, services and employment. The GOSR offers a tool to help address this gap. It identifies and quantifies the key elements of ocean science at the national, regional and global scale, including workforce, infrastructure and publications.

Call for action

1. **Facilitate international ocean science cooperation**. Increasing international cooperation will enable all countries to engage in ocean research, develop communication and publication strategies, and ultimately increase global scientific output and impact.

2. **Support global, regional and national data centres for effective and efficient management and exchange of ocean data and promote open access**. The adoption and implementation of internationally-accepted standards and best practices for the management and exchange of data will result in more effective and efficient global, regional and national ocean data centres. Benefits from existing and future ocean research would be enhanced through the adoption and implementation of data policies that support open access.

3. **Explore and encourage alternative funding models.** Government funding for academic research is limited, and competition for grants can be expected to remain high in the future. International collaborations in the form of joint ocean science projects and expeditions, shared infrastructure and new technology development will reduce the costs of field expeditions and enable countries to strengthen their range of scientific expertise.

4. **Enable ocean science-policy interactions through diverse avenues.** The changes in the global ocean pose a multitude of challenges to understanding ocean functions and translating scientific knowledge to support global ocean stewardship. Given the plethora of organizations involved in ocean management, strong coordination mechanisms to enable science-policy interactions would help prepare society to respond to global ocean change.

5. **Align national reporting mechanisms on ocean science capacity, productivity and performance.** Reporting mechanisms to assess and track developments in the technical and human capacities in ocean science worldwide are indispensable to evaluate investments, monitor changes and inform policy- and decision-makers. Aligning reporting mechanisms would support the collation and interpretation of global ocean science metrics. This would enable developments in ocean science to be traced and opportunities and challenges in global ocean science to be identified.

Facts and figures

Who is doing ocean science?

Ocean science depends on skilled individuals and a broad array of infrastructure. Technological advances and international collaboration to transfer marine technology are key to leveraging investigation and observation of the global ocean. The 'human resources' that drive ocean science are concentrated in certain countries and vary worldwide by age and gender (Figure ES2).

Female scientists comprise on average 38% of the researchers in ocean science, about 10% higher than the global share of female researchers. However, gender balance differs significantly between different categories of ocean science and between countries (Figure ES3).

The number of researchers per capita varies substantially among countries around the world (> 300 to < 1 per million inhabitants).

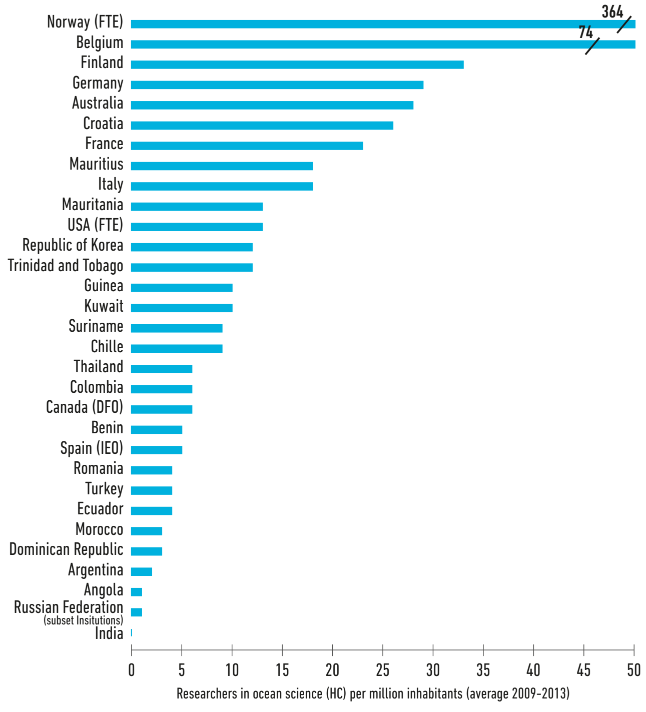


Figure ES2. Average number of national ocean science researchers (headcount, HC) employed per million inhabitants (2009–2013). In some cases, the reported information was not the national average: for Norway and the USA, data represent full time equivalent (FTE) ocean research positions; for Canada, HC information was provided only for Fisheries and Oceans Canada (DFO); and for Spain, HC represents only the Spanish Institute of Oceanography (IEO). *Sources*: GOSR questionnaire (ocean science), 2015; UIS (inhabitants), 2015.

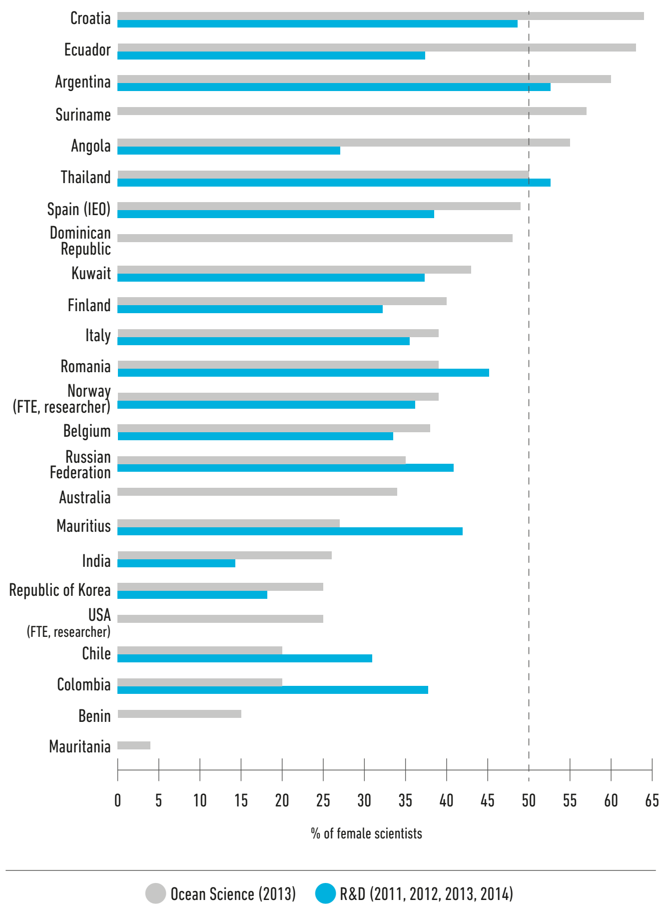


Figure ES3. The proportion (% total) of female researchers in ocean science (headcounts; grey bars) and in R&D (blue bars). *Sources*: GOSR questionnaire (ocean science), 2015; UIS (R&D), 2015.

What is used for ocean science?

Ocean science institutions and marine laboratories play a vital role in support of ocean research. They are critical for addressing several scientific issues, including studies of the structure and functioning of marine and coastal food webs, ecosystem biodiversity and human impacts on coastal environments. The global landscape of ocean science research institutions, marine labs and field stations depends on national research focus areas and research organizations.

Worldwide, many (39%) ocean science research institutions work across a broad range of issues, whereas others specialize in more limited themes such as observations (35%) or fisheries (26%). The USA has the highest number of research institutions varying in size (315) – roughly equal to the total number of research institutions in Europe combined and greatly exceeding the number of institutions operated in Asia and Africa.

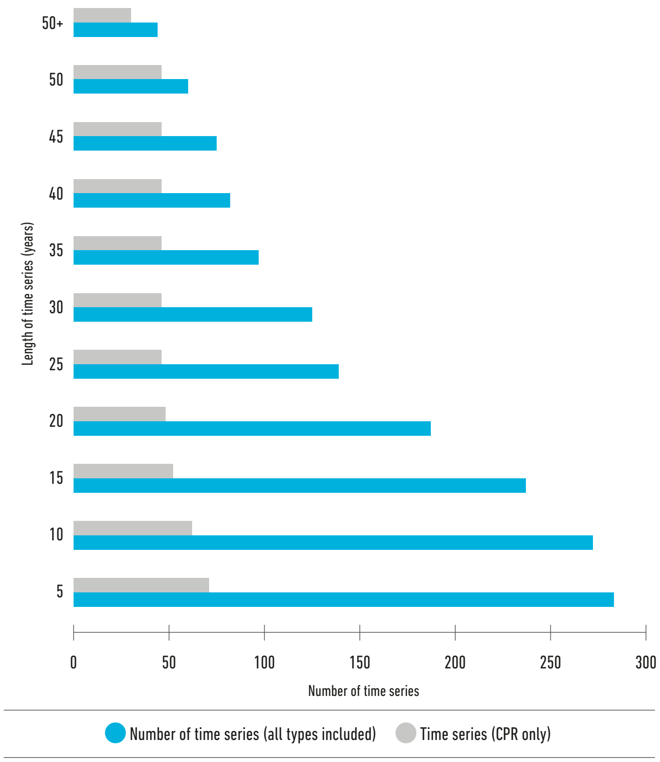


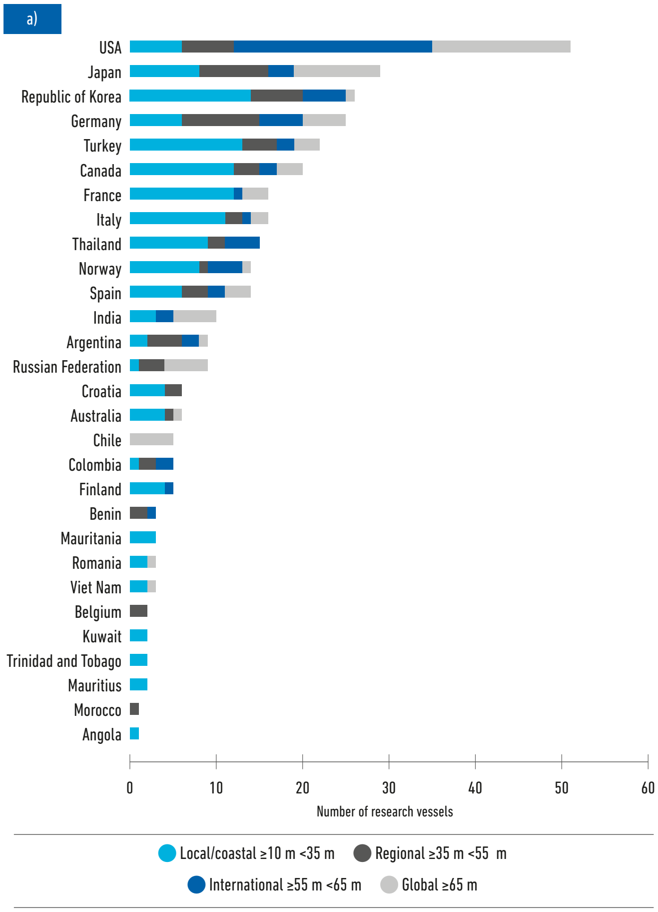
Figure ES4. Histogram of ship-based time series sorted by their span in years (2012 status). The Continuous Plankton Recorder (CPR) time series are plotted separately, highlighting the significant contribution to the longer time spans. *Source*: IGMETS, 2016.

Marine field stations and laboratories provide access to a range of environments, including coral reefs, estuaries, kelp forests, marshes, mangroves and urban coastlines. Globally, 784 marine stations are maintained by 98 countries; the majority are located in Asia (23%), followed by Europe (22%), North America (21%), Antarctica (11%), South America (10%), Africa (8%) and Oceania (5%).

Sustained, ship-based time series, some maintained for more than 50 years, enable investigation of remote locations, including along the continental shelf and in the open ocean (Figure ES4).

Ongoing investment in research vessels, together with the development and deployment of novel technologies such as sensors, probes and automated underwater vehicles, help to advance ocean science. Moorings and buoys gather vital information about the global ocean and benefit from international coordination and collaboration. For example, the Argo programme, established in 2000, is maintained by 20 countries.

Globally, at least 325 research vessels are currently in operation (Russian Federation, USA and Japan together maintain more than 60% of the total), ranging from 10 m to more than 65 m in length, with some built more than 60 years ago, while others have been in operation for less than 5 years. The average age of national fleets varies between < 25 years (Norway, Bahamas, Japan and Spain) and > 45 years (Canada, Australia and Mexico). More than 40% of research vessels focus primarily on coastal research, while 20% engage in global research (Figure ES5).



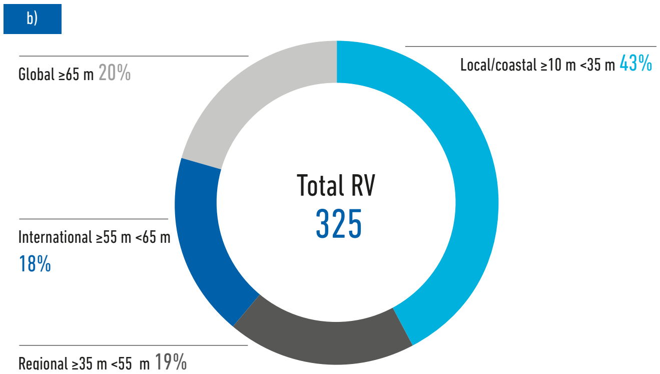


Figure ES5. a) Number of nationally maintained research vessels (RV), classified into four different ship size classes: local/coastal ≥ 10 m to < 35 m, regional ≥ 35 m to < 55 m, international ≥ 55 m to < 65 m, global ≥ 65 m. **b)** Relative proportion of the different ship sizes summarizing all research vessels, accounted for in a). *Source*: GOSR questionnaire, 2015.

How much do countries spend on ocean science?

The GOSR is the first international endeavour to capture governmental funding of ocean science. This assessment includes the contributions of 29 countries, which responded to the GOSR questionnaire by submitting information for the time period 2009–2013. Despite methodological and data collection constraints, some key trends in ocean science funding were identified. Based on the GOSR assessment, government funding for ocean science remains modest overall. Ocean science funding, like other scientific domains, is facing sustainability challenges in a number of countries.

To support sustainable development, continuous ocean research supported by long-term public and private funding will need to be secured. The GOSR provides baseline information on ocean science funding, which can be used as a starting point for more directed, tailored investment, new capacity-development strategies and enhanced marine technology transfer and knowledge exchange.

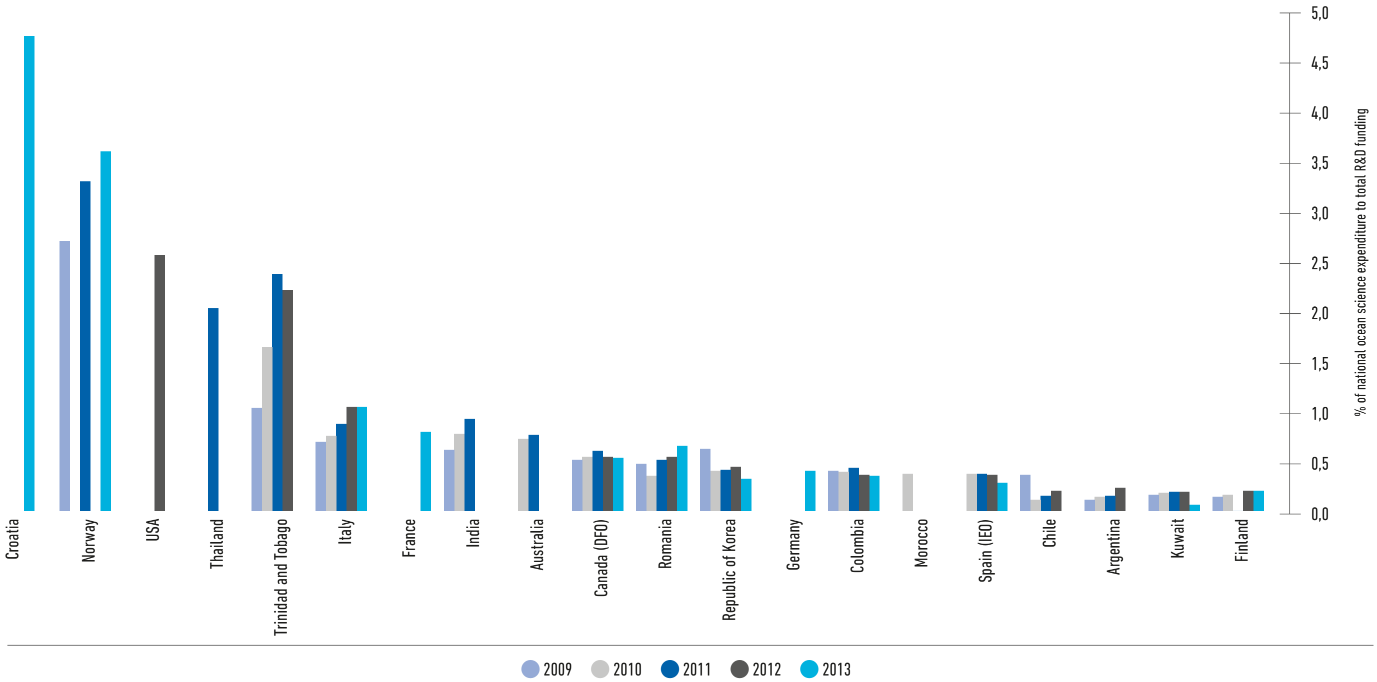


Figure ES6. National expenditure in ocean science as a percentage of national research and development (R&D) expenditure for 25 countries that answered the GOSR questionnaire and provided information regarding national governmental funding for ocean science. *Sources*: GOSR questionnaire (ocean science funding), 2015; UIS (R&D funding), 2015.

Ocean science funding varies between < 0.04% and 4% of national research and development funding. Countries with large dedicated ocean science budgets include USA, Australia, Germany, France and Republic of Korea (Figure ES6).

How is ocean science performing globally?

The GOSR examines the evolving global picture of ocean science performance, by individual countries and international collaborations, to illuminate how ocean science knowledge is published and shared. Bibliometrics is used as a tool to assess the quantity and quality of ocean science research output, as indicated by total number of publications and citations. Ocean science performance is analysed according to four categories: production (amount of research performed), quality (impact of publications), topicality (research areas pursued) and collaboration (amount produced through international partnerships and institutional connections).

The production of global ocean science is increasing. Between 2010 and 2014, more than 370,000 manuscripts in ocean sciences were published and more than 2 million articles were cited. There is some relationship between quantity and quality in ocean science performance; however, countries with the largest numbers of publications are not necessarily the most highly cited (Figure ES7).

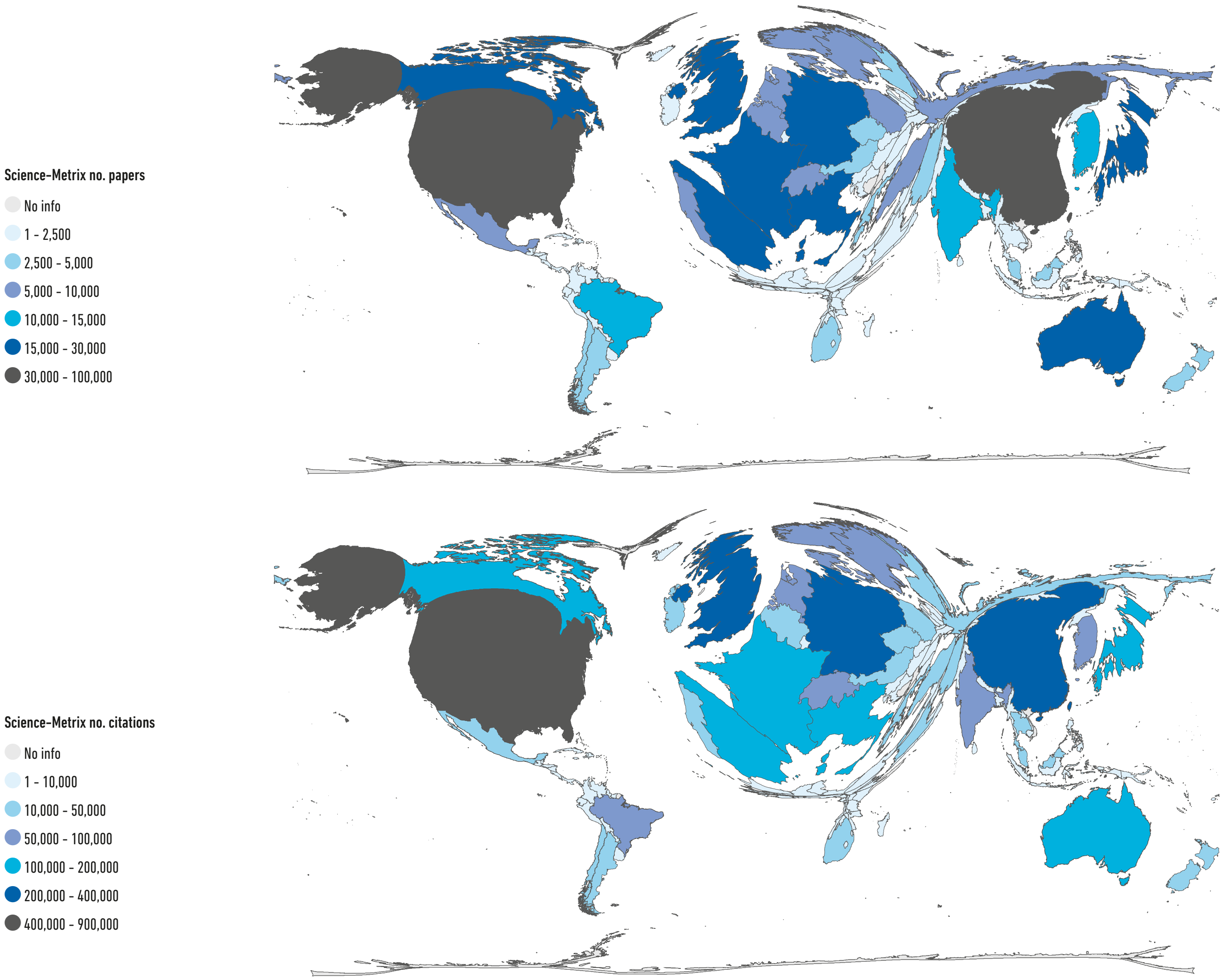


Figure ES7. Publication and citation map of the world. The area of each country is scaled and resized according to the number of ocean science publications (top) or citations received (bottom). Different colours indicate a different number of publications (top) or citations (bottom) (Annex F).

Ocean science output is increasing, as measured by number and citation of scientific publications in time periods 2000–2004 and 2010–2014. The strongest relative growth in ocean science output was seen in China, Iran, India, Brazil, Republic of Korea, Turkey and Malaysia. China has become a major source of new publications, with the USA, Canada, Australia and European nations (UK, Germany, France, Spain and Italy) remaining the top producers of ocean science publications.

Specialization in ocean science varies around the world. Some regions specialize in certain categories of ocean science more than others, such as 'marine ecosystem function and processes' in North and South America, 'human health and well-being' in Africa (Figure ES8), 'ocean technology and engineering' in Asia, 'ocean and climate' in Europe, and 'blue growth' in Oceania. National positional analysis in ocean science by categories shows that some countries lead in certain categories, such as Japan and the Russian Federation in 'ocean crust and geohazards'.

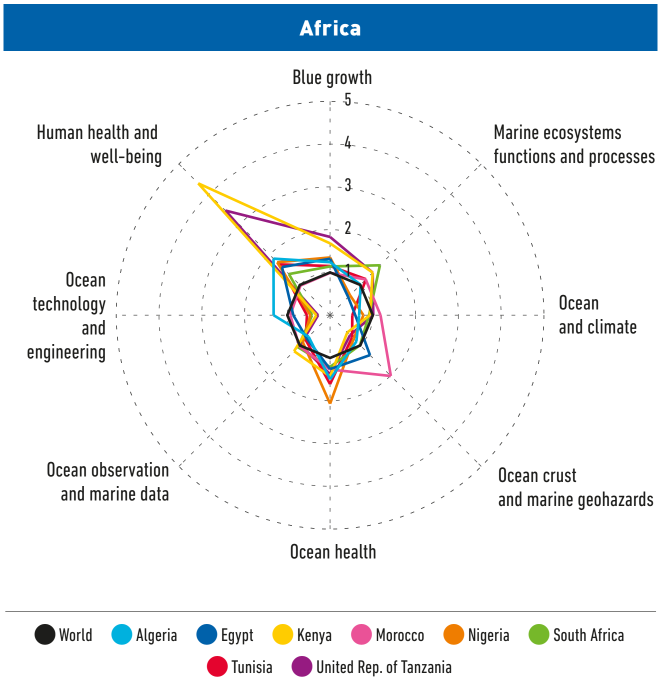


Figure ES8. National strengths (specialization index) in ocean science categories (for African nations accounting for at least 300 publications in the time period 2010–2014) compared to the world average (Annex F).

R&D expenditure influences ocean science performance. Countries with high GDP (and high GDP per capita) and R&D expenditure also show high ocean science performance in terms of publications and citations.

Ocean science collaboration networks are changing the global architecture of ocean science and are often formed on a regional basis. International ocean science collaboration is important as it increases citation rates and has a positive effect on science impact (Figure ES9).

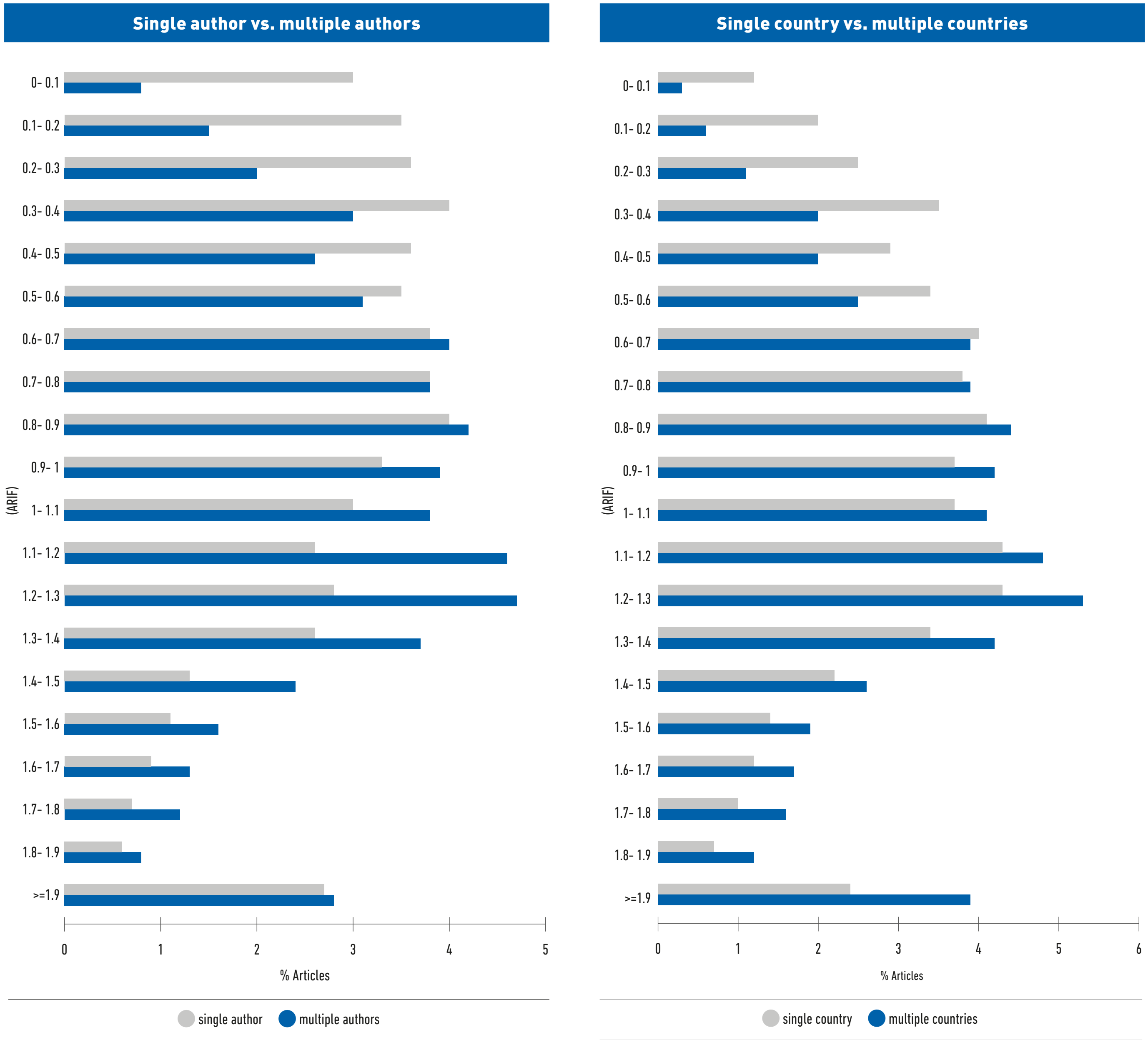


Figure ES9. Comparison of average relative impact factors (ARIF) in articles produced by: single author (grey bars) versus multiple authors (dark blue bars), and authors all from the same country (domestic, grey bars) versus multiple counties (international, dark blue bars; Annex F).

How do we store and manage ocean science data?

Modern ocean science and the application of new technology and observation tools produces new kinds of data at an accelerated rate and in an unprecedented amount. These recent developments are creating a demand for novel means of data management and storage to serve the needs of different audiences. Regionally and globally, there is a diverse array of organizations, partnerships and programmes working with data and information compilation, sharing and management. The GOSR analysis does not reveal any significant differences between regions in terms of user audiences, except for the Asia/Pacific where national researchers are the top clients.

The majority of ocean data products provided by data centres are metadata, raw data and GIS products (Figure ES10).

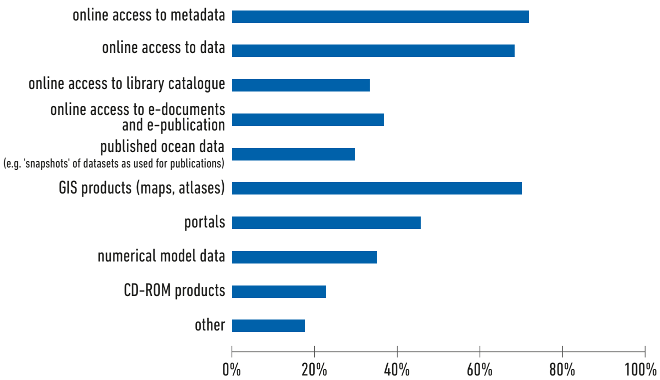


Figure ES10. The data and information products provided to clients by data centres, (% respondents). *Source*: IODE survey, 2016.

The core users of data, products or services provided by data centres are national and international researchers, as well as the general public, policy-makers and the private sector (Figure ES11).

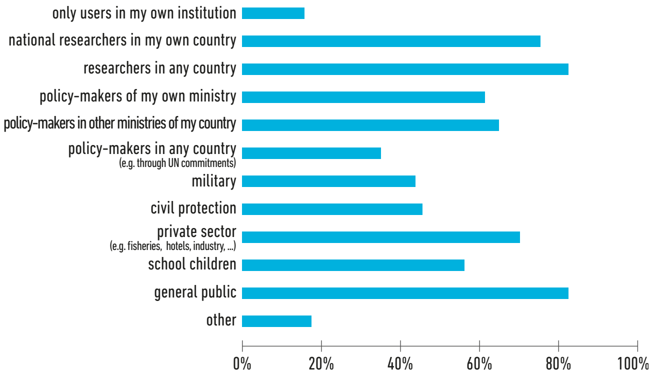


Figure ES11. Clients and end users of data, products or services provided by data centres (% respondents). *Source*: IODE survey, 2016.

Globally, 63% of data centres restrict access to 'certain' data types and 40% apply a restriction during a certain period of time (Figure ES12).

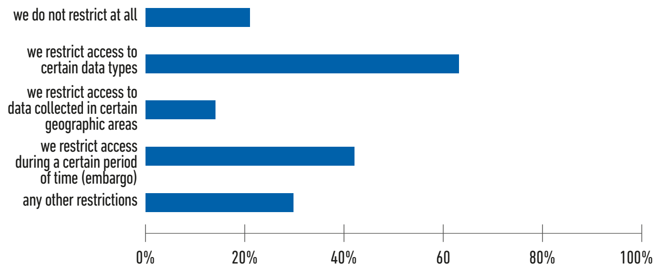


Figure ES12. The percentage of data centres which do not restrict or do restrict access to certain data types, to data collected in certain geographic areas, during a certain period of time, or apply any other restrictions (% respondents). *Source*: IODE survey, 2016.

Impact of ocean science: science in policy

The GOSR provides examples of how the needs of policy-makers can influence the design of tailored scientific research programmes and how science can influence the development and implementation of marine policy. These examples of the value of ocean science for addressing environmental challenges could be an inspiration for future efforts. Examples considered by the GOSR include:

- reduced eutrophication of marine waters, e.g. under the European Community Nitrates and Urban Waste Water Directives;
- national, regional and global management systems for harmful algal blooms;
- regulation of ocean fertilization, e.g. under the *1972 Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (London Convention) and its related 1996 Protocol (London Protocol);
- regulation of fisheries, e.g. via the total allowable catches agreed by countries fishing in the North Sea; and
- transboundary protection and conservation strategies, e.g. the *Benguela Current Convention.*

Ocean science-policy interaction can play a role in the protection and preservation of the marine environment and the conservation and sustainable use of marine resources.

International ocean science cooperation is essential to increase scientific knowledge, develop research capacity and transfer marine technology (i.e. SDG target 14a). Ocean science is also critical to inform a range of international legal and policy developments concerning, for example, climate change and the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction. The GOSR offers an overview of global ocean science capacity and thus provides a tool to achieve sustainable development and improve ocean health for all.

Ocean science will continue to play a key role in implementing the 2030 Agenda and achieving the conservation and sustainable use of the ocean and marine resources as set out in SDG 14.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NO SMOKING

1

Introduction

1. Introduction

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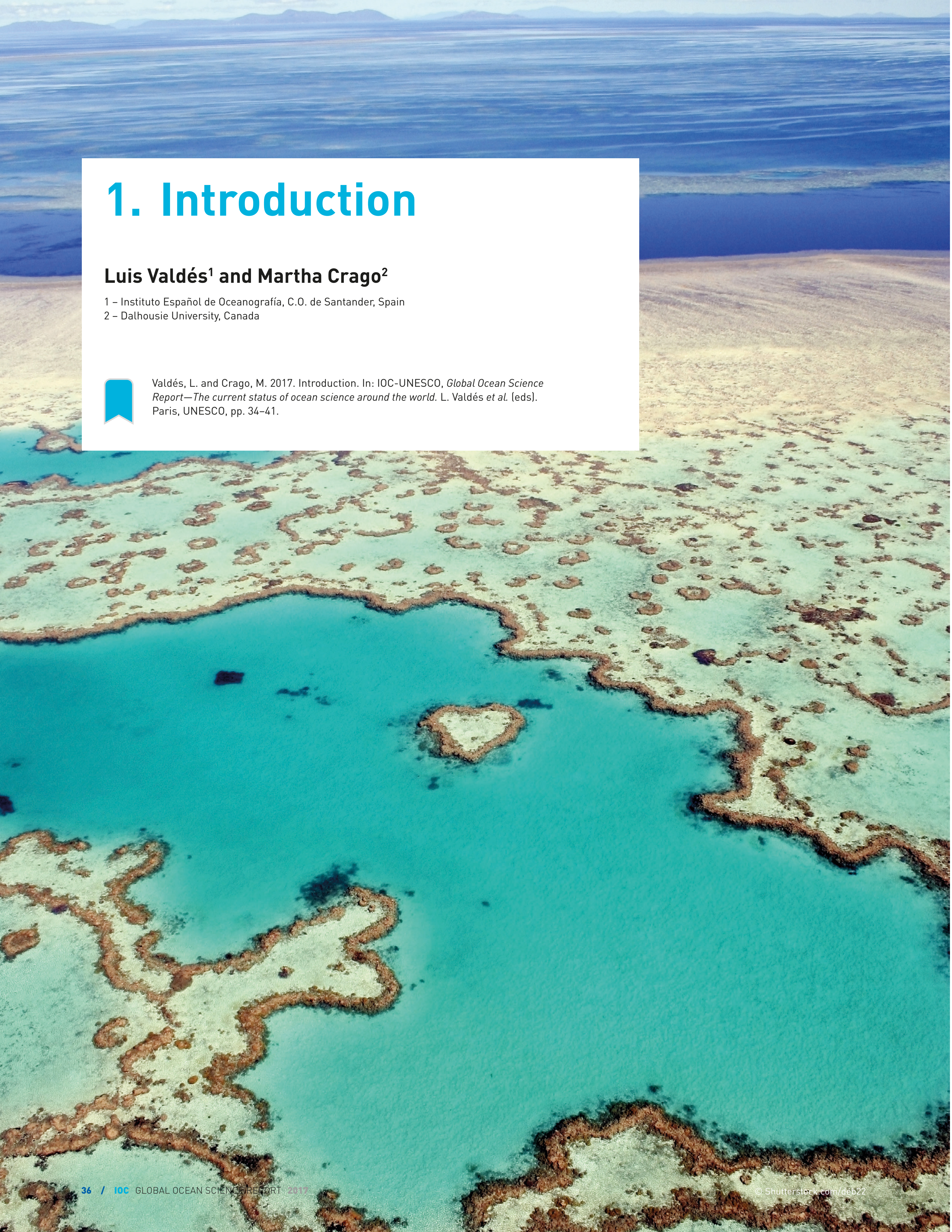
Valdés, L. and Crago, M. 2017. Introduction. In: IOC-UNESCO, *Global Ocean Science Report—The current status of ocean science around the world.* L. Valdés *et al.* (eds). Paris, UNESCO, pp. 34–41.



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1.1. Motivation for a Global Ocean Science Report

Ocean science has evolved rapidly in recent years in parallel with growing international interest in ocean functionality, climate change,[1] environmental protection and the conservation of ocean resources. More than ever, the drivers for ocean scientific research are connected to the sustainable use of the oceans. As such, the main ocean science challenges of our time are interdisciplinary, involving natural and social sciences to investigate issues such as ocean acidification, micro-plastics, hypoxia, blue carbon, blue growth and governance. To guide new developments, a baseline of the existing capacity of ocean science to empower society, sustain the environment and generate knowledge for the development of useful products, services and employment is needed.

To influence and inform action, the interface between science and policy must be strengthened to increase engagement between science, society and decision-makers. The ability to make science understandable to those who make decisions about the future is critical. Several international instruments and science-policy interfaces have been formally established by the United Nations (UN), such as the UN World Ocean Assessment, the Intergovernmental Platform on Biodiversity and Ecosystem Services and the Intergovernmental Panel on Climate Change, which ensure that updated and accurate science is appropriately reflected in high-level policy discussions (e.g. conferences of the parties of UN treaties, such as the Convention on Biological Diversity and the UN Framework Convention on Climate Change). Other science-policy assessments, such as the UNESCO *Science Report* and the *World Social Science Report* (UNESCO, 2015; ISSC, IDS and UNESCO, 2016) and reports published by the Organisation for Economic Co-operation and Development (OECD, 2014) and the European Commission (European Commission, 2009), highlight patterns of scientific productivity and demonstrate the value of scientific collaboration. These assessments provide a basis for understanding and promoting knowledge-sharing and dissemination, identifying the opportunities and benefits of international collaboration and harnessing international scientific collaboration to address global challenges.

Ocean science is 'Big Science', involving sophisticated and costly equipment, such as satellites, research vessels, remote operated vehicles and robotics. Advancing scientific research to improve knowledge and understanding of the changing global ocean requires concerted international cooperation. Talent is a key part of this equation. Programming, sampling, analysing and performing any scientific task requires the full dedication of thousands of skilled scientists working in marine laboratories and in remote regions from the Arctic to the Antarctic and from the coast to the high seas, every single day all year round. These researchers collaborate with each other, motivated by the desire to work with the very best people in the very best facilities, seeking new knowledge to advance their field or to tackle specific challenges.

UNESCO advocates that science is a global enterprise; its Intergovernmental Oceanographic Commission highlights this vision for ocean science. According to the UK Royal Society (2011): *'there are over 7 million researchers around the world, drawing on a combined international R&D spend of over US$1,000 billion and reading and publishing in around 25,000 separate scientific journals per year'*. Although reports on the status of global science (in general) have been published by UNESCO (2010, 2015), the OECD (2014) and the Royal Society (2011), this has never been attempted for ocean science on a global scale.[2]

The IOC considers that a global compilation of information concerning the status of global ocean science is necessary. Science is a main pillar for sustainable development and science is also an instrument for peace (UNESCO, 2015). The science dimension of diplomacy has fundamental significance at a time when science has tremendous power to shape the future of humanity and when it is no longer appropriate to design science policy in purely national terms, especially when addressing issues affecting the entire planet such as climate change and the sustainable management of the 'global ocean commons'.[3]

The Global Ocean Science Report (GOSR) aims to identify and quantify the key elements of ocean science, including workforce, infrastructure and publications. It serves as a resource to foster international ocean science cooperation and collaboration and facilitate sharing of expertise and facilities. The GOSR supports ocean governance and promotes common scientific interests in reducing the risks from ocean hazards, developing scientific capacity and increasing benefits from conservation and sustainable use of ocean resources. By consolidating ocean science issues into one single assessment, the GOSR

1 Climate change is an international priority based on scientific consensus and States have signed binding agreements to reduce emissions of greenhouse gases and undertake actions to mitigate the effects of climate change (e.g. UNFCCC Conference of the Parties to the United Nations Framework Convention on Climate Change, Paris, 2015).

2 National ocean science reports have been published for Canada (CCORU, 2013) and Belgium (Herman *et al.*, 2013).

3 Global commons is a term typically used to describe international, supranational and global resource domains in which common-pool resources are found (Ostrom, 1990). Global commons include the earth's shared natural resources, such as the oceans, the atmosphere and the Antarctic.

aims to contribute to strengthening the science-policy interface for managers, policy-makers, governments and donors, as well as broader political and scientific audiences beyond the ocean community.

1.2. The Global Ocean Science Report as a collaborative action towards science for sustainable development

Sustainable development calls for concerted efforts towards building an inclusive, sustainable and resilient future for people and planet by harmonizing three core elements: economic growth, social inclusion and environmental protection. Science is a fourth core element, essential to understanding and achieving sustainability.

Sustainability science has emerged in the twenty-first century as a new academic discipline.[4] According to the Proceedings of the National Academy of Sciences of the USA[5], sustainability science *'deals with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems.'*

The ocean, once thought to be a vast, resilient area able to absorb practically unlimited waste and withstand increasing human population, fishing and shipping pressures, is now known to be increasingly vulnerable to human activities. Ocean and coastal areas are major contributors to the global economy and fundamental to global well-being through direct economic activities, provision of ecosystem services, and as home to the majority of the world's population (Box 1.1). In addition, the ocean drives change and variability in the climate system, influencing rainfall and desertification, even far from coasts. Global sustainability and stewardship need to be underpinned by good understanding and monitoring of the global ocean.

4 This new field of science was officially introduced with a 'Birth Statement' at the World Congress 'Challenges of a Changing Earth 2001' in Amsterdam, organized by the International Council for Science (ICSU), the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP). The IOC is the parental body for WCRP and also provided support to core projects within the now concluded IGBP, some of which now continue as part of Future Earth.

5 http://sustainability.pnas.org/page/about (Accessed 17 November 2016).

Enhancing conservation and implementing good practices in the management and use of ocean-based resources through international law will help mitigate some of the challenges facing our ocean. The conservation and sustainable use of the ocean is reflected in SDG 14, one of the 17 Sustainable Development Goals that make up the 2030 Agenda for Sustainable Development (UN, 2015). SDG 14 establishes a framework to sustainably manage and protect marine and coastal ecosystems and a foundation for better integration of international science and environmental governance.

Box 1.1. 2030 Agenda for Sustainable Development, Facts and Figures for Sustainable Development Goal 14 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development' (UN, 2015).

SDG14 Oceans and Seas: Facts and Figures

- Oceans cover three-quarters of the Earth's surface, contain 97 % of the Earth's water and represent 99% of the living space on the planet by volume
- Over 3 billion people depend on marine and coastal biodiversity for their livelihoods
- Globally, the market value of marine and coastal resources and industries is estimated at US$3 trillion per year, or about 5% of global GDP
- Oceans contain nearly 200,000 identified species, but actual numbers may lie in the millions
- Oceans absorb about 30% of carbon dioxide produced by humans, buffering the impacts of global warming
- Oceans serve as the world's largest source of protein, with more than 3 billion people depending on the oceans as their primary source of protein
- Marine fisheries directly or indirectly employ over 200 million people
- Subsidies for fishing are contributing to the rapid depletion of many fish species and are preventing efforts to save and restore global fisheries and related jobs, causing ocean fisheries to generate US$50 billion less per year than they could
- As much as 40% of the world oceans are heavily affected by human activities, including pollution, depleted fisheries and loss of coastal habitats

While the SDGs are not legally binding, governments are expected to take ownership and establish national frameworks to achieve the goals and have the primary responsibility to follow up and review progress through national, regional and global level analyses. This will require quality, accessible and timely data collection and strengthened cooperation among UN agencies and Member States.

The GOSR aims to serve as a tool to achieve SDG 14 by providing a status report on global ocean science. The GOSR seeks to enable States to optimize the use of scientific resources, promote capacity-building, transfer technology and facilitate international cooperation in marine research and management with due regard to the needs of developing countries. To this end, the GOSR is framed around the contribution of ocean science to sustainable development concepts. These are grouped into seven categories plus one overarching theme,[6] as follows:

- Marine ecosystem's functions and processes
- Ocean and climate
- Ocean health
- Human health and wellbeing
- Blue growth
- Ocean crust and marine geohazards
- Ocean technology and engineering
- *Overarching theme*: Ocean observation and marine data

1.3. Mandate, objectives and outline

As part of its voluntary commitment to the Rio+20 United Nations Conference on Sustainable Development and the SDG 14 targets, the Intergovernmental Oceanographic Commission of UNESCO plays a leading role in facilitating the development and implementation of a global strategy to build national and regional capacity in ocean affairs in order to advance sustainable ocean management at all levels. IOC Member States recognize that the science-policy interface requires baselines and assessments of nations' needs and investments in ocean science on a regular basis. However, there has been no global mechanism for assessing and reporting the level of capacity, investments, performance and needs of nations in ocean science, observation and services. In this regard, the GOSR aspires to be the tool to monitor ocean science achievements in the light of target 14a[7] within SDG 14. The feasibility of, and demand for, similar global mechanisms has been shown by ongoing national and international initiatives. The GOSR was prepared under the auspices of IOC to fulfil this vision and mandate for ocean science.

6 These categories were defined by an expert group and validated by the IOC Executive Council in 2014 (Decision EC-XLVII/Dec.6.2).

7 SDG 14, target 14a.: *Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission* Criteria and Guidelines on the Transfer of Marine Technology, *in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries.*

The ambitious goal of the GOSR is to present an overview of ocean science capacity that exists worldwide, including existing physical infrastructure and facilities, human resources, financial investments, scientific productivity and scientific collaboration at national and international levels. The GOSR aims to:

I. Deliver an overview of where and by whom ocean science is conducted, as well as its quality and impact on national and international governance;

II. Improve our knowledge of the human and institutional capacity of IOC Member States in terms of marine research, observations and data/information management;

III. Deliver a global overview of performance on key fields of research regarding sustainable development and blue growth.

By highlighting patterns in the production of ocean science and the organization of scientific collaboration, the GOSR provides a basis to understand and promote knowledge sharing and dissemination, illustrate the benefits of international collaboration and identify opportunities for international collaboration to address ocean challenges more effectively.

The use of scientific methods in the evaluation and presentation of results was a guiding principle during the preparation of the report. The GOSR findings and assessments were made based on relevant data and objective information. A holistic and balanced approach to scientific input and stakeholder participation was fostered to avoid bias in the analysis of data.

The report is streamlined and progressively structured in eight chapters:

- **Chapter 1** introduces the motivation and objectives of the GOSR
- **Chapter 2** discusses the data collection and methodology
- **Chapter 3** presents data on global ocean science equipment and human resources
- **Chapter 4** examines investment in ocean science
- **Chapter 5** analyses research productivity, science impact and other quantitative indices of performance and international collaboration
- **Chapter 6** discusses oceanographic information management and exchange
- **Chapter 7** discusses the role of international supporting organizations in ocean science

- **Chapter 8** provides examples of the contribution of ocean science to policy development

The ultimate goal of the GOSR is to support the achievement of policy goals by providing an overview of the status of global ocean science resources, investments and productivity. The vast scale of the global ocean and the complexity of scientific and policy challenges to achieve sustainable development demands international collaboration. Ocean scientists have a long tradition of working with colleagues across national borders to advance understanding and management of the global ocean commons. The report offers decision-makers an unprecedented tool to identify gaps and opportunities to advance international collaboration in ocean science and technology and harness its potential to meet societal needs, address global challenges and drive sustainable development for all.

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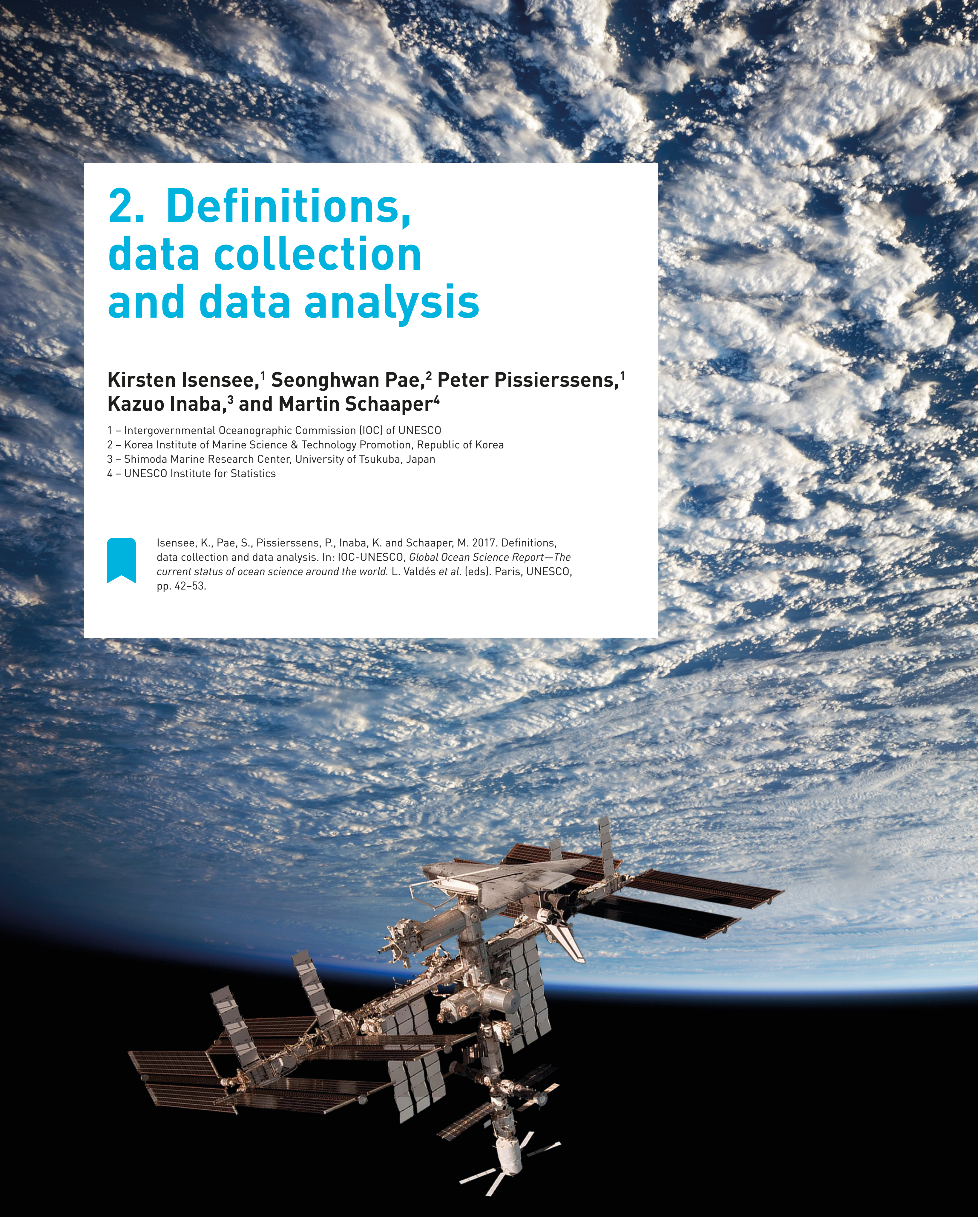
2

Definitions, data collection and data analysis



2. Definitions, data collection and data analysis

Kirsten Isensee,[1] Seonghwan Pae,[2] Peter Pissierssens,[1] Kazuo Inaba,[3] and Martin Schaaper[4]

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3 – Shimoda Marine Research Center, University of Tsukuba, Japan
4 – UNESCO Institute for Statistics

Isensee, K., Pae, S., Pissierssens, P., Inaba, K. and Schaaper, M. 2017. Definitions, data collection and data analysis. In: IOC-UNESCO, *Global Ocean Science Report—The current status of ocean science around the world.* L. Valdés *et al.* (eds). Paris, UNESCO, pp. 42–53.

2.1. Preparation process

A suite of complementary approaches and methods was used to underpin the information presented and discussed in the Global Ocean Science Report (GOSR). The chosen methodologies allow information to be captured about different aspects of ocean science, including research funding, human and technical capacities and outputs (e.g. publications), as well as supporting organizations and facilities.

A variety of open source and quality-controlled resources, together with targeted surveys, were used to collect the data and information that provide the foundation for this report. The GOSR combines quantitative data such as the number of peer-reviewed publications, research vessels and the extent of national funding with qualitative data, e.g. the existence of ocean science national strategies. Throughout the report ocean science data are compared to information on natural sciences and/or research and development (R&D) in general. This kind of analysis allows to put ocean science in a broader perspective. Cross-references between independent quantitative indicators as provided in Chapters 3, 4, 5 and 6, based on the methodology described in this chapter, and findings from Chapters 7 and 8, help the reader to navigate through the report.

Data compilation tools include: 1) tailored questionnaires; 2) peer-reviewed literature, national reports, web-based sources; and 3) bibliometrics based on international literature databases (Section 2.3.2). Access to some types of quantitative measurements is limited or unavailable. Currently, national reporting mechanisms to obtain the type of information requested in the GOSR questionnaire (Annex D) are often not in place. By adopting a standardized approach as developed in the first edition of this report, an important step is made towards systematic reporting on global ocean science.

The Editorial Board served as an external and independent international panel of ocean science experts with experience in science diplomacy, statistics, and assessments and evaluation. The Editorial Board gave advice on the structure and content, drafted chapters and reviewed parts of the report. The main tasks of the Editorial Board were to:

I. Provide continued guidance for the successful publication of the first edition of the GOSR.

II. Encourage Member States to provide relevant data and information.

III. Identify appropriate methods of accessing relevant information.

IV. Contribute as co-authors to the drafting process of the different chapters.

V. Actively promote the report to potential users and stakeholders.

VI. Establish liaisons with international organizations, conventions and panels with interest in the report and which will benefit from the published results.

2.2. Definitions and classification of ocean science in categories

A definition of ocean science, with further classification into categories, enables global comparisons and an interdisciplinary analysis of ocean science production and performance, in line with the 2030 Agenda for Sustainable Development, especially Sustainable Development Goal 14: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'. In the context of the IOC governing body mechanism, in 2014, an ad hoc IOC group of experts (Methodological Expert Group, 2013) and the Editorial Board of the GOSR agreed to focus certain parts of the analysis on eight major categories recognized as high-level themes in national and international ocean research strategies and policies (Figure 2.1). These categories cover integrative, interdisciplinary and strategic ocean research areas.

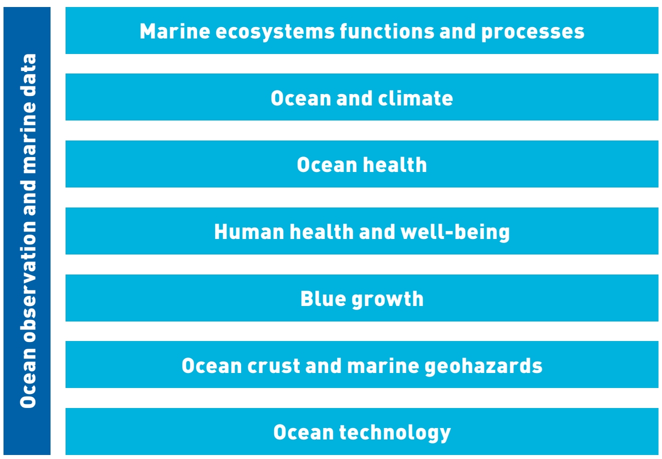

Figure 2.1. Ocean science categories considered in the GOSR.

The Expert Panel on the Canadian Ocean Science Report (Council of Canadian Academies, 2013) offers the following definition: '*Ocean Science, ... , includes all research disciplines related to the study of the ocean: physical, biological, chemical, geological, hydrographic, health, and social sciences, as well as engineering, the humanities,*[1] *and multidisciplinary research on the relationship between humans and the ocean...Ocean science seeks to understand complex, multi-scale social-ecological systems and services, which requires observations and multidisciplinary and collaborative research*.' The Editorial Board recognizes this definition as a useful description of ocean science, supporting the methodology applied for the analysis presented in the report.

2.2.1. Classification of ocean science categories

Marine ecosystems functions and processes: This category refers to marine ecosystem's structure, diversity and integrity and includes abiotic and biotic characteristics. Marine ecosystem functions include biogeochemical, chemical, physical and biological processes. They are characterized by nutrient cycles, energy flow, exchanges of material, as well as trophic dynamics and structure. All these processes are marked by a variability in – and diversity of – natural dynamics, including seasonal, temporal and spatial differences and perturbations. The report comprises the following topics under *Marine ecosystems functions and processes:* biodiversity; physical setting; primary production; consumption; sedimentation; respiration; aerobic and anaerobic processes across the different trophic levels; biological pump, etc.

Ocean and climate: This category refers to research on the interaction between the ocean and the atmosphere to provide better predictions of reciprocal changes in the ocean and climate system. The *ocean and climate* category comprises the following topics: palaeoceanography; ocean warming; ocean acidification; deoxygenation; sea-level rise; changes in ocean circulation and air-sea interaction, etc. but does not include studies on extreme weather events.

Ocean health: This category refers to research covering the condition of the marine environment from the perspective of adverse and cumulative effects caused by anthropogenic activities, in particular, changes in biodiversity, genetic diversity, phenotypic plasticity, habitat loss and alteration in ecosystem structure and processes. *Ocean health* comprises studies on marine pollution, alien and invasive species, disruption of ecosystems, marine protected areas, and marine spatial planning, etc.

Human health and well-being: This category includes research on the relationship between the ocean and human health and well-being. *Human health and well-being* covers physical and social studies on provision of marine ecosystem services, in particular food security as well as recreation, harmful algae blooms, and human-related social, educational and aesthetic values, etc.

Blue growth: This category refers to the research on – and in support of – sustainable use of marine resources, including the research on economically important species with regard to food security (fisheries and aquaculture). *Blue growth* further covers studies on the utilization of new energy resources in the ocean and marine bio-resources, as well as clean technologies, pharmaceuticals, cosmetics and desalination, etc.

Ocean crust and marine geohazards: This category refers to geological/geophysical marine research, including hydrothermal vents, seismology, ocean drilling, movements and associated marine hazards (tsunamis, gas/fluid escape above huge sub-seafloor, rapid sea-level rise, flooding, hurricanes and extreme coastal weather events), etc.

Ocean technology: Research related to marine innovation and the design and development of equipment and systems for marine science and industries. This category covers studies on marine engineering, such as the development of marine energy solutions, satellites and remote-sensing techniques, Remotely Operated Vehicles (ROV), gliders, floats, sensors, new measurement devices and techniques, etc. in addition to marine geoengineering (e.g. solar radiation management and carbon dioxide removal techniques).

Ocean observation and marine data: This category is relevant for all categories of ocean science. It includes the collection, management, dissemination and use of marine data and information to create knowledge on the seas and ocean. This cross-cutting category underpins all marine and maritime activities, in particular marine scientific research. However, it also covers studies on – and development of – marine data platforms, marine databases, data reporting and management activities.

The eight ocean science categories were used to obtain bibliometric data to enable an analysis of ocean science performance (Chapter 5). According to the definition of the category, a set of keywords was selected.

1 The Editorial Board did not include members with specific expertise in humanities or social sciences.

2.2.2. Classification of ocean science research fields

In order to facilitate the data acquisition on the research facilities, equipment and human resources, three categories of ocean research fields were defined in the GOSR questionnaire for subsequent analysis (Section 2.2.1.).

Fisheries: Research related to marine fisheries, mariculture (open ocean) and aquaculture (coastal and indoor).

Observations: Ocean science related to coastal and open ocean monitoring, data repositories, measurements to track harmful algal blooms and pollution, satellite measurements, buoys and moorings.

Marine research/other ocean science: Areas of ocean science, which do not fit in the other two categories, such as experimental investigations and process studies.

2.3. Data resources and analysis

2.3.1. Global Ocean Science Report questionnaire and IODE survey

A major tool in the data-gathering process for the report was a questionnaire asking for national information on ocean science conducted by IOC Member States. The survey was developed and reviewed in consultation with representatives of Member States in a working group. This survey collected core data and information to assess indicators and evidence to assess national capacity, progress and challenges for ocean science. National coordinating bodies for liaison with IOC ensured coordination with the community of marine scientists and institutions in their respective countries and submitted data from January until November 2015.

In total, the questionnaire compiled information on 41 items, which were grouped under 8 themes in a quantitative section from A to G and a non-quantitative section H (Annex D). Some cross-cutting questions address several chapters of the report:

a. ocean science landscape,
b. research investments,
c. research capacity and infrastructures,
d. oceanographic data and information exchange,
e. capacity-building and transfer of technology,
f. regionally and globally supporting organizations on ocean science,
g. sustainable development, and
h. non-quantitative information.

The quantitative section (A-G) addressed information related to human and technical capacity available in each country. The non-quantitative section (H) addressed national ocean science strategies and challenges encountered in order to conduct ocean science, as well as national recommendations and ocean science needs.

The IOC Secretariat received 34 national replies to the questionnaire (23% of IOC membership). The following Member States submitted national information: Angola, Argentina, Australia, Belgium, Benin, Canada, Chile, China, Colombia, Croatia, Dominican Republic, Ecuador, Finland, France, Germany, Guinea, India, Italy, Japan, Kuwait, Mauritania, Mauritius, Morocco, Norway, Republic of Korea, Romania, Russian Federation, Spain, Suriname, Thailand, Trinidad and Tobago, Turkey, United States of America and Vietnam (Figure 2.2). These countries produced about 75% of ocean science publications during the time period 2010–2014. On average, the countries answered 77.4% of the questions. More detail on the proportion of answers received for each theme is provided in Figure 2.3.

Most of the data requested in the questionnaire cover the period 2009–2013. The information provided was partly verified with the national focal points, to address individual inconsistencies, and analysed subsequently.

Analysing additional sources, e.g. participant lists of international conferences, national plans and national reports served to minimize such uncertainties.

Some of the data presented in Chapter 6 (Oceanographic data, information management and exchange) is based on the data obtained from an additional online survey carried out between 24 June and 19 September 2016 by the IOC International Oceanographic Data and Information Exchange (IODE) Programme among national coordinators for data management, national coordinators for marine information management and Associate Data Unit contact points. Out of 114 contacts, a total of 78 (69%) data centres responded.

The analysis of responses to the questionnaire was conducted within certain limitations. In particular, the qualitative questions are at risk of being influenced by subjective perceptions.

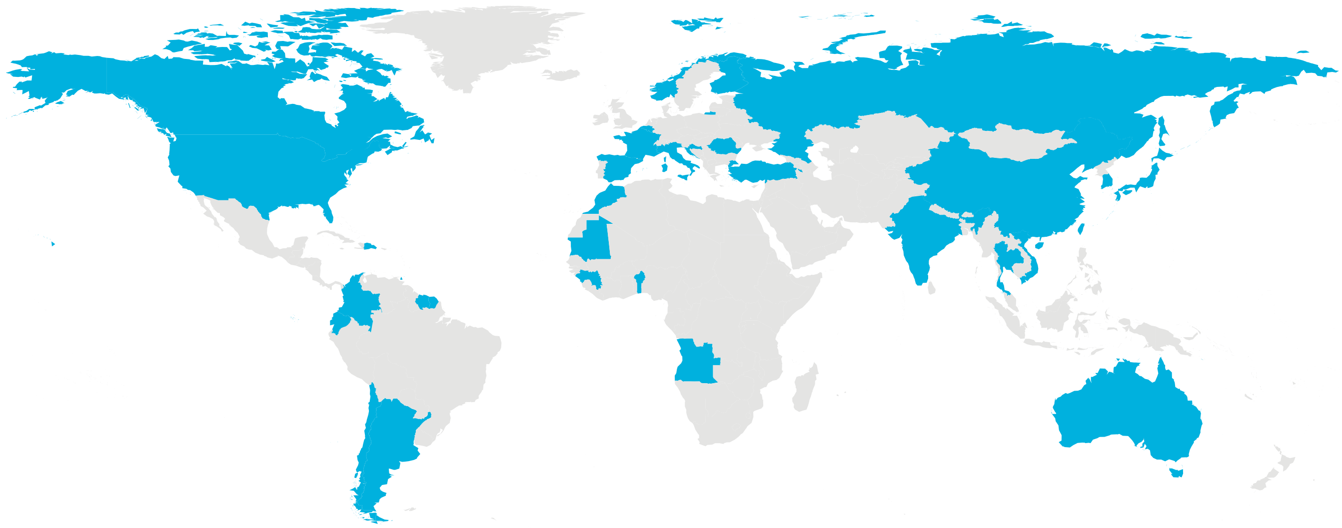

Figure 2.2. Global map indicating the Member States that responded to the questionnaire (blue).

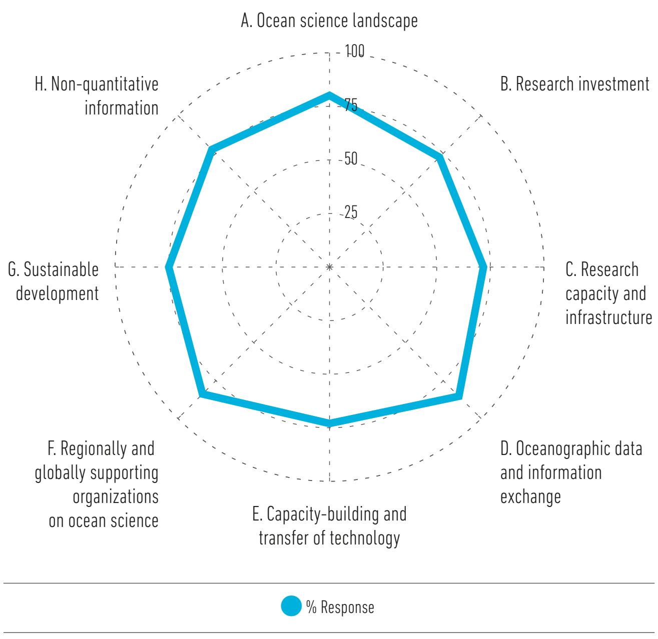

Figure 2.3. Questionnaire analysis – response rate by theme, calculated based on the total number of responses received to the questionnaire in general (n=34)

2.3.2. Bibliometric data

Bibliometrics refers to the study of patterns in a collection of scientific publications in a literature database – namely peer-reviewed articles in academic journals (Pritchard, 1969). Bibliometric analysis uses a standardized method to compare the publication output of entities such as countries and research institutions. As a measure of output, bibliometric indicators are a proxy measurement of overall research productivity. This study, presented in Chapter 5, does not intend to conduct a qualitative evaluation of ocean science between countries, but presents the information required for an overview of ocean science productivity across its scientific categories at the global level. They allow the comparison of ocean science output of single countries to each other. The analysis is also used to describe patterns of collaboration and output of organizations.

The bibliometric datasets were provided by Science-Metrix.[2] The report covers worldwide scientific literature output in ocean science from 2010 to 2014. The main source of data was the Web of Science (WoS) by Thomson Reuters,[3] which features peer-reviewed (work evaluated by one or more people of similar

2 http://www.science-metrix.com/

3 https://www.thomsonreuters.com/

competence to the producers of the work) publications from more than 8,500 scientific journals across 150 disciplines. However, to be as inclusive as possible, the analysis was supplemented by articles in other science journals. In total 16,314 journals, captured by queries using more than 1,900 search terms, were included in the analysis, comprising more than 370,000 articles.

Papers with co-authors from multiple organizations and/or countries were used to identify collaboration networks and to generate figures reflecting patterns of co-authorship among organizations. The Editorial Board acknowledges that collaboration may take many forms other than co-authorship, including the organization of conferences and meetings, joint experiments, sharing data, and other activities not captured by bibliometric data.

The quality of the datasets was validated with precision and recall tests. When deemed necessary, the keywords were revisited, modified and complemented, and new iterations on precision and recall tests were conducted.

2.3.2.1 Bibliometric indicators

Number of papers: This is an analysis of the number of publications obtained using full counting. In the full-counting method, each paper is counted once for each entity (e.g. country, organization, researcher) listed in the address field. For example, if a paper is authored by two researchers from the US National Oceanic and Atmospheric Administration, one from the Chinese Academy for Science and one from the Xiamen University, the paper is counted – at the institutional level – once for NOAA, once for the Chinese Academy for Science, once for the Xiamen University, once for the United States and once for China at the country level.

Average of relative citations (ARC): This is an indicator of the scientific impact of papers produced by a given entity (e.g. a country or an institution) relative to the world average (i.e. the expected number of citations). All the citations received by each publication are counted for the year in which it was published and for all the following years up to the most recent publications indexed in the database. For example, for papers published in 2010, citations received in 2010, 2011, 2012, 2013 and 2014 are counted in this analysis. To account for different citation patterns across categories of science (e.g. there are more citations in biomedical research than in mathematics) and for differences in the age of publications (e.g. changes in citation patterns over the years), each citation count of a publication is divided by the average citation count of all publications of the corresponding document type (i.e. a review would be compared to other reviews, whereas an article would be compared to other articles) that were published in the same year in the same subfield to obtain a relative citation count (RC). When the ARC is above one, it means that an entity scores better than the world average; when it is below one, it means that an entity publishes papers that are not cited as often as the world average. Science-Metrix considers that an entity must have at least 30 publications with a valid RC score in order for the ARC to be calculated, as this can otherwise lead to unreliable results.

Average of relative impact factors (ARIF): The ARIF is a measure of the expected scientific impact of publications produced by a given entity (e.g. a country or an institution), based on the impact factors (IF) of the journals in which they were published. In this study, Science-Metrix computes and uses a symmetric IF based on the document types that are used throughout the report for producing bibliometric data. The IF of publications is calculated by ascribing to them the IF of the journal in which they are published, for the year in which they are published. Subsequently, to account for different citation patterns across fields and subfields of science (e.g. there are more citations in biomedical research than in mathematics), each IF of a publication is divided by the average IF of all papers of the corresponding document type (i.e. a review would be compared to other reviews, whereas an article would be compared to other articles) that were published in the same year in the same subfield to obtain a relative impact factor (RIF). In this study, the IF of a journal is computed over five years. For example, in 2007, the IF of a journal would be equal to the number of citations to articles published in 2006 (8), 2005 (15), 2004 (9), 2003 (5) and 2002 (13) divided by the number of articles published in 2006 (15), 2005 (23), 2004 (12), 2003 (10) and 2002 (16) (i.e. IF = numerator [50] / denominator [76] = 0.658). The ARIF of a given entity is the average of its RIFs (i.e. if an institution has 20 publications, the ARIF is the average of 20 RIFs, one per publication). When the ARIF is above one, it means that an entity scores better than the world average; when it is below one, it means that an entity publishes in journals that are not cited as often as the world average. Science-Metrix considers that an entity must have at least 30 publications with a valid RIF score in order for the ARIF to be calculated, as this can otherwise lead to unreliable results.

Specialization index (SI): The SI is an indicator of research intensity in a given entity (e.g. an institution) for a given research area (e.g. a field or category), relative to the intensity in a reference entity (e.g. the world, or the entire output as measured by the database) for the same research area. In other words, when an institution is specialized in a field, it places more emphasis on that field at the expense of other research areas. In this study, two references have been used: the world in all science and the world in ocean science only. Using the latter reference will give specialization centred around ocean science.

The SI is formulated as follows:

$$SI = \frac{(XS/XT)}{(NS/NT)}$$

Where:
XS = Publications from entity X in a given research area (e.g. papers by Germany in ocean health)
XT = Publications from entity X in a reference set of papers (e.g. total papers by Germany)
NS = Publications from reference entity N in a given research area (e.g. world papers in ocean health)
NT = Publications from reference entity N in a reference set of papers (e.g. total world papers OR world papers in ocean science)

In case the data sets provided could not fulfil the previously mentioned criteria, this is indicated, by either N/C (not calculated), or N/A (not applicable).

2.3.2.2 Potential and limitations of bibliometric datasets

Bibliometric analyses build on a globally distributed extensive dataset, covering the majority of published peer-reviewed articles. The publication of scientific articles in peer-reviewed journals is the cornerstone of research dissemination in ocean science. Therefore, the different bibliometric indices can be used as proxies for research activity. Secondly, bibliometric analyses are able to provide information about research productivity (i.e. the quantity of journal articles produced), specialization, collaboration activities and research impact (measured through citations). When used appropriately, citation-based indicators can be valid measurements to discuss the impacts of scientific output.

The limitations of bibliometric analyses fall into three main categories. Firstly, all bibliometric indicators are based on one type of research output, namely peer-reviewed articles published in journals. Other forms of research output, which may or may not be peer-reviewed, such as patents, conference presentations, national reports and technical series, are not taken into account. Secondly, the results of bibliometric analyses are influenced by the choice of the classification system (ocean science divided into eight major categories) applied by the report and by the database used (in this case: WoS – Thomson Reuters). As mentioned, additional journals were identified and included in the analysis to account for the multidisciplinary nature of ocean science and address this limitation. In addition, articles that are not written in English, or at least have an English abstract, are not included in the database and are therefore not part of this study. Thirdly, bibliometric indicators are also sensitive to the time periods under consideration. Older papers are naturally more cited than recent publications. These effects are minimized by standardized citation metrics relative to average citations for papers of the same type, the same year, with the same specialty. In addition, new investments in ocean science are not directly echoed in the scientific output, as fieldwork, analysis and publication require a few years before being properly reflected in the bibliometric analysis.

2.3.3. Additional resources

In addition to the questionnaire and the data provided by Science-Metrix, supplementary resources were used to improve the data sets available for the analysis within the report. Further information was obtained from published resources, e.g. web-based assessments, national and international reports, produced by intergovernmental organizations and international acknowledged partners of IOC-UNESCO. The relevant references are acknowledged in each chapter.

Resources assessing and reviewing the national human capacities in ocean science are scarce. This and the limited information provided through the questionnaire resulted in a need to obtain additional data documenting, for instance, gender equality among researchers in ocean science in a different way (Chapter 3). For this purpose, lists of participants attending *international ocean science conferences/symposia* from 2009 to 2015 were used. The criteria for international conferences to be included in this assessment are: 1. Minimum of 50 participants from at least 10 different countries attended; 2. Experts of the hosting country never exceeded 50% of the total number of participants; 3. Open registration process. The full list of conferences selected for each ocean science category indicates the number of participants, countries represented and the overall gender ratio of experts subscribed for the meeting (Annex E).

To obtain the number and geographical distribution of *marine stations* worldwide (Chapter 3) information was gathered using a variety of resources, in particular the World Association of Marine Stations (WAMS), local organizations of marine stations (MARS, NAML, JAMBIO, TMN), the IOC Sub-Commission for Africa and the Adjacent Island States, websites referring to marine stations locally and globally, a web-search based on the search engine (www.google.com, 2016) with the following keywords: marine station/ biological/ oceanographic/ fisheries, in addition to direct requests to the research community in Australia, Brazil, China, Iran, Philippines, Republic of Korea, Russian Federation, Singapore and Thailand. *Marine stations* as used in the context of the report are defined as field stations where scientific research and observation of marine organisms, ecosystems and environments are carried out. Marine stations vary in size, infrastructure and of course the marine environment that they are placed in or close to. They are further categorized as field stations, large or small, located near the coastline with at least one permanent member of staff. Besides their importance for ocean science, marine stations can also contribute to education, conservation and outreach activities related to the coast and its ecosystems. A variety of organizations can manage marine stations, including national and local government, public or private universities, private companies or foundations.

2.3.4. Parameters for normalization

In order to normalize data, improve comparability and allow benchmarking between different countries, some parameters were introduced to put absolute numbers of certain parameters (e.g. financial resources allocated for ocean science, technical and human resources) into perspective.

Gross Domestic Product[4] (GDP): Sum of gross value added by all resident producers in the economy, including distributive trades and transport, plus any product taxes and minus any subsidies not included in the value of the products. It is the primary indicator used to gauge the health and size of a national economy. Within the analysis presented, the average annual GDP (in US$) of a country during the time period 2009–2013 was considered.

4 Definition by the UNESCO Institute for Statistics (UIS) - glossary

Gross domestic expenditure on research and experimental development (GERD): GERD as a percentage of GDP is the total intramural expenditure on R&D performed in a national territory or region during a given year, expressed as a percentage of GDP of the national territory or region (defined by the *Frascati Manual* (OECD, 2015), adapted by the UNESCO Institute for Statistics). UIS collects data on resources devoted to research and experimental development (R&D) through its R&D statistics survey. In addition, it obtains data directly from the Organisation for Economic Co-operation and Development (OECD), Eurostat, the Ibero-American and Inter-American Network on Science and Technology Indicators (RICYT) and the African Science, Technology and Innovation Indicators (ASTII) Initiative of the African Union/NEPAD Planning and Coordinating Agency for countries that participate in the data collections of these organizations. Data obtained from the OECD are based on the OECD's Research and Development Statistics database (April 2015). Data obtained from Eurostat are based on the Eurostat Science and Technology database, as of April 2015. Data received from RICYT are as of April 2015. Data obtained from ASTII are based on the African Innovation Outlook I (AU–NEPAD, 2010) and the African Innovation Outlook II (NEPAD, 2014).[5]

2.4. Visualization

Data visualization helps to communicate often complex information in a clear and effective way via statistical graphics, plots and information graphics. It enables the audience to see visual representations of analyses, facilitates the understanding of data sets and possibly enables the identification of new patterns.

Positional analysis*:* Positional analysis graphs visualize the composite performance of institutions (Figure 2.4 below and Chapter 5). They assist in the interpretation of the strengths and weaknesses of an institution through the use of several separate indicators. These graphical representations logically combine three of the previously mentioned indicators (number of papers, SI and ARC). The SI and ARC are log-transformed in order to produce a better visual. The position of an entity in one of four quadrants can therefore be interpreted as follows:

- **Quadrant 1**: Located at the top right of the graph. Entities in this quadrant specialize in the given domain and their activities have a high impact, meaning that their papers are more frequently cited than the world average in this domain.

5 http://data.uis.unesco.org

2

- **Quadrant 2:** Located at the top left of the graph, this quadrant is synonymous with high-impact scientific production, but the entities are not specialized in the domain.
- **Quadrant 3:** Located at the bottom left of the graph, institutions positioned in this quadrant showed an intensity of activity and its impact below the world average in the domain.
- **Quadrant 4:** Located at the bottom right of the graph, this quadrant signals specialization in the domain, whereas output impact is below the world average.

Collaboration network: This illustrates the collaborations between authors from different entities (country, institution, etc.). Collaborations are computed in full counting. For example, for a paper authored by two researchers from University A, one author from University B and one author from University C, only one collaboration will be counted for the pair A-B and one collaboration for the pair University of A-C, as well as B-C. The width of the ties between entities is proportional to the number of collaborations between the two entities and the size (area) of the bubbles representing each entity is proportional to the number of articles published by the entity. The spatial arrangement of the network is a function of the number of collaborators and the collaboration intensity (the more entities collaborate together, the more they will be clustered). In this study, the top 40 most publishing countries in each category are used for country networks and the top 40 most publishing institutions in each pillar were selected for institution networks.

Diffusion cartogram: Diffusion cartograms are used to illustrate the scientific output with regard to the geographical extent of the countries (Chapter 5, Figure 5.2). The applied diffusion-based method allows the creation of different density-equalizing maps. The method starts with an inhomogeneous distribution of the research contribution (citations, number of publications) and the following diffusion process evolves until a homogeneous equilibrium state is reached. The displacements are then reinterpreted to generate the cartogram (Gastner and Newman, 2004).

Choropleth map: A choropleth map is a thematic map in which areas are shaded or patterned in proportion to the measurement of the statistical variable being displayed on the map. The choropleth map provides an easy way to visualize how a measurement varies across a geographic area or it shows the level of variability within a region.

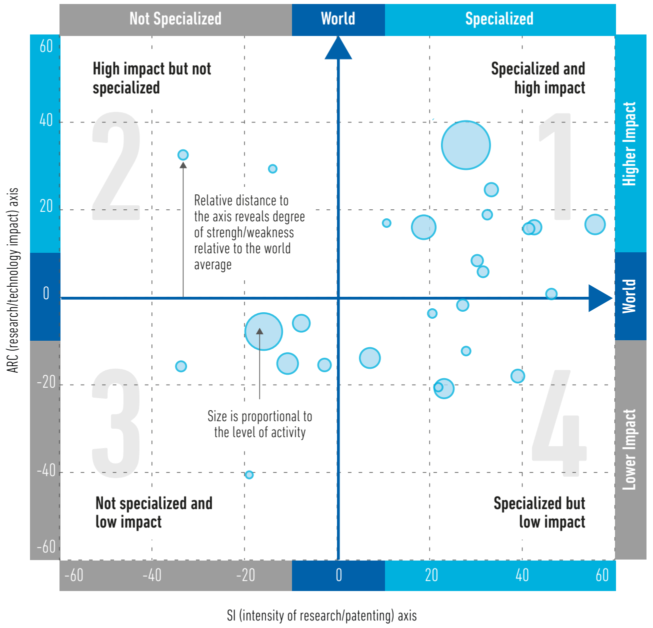

Figure 2.4. Example for figure illustrating the positional analysis, for the Specialization Index (SI) and the Average of Relative Citations (ARC) as presented in Chapter 5.

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3

Research capacity and infrastructure

3. Research capacity and infrastructure

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3.1. Introduction

The output of ocean science, as defined in Chapter 2, is determined by the people conducting it, the technical infrastructure available in their institutions/laboratories, the financial support they receive, and the scientific priorities set by the respective countries or donors. This can be specific to ocean science but is often in a broader context of high-level general policy settings in a region and internationally. The institutional architecture of the ocean science and technology system and the factors of production are the foundation for successful and competitive marine research. This chapter examines global ocean science capacity, including human resources for ocean science, national ocean science research institutions, related field stations, research vessels and some specialized technical infrastructure.

3.2. Human resources

Human resources in ocean science are recruited based on a broad range of criteria, including motivation, knowledge, experience, skills and a curiosity to improve knowledge of the ocean and related processes. Though all these criteria are important in understanding the current state of human resources in ocean science, limited information prevents a comprehensive analysis on training, education level, experience and skills. This section examines the number of employees, gender equality and age distribution in ocean science.

3

Table 3.1. Total ocean science personnel, total ocean science researchers, % of researchers to total ocean science personnel in 2013.[1] *Source*: GOSR questionnaire, 2015.

Country	Total ocean science personnel (HC, 2013)	Total ocean science researchers (HC, 2013)	% of researchers to total ocean science personnel (HC, 2013)
China	38 754	N/A	
USA (FTE, researchers, selected institutions)	N/A	4 000	
Germany	3 328	2 385	72
France	3 000	1 500	50
Republic of Korea	2 415	606	25
Italy	2 170	1 141	53
Norway (FTE, researchers)	N/A	1 786	
Thailand	1 610	412	26
Australia	1 581	798	50
Colombia	1 267	540	43
Belgium	1 075	830	77
India	971	452	47
Spain (IEO)	630	222	35
Turkey	539	404	75
Chile	464	159	34
Canada (DFO, researchers)	378	305	81
Argentina	335	212	63
Russian Federation (subset of institutions)	307	211	69
Finland	281	180	64
Mauritania	240	70	29
Romania	222	104	47
Croatia	150	110	73
Mauritius	140	34	24
Guinea	136	120	88
Morocco	125	120	96
Trinidad and Tobago	95	20	21
Dominican Republic	94	29	31
Kuwait	90	35	39
Benin	89	67	75
Suriname	75	5	7
Ecuador (FTE)	71	66	93
Angola	55	31	56

1 Table 3.1 'Country' acronyms: DFO-Fisheries and Ocean Canada; IEO-Spanish Institute of Oceanography; Russia subset of institutions – N.N. Zubov State Oceanographic Institute, Hydrometeorological Scientific and Research Center of the Russian Federation, Arctic and Antarctic Scientific and Research Institute, Far-Eastern Regional Scientific and Research Hydrometeorological Institute, All-Russian Scientific and Research Institute of Hydrometeorological Information – World Data Center.

Table 3.1 shows the total number of ocean science personnel (including researchers and technical support staff), the total number of ocean science researchers, and the proportion of ocean science researchers compared to the total ocean science personnel employed in 28 countries in 2013. The total number of ocean science personnel ranges from 55 in Angola up to 38,754 in China (Table 3.1). Based on available data, the average ratio of scientists to technical support staff is 1:1 (on average, 46 % of ocean science personnel are researchers). However, it has to be highlighted that some of the records herein only represent rough estimates (e.g. USA, France) and a subset of the national ocean research institutions (USA, Spain, the Russian Federation, Canada). Also, some data are given as numbers of researchers with no breakdown for technical support staff. In some cases, information submitted only reflects the Full Time Equivalent (FTE) and not the actual number of staff (headcounts, HC). This illustrates the difficulty in comparing ocean science human resources across countries.

Based on the data provided via the GOSR questionnaire (Table 3.1), the average numbers of ocean science researchers per million inhabitants (2009–2013) were calculated for the respondent countries (Figure 3.1). There are variations among the countries; Norway has a strikingly high number with 364 researchers per million inhabitants, followed by Belgium with 74, while other countries show much lower numbers of researchers per million inhabitants, ranging from 33 to less than 1. Differences in population density, length of coastline and economic importance of marine resources can be assumed to influence the results. Data on human resources are particularly scarce for Small Island Developing States (SIDS), this is likely due to human resource and financial constraints required for generating the information.

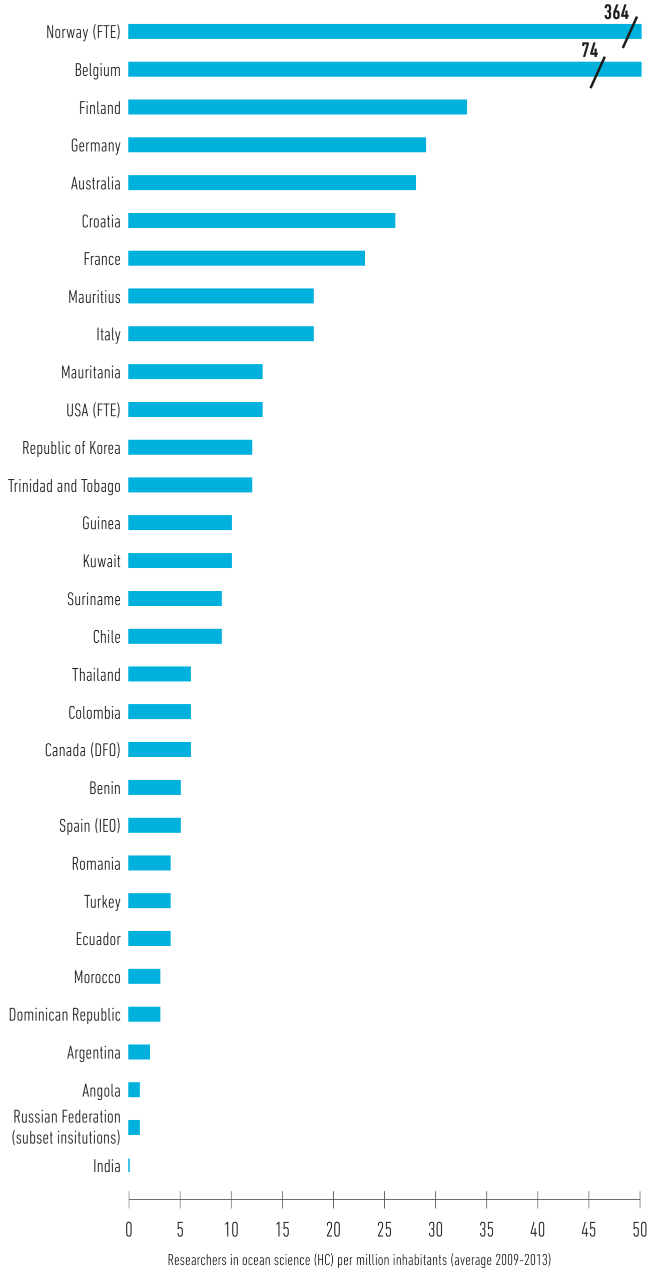


Figure 3.1. Average national ocean science researchers (Headcount - HC) employed per million inhabitants (2009–2013).[2] (Based on a subset of the data presented in Table 3.1, researchers employed in ocean science. *Sources:* GOSR questionnaire (ocean science), 2015; UIS (inhabitants), 2015.

2 The presented information deviates between HC or FTE as follows: Norway and the USA data represent FTE ocean research positions, Canada provided HC for Fisheries and Ocean Canada (DFO); Spain provided HC for the Spanish Institute of Oceanography (IEO); the Russian Federation for selected oceanographic institutions (N.N. Zubov State Oceanographic Institute, Hydrometeorological Scientific and Research Center of the Russian Federation, Arctic and Antarctic Scientific and Research Institute, Far-Eastern Regional Scientific and Research Hydrometeorological Institute, All-Russian Scientific and Research Institute of Hydrometeorological Information–World Data Center).

3.2.1. Distribution of age among ocean science researchers

A subset of countries also provided information regarding the age of the employed ocean science researchers (Figure 3.2). On the one hand, previous capacity-building efforts in developing countries presumably resulted in a comparably young researcher community in less developed countries, including Benin, Mauritius, Suriname and Trinidad and Tobago. These countries together with Belgium, Colombia, Ecuador and Morocco reported that more than 50% of the ocean science researchers are aged below 40. On the other hand, eight countries submitted data showing that more than 50% of the researchers are aged over 50: Argentina, Chile,[3] Finland, Guinea, Kuwait, Romania, the Russian Federation and Spain.[4]

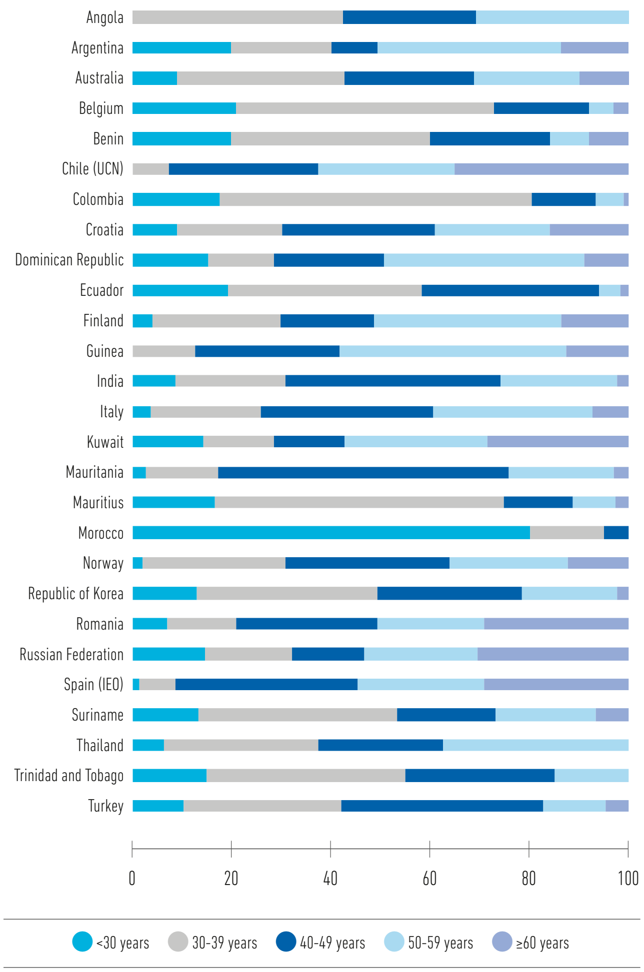


Figure 3.2. Proportion (%) of age cohorts (< 30 years, 30-39 years, 40-49 years, 50-59 years, ≥ 60 years) of ocean science researchers. *Source*: GOSR questionnaire, 2015.

3.2.2. Gender equality in ocean science

Twentieth-century science was dominated by men (UNESCO, 2015). Though women have contributed to science since early times, this has not always been fairly acknowledged. Studies of science have described the lack of equality among women and men concerning scientific and technological production, as well as the existence of obstacles that are specific to women when accessing relevant positions in academia, industry and administration (UNESCO, 2015). Such barriers result in gender-based biases that reflect the social nature of science and technology and inform the strategies that can be used to overcome this inequality.

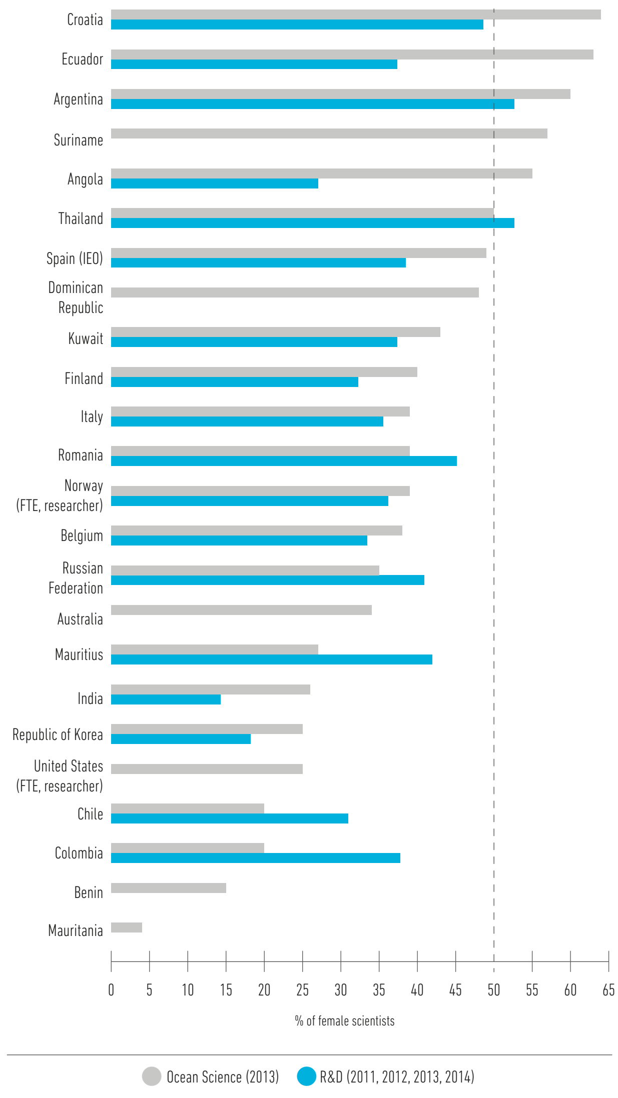


Figure 3.3. The proportion (% total) of female researchers in ocean science (headcounts; grey bars) and in R&D (blue bars). Dashed line indicates 50% of female contributions. *Sources*: GOSR questionnaire (ocean science), 2015; UIS (R&D), 2015.

3 Data represent information for the Catholic University of the North, Chile.

4 Data represent information for the Spanish Institute of Oceanography.

Some insights on the proportion of female ocean science researchers are gained by analysing the data submitted via the GOSR questionnaire (2013) with published data for female researchers employed in R&D overall (Figure 3.3). In 2013, on average, 38% of the researchers in ocean science were women, about 10% higher than the global share of female researchers (UNESCO, 2015). Yet, female participation within ocean science ranges from 4% to more than 62%, while values for R&D vary only between 18 and 53% for the subset of countries analysed in this report. Croatia, Ecuador, Argentina, Suriname and Angola reported that more than half of the ocean science researchers are women (Figure 3.3).

An alternative approach for obtaining data for gender distribution is the identification and classification of participants, in terms of gender and affiliation, attending selected international conferences/symposia. The following assessment includes data from conferences focusing on ocean science and environmental science in general and five of the eight ocean science categories considered in Chapter 2 (Annex E): *Human health and well-being*; *Ocean and climate*; *Marine ecosystem functions and processes*; *Ocean observation and marine data*; *Ocean technology*.[5] The assessment addresses three regions: the Mediterranean Sea (data provided by the Mediterranean Science Commission, CIESM); the North Atlantic Ocean (data provided by the International Council for the Exploration of the Sea, ICES); and the North Pacific Ocean (data provided by North Pacific Marine Science Organization, PICES; Figure 3.4). In total, the gender and the country of their respective research institution were identified for more than 15,000 participants. Clearly, the geographical distribution of international conferences is not balanced. Though capacity-building efforts led to more ocean science in the southern hemisphere and greater scientific impact comparing the time periods 2000–2004 and 2010–2014 (Chapter 5; Figure 5.2), most of the conferences still take place in the northern hemisphere.

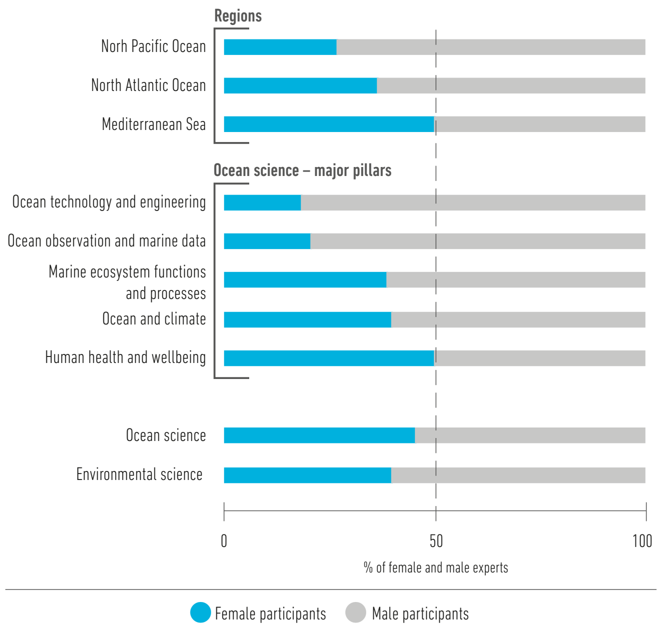


Figure 3.4. Relative proportion (%) of male and female experts attending international scientific conferences/symposia (Annex E).

Although the gender distribution of participants in general ocean science conferences/symposia is close to parity (Figure 3.4), there are important differences among the various categories of ocean science. There is a stronger representation of men, especially in conferences/symposia focusing on *Ocean technology and engineering* and *Ocean observation and marine data*. There are also differences between regions: gender representation of participants to conferences/symposia in the general field of ocean science in the Mediterranean Sea is roughly equal, but a higher proportion of conference participants in the North Atlantic and North Pacific Ocean are men. The nationality of researchers attending ocean science conferences/symposia also varies between research categories (Figure 3.4).

While females make up between 25–66% of scientific experts attending international ocean science conferences, the gender distribution of experts varies greatly between countries[6] and categories of ocean science (Figure 3.5). Ocean science conferences focusing on *Human health and well-being* for example, are attended equally by female and male experts. In contrast, participants attending ocean technology and engineering conferences are predominantly men, with the exception of Sweden and Turkey.

5 No international conferences that fulfilled the GOSR criteria (Chapter 2) for the topics related to *Ocean health, Ocean crust and marine geohazards, or Blue growth* were identified and hence these categories could not be included in the analysis.

6 Top 20 countries in ocean science publication for the period 2010–2014 considered in this analysis (Chapter 5).

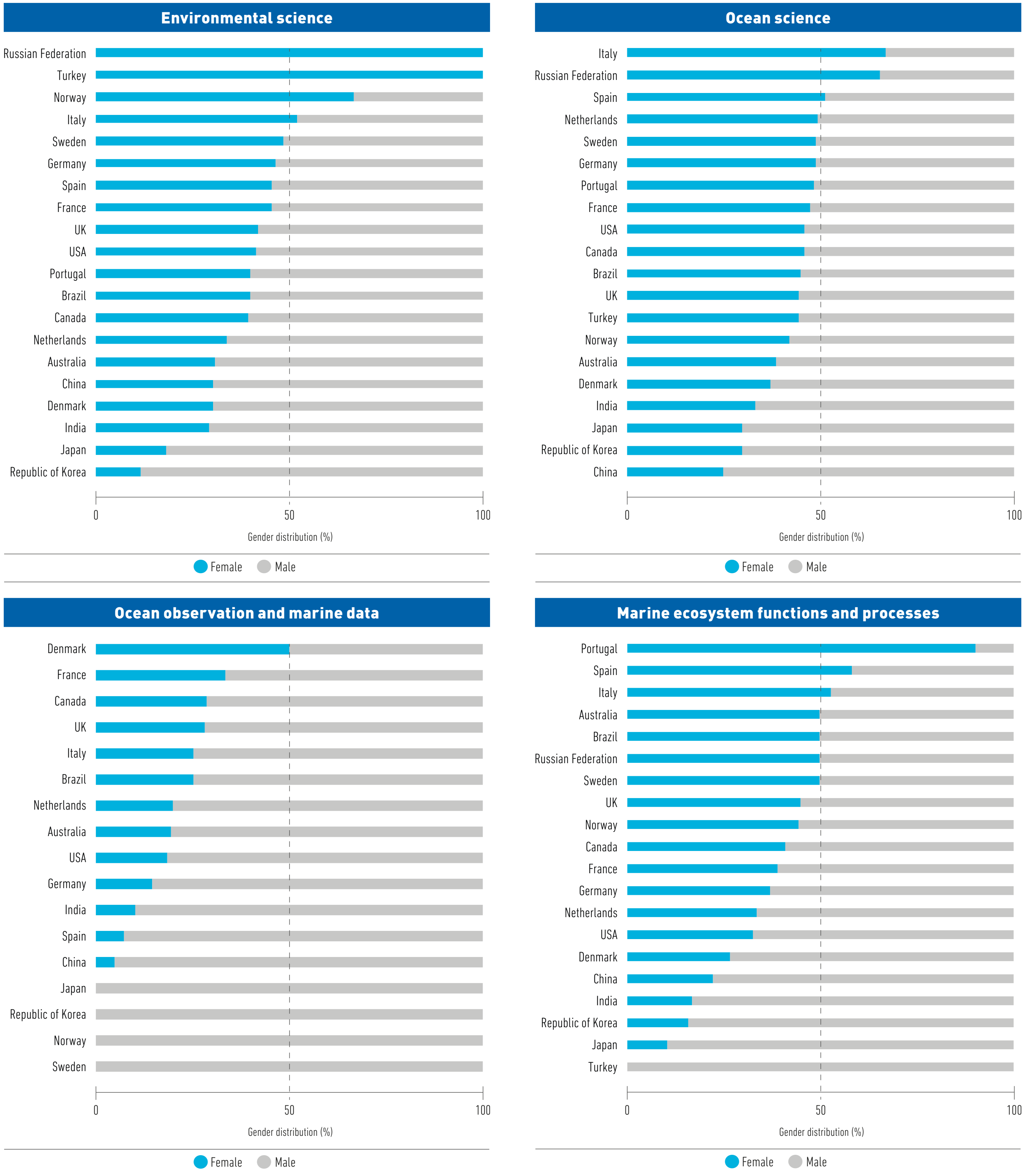
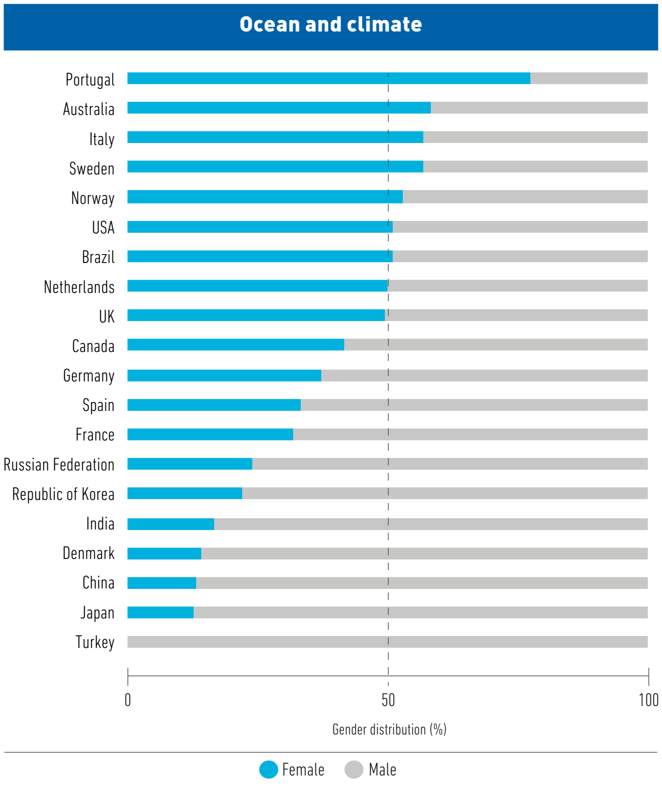
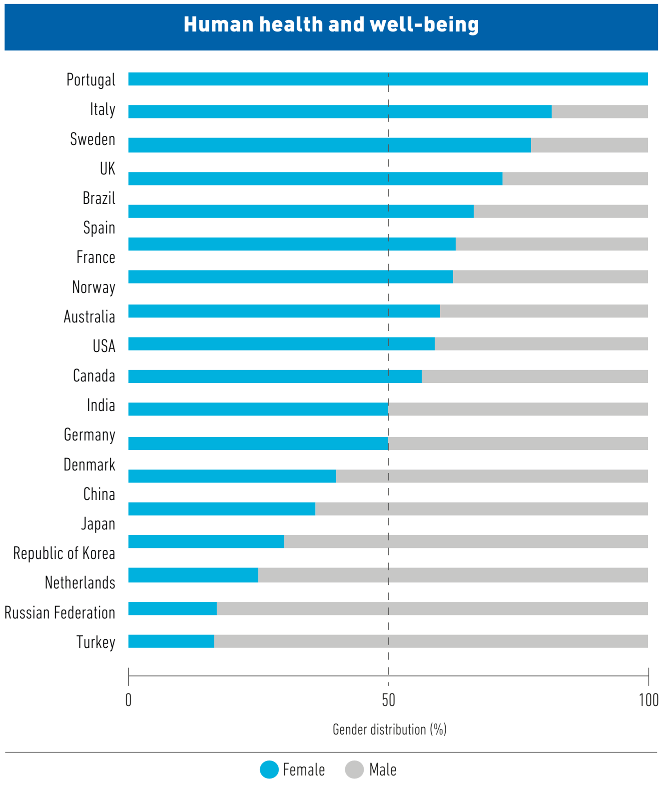


Figure 3.5. Relative proportion (%) of female and male experts attending international scientific conferences/symposia with different foci (environmental science, ocean science, human health and well-being, ocean and climate, marine ecosystem functions and processes, ocean observation and marine data, ocean technology and engineering) for the top 20 countries publishing in ocean science (Annex F).





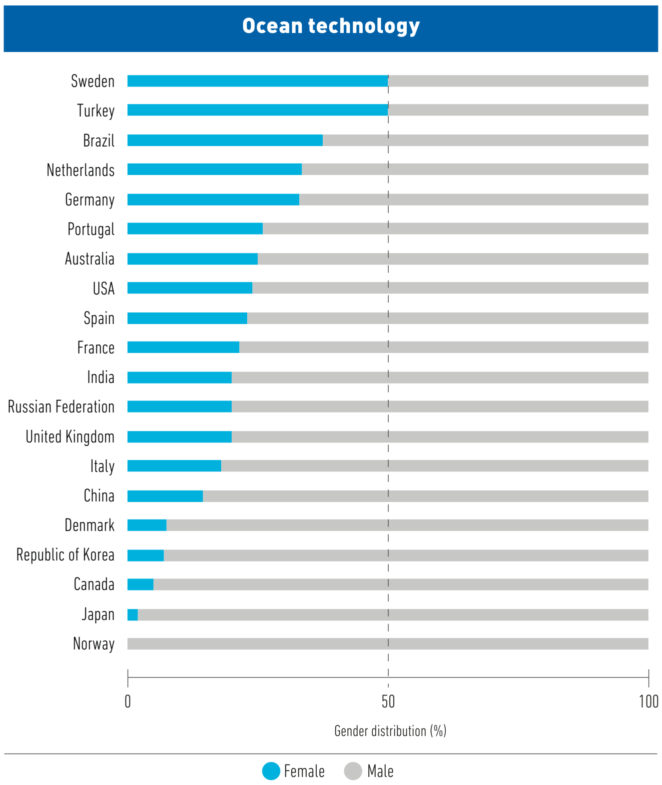


Figure 3.5. *continued*

The challenges facing women in oceanography follow the broad trends seen in science overall. The percentage of females in oceanography academia decreases with increasing faculty rank, from 40% at the level of assistant professor, to 30% at the level of associate professor, and to 15% at the full or senior faculty level in the USA (Orcutt and Cetinić, 2014). Similar findings were obtained by a study on the general scientific workforce in the UK, also suggesting a 'glass ceiling' situation with a concentration of women in lower managerial and professional roles and marked underrepresentation in senior management positions (Royal Society, 2014). In 2011, another study showed that even though female PhDs reached parity with male PhDs in physical oceanography, this is not translated into gender parity at the tenure-track faculty position level (Thompson *et al.*, 2011).

This glass ceiling suggests a tension between the meritocratic promotion structures in science and the individual career trajectories of men and women due to different challenges in science as well as their private lives. Meanwhile, the enforcement of gender equity policies and measures supporting women, and the actual effect on the composition of research teams from universities and research centres, ought to be evaluated for ocean science. It is therefore important to assess the values and practices governing the hiring process, mentoring, tenure and promotion of candidates in science.

3.3. Ocean science institutions, marine laboratories and field stations

Ocean science institutions and marine laboratories play a vital role in support of ocean research. They are critical in addressing a variety of scientific questions, such as studies of coastal food webs, ecosystem biodiversity and human impacts on coastal environments. They play an important role in the co-location of researchers and technologists with a range of skills, experience and knowledge, and thereby allow any individual access to skills and knowledge across disciplines. In addition, higher education is becoming increasingly important for ocean science institutions.

Marine field stations and laboratories provide access to a range of environments, including coral reefs, estuaries, kelp forests, marshes, mangroves and urban coastlines. These facilities are valuable platforms that support research and provide opportunities for educational outreach, such as graduate and undergraduate training, public education and citizen science. Many marine research institutions also support long-term observational studies that provide vital baseline data for understanding natural systems, such as natural variations and human impacts on ecosystem processes, enabling comparative studies that provide broad insights into ecological processes. However, the ocean research landscape varies between countries, with differing levels of ocean science infrastructure and related research facilities largely influenced by different types of research organizations (national, federal and/or academic).

3.3.1. Ocean science institutions

Figure 3.6 shows the top 40 countries in terms of ocean science-related institutions. The results indicate the different modalities of organization of national scientific schemes and subsequent architecture of science infrastructure (e.g. centralized with some centres of specialized science, spatially equally distributed regional centres).

Countries that invest in ocean science (Chapter 4) and publish in ocean science (Chapter 5) also have numerous institutions focusing on marine research (Figure 3.6). Based on the data extracted from the GOSR questionnaire, the total number of ocean science institutions in Europe is about the same as for the USA.

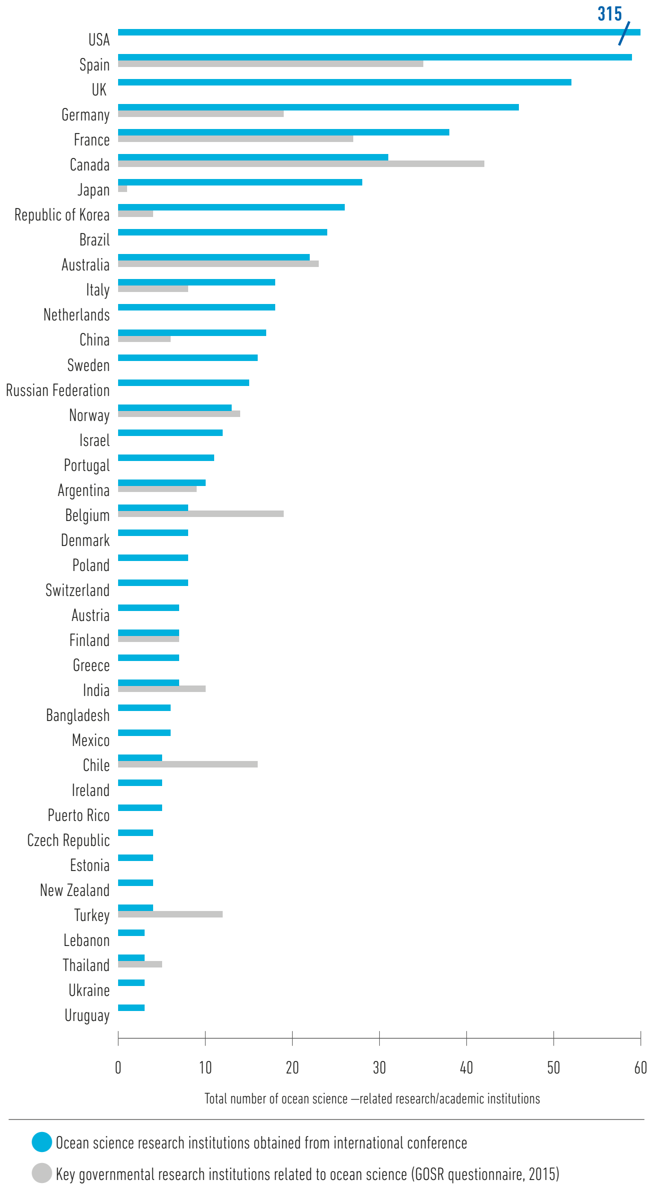


Figure 3.6. Total number of institutions/facilities and universities by country (top 40) represented in at least two of the following list of international conferences: Third International Symposium on the Ocean in a High CO_2 World, 2012, Monterey, USA; Second International Symposium Effects of Climate Change on the World's Oceans, 2012, Yeosu, Republic of Korea; Third International Symposium on the Effects of Climate Change on the World's Oceans, 2015, Santos, Brazil; Aquatic Science Meeting ASLO, 2013, New Orleans, USA; Aquatic Science Meeting, 2015, Granada, Spain; OceanObs'09, 2009, Venice, Italy (blue bars) and total number of key governmental research institutions related to ocean science (grey bars). *Source*: GOSR questionnaire, 2015.

Sometimes the total numbers submitted to the GOSR questionnaire were lower compared to those obtained from the international conferences/symposia lists of participants. One possible explanation is that academic institutions that are not actively supported as key oceanographic institutions by their governments are still conducting ocean science and send experts to present the latest outcomes in ocean science and related research.

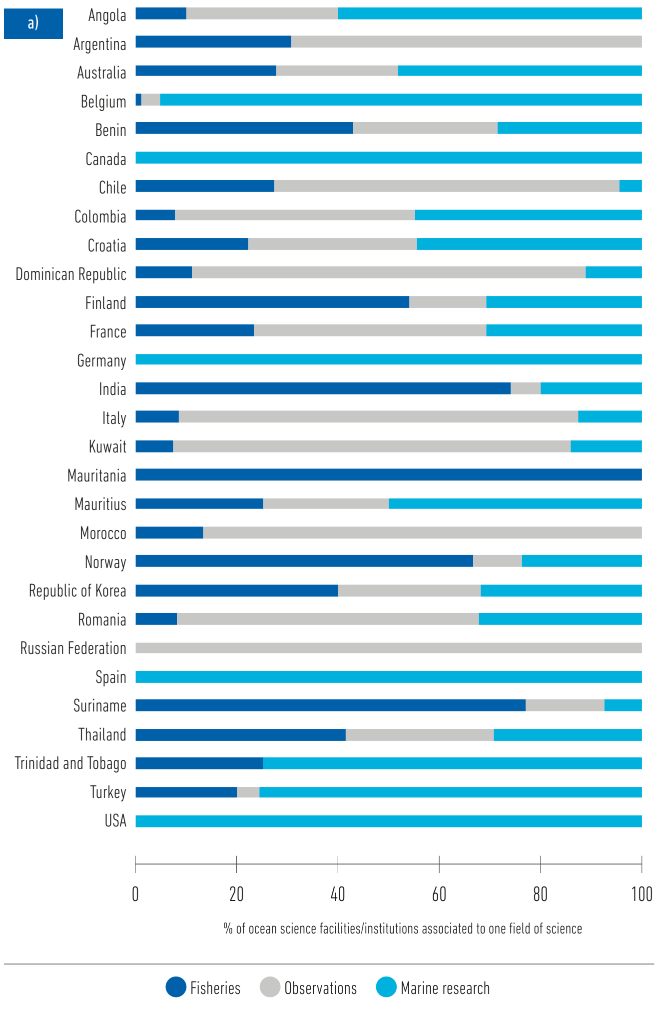
Some research institutions specialize in particular fields. Twenty-nine countries provided data concerning the proportion of institutions focusing on specific fields of science (fisheries, observations, marine research; Figure 3.7). Focusing on one field does not exclude the conduct of ocean science in other fields. Indeed, ocean observation is a key tool to answer scientific questions in most ocean science categories, e.g. providing the basis for scientific studies on ocean change.

In total, facilities of 'other ocean science' comprise the highest proportion (54%) compared to observations (27%) and fisheries (19%), when only considering countries that classified institutions to at least two categories. Presumably, countries that listed all institutions for one research field could not obtain the information to differentiate types of ocean science facilities at the national level.

The relative proportion of institutions specializing in a field might reflect national research priorities, economic importance of ocean resources and therefore the investment in related science. India, Norway and Finland, for example, have a high proportion of their institutions specialized in fisheries, while Italy, the Russian Federation, France, Argentina and Kuwait seem to concentrate their efforts in ocean observations.

Some marine stations have existed for more than 100 years, such as Stazione Zoologica Naples (Italy), Roscoff (France), Kristineberg (Sweden), Santander (Spain), Misaki Marine Biological Station (Japan), Marine Biological Laboratory, Woods Hole (USA) and the Marine Biological Association, Plymouth (UK). The majority of marine stations, however, were founded from 1950 to 2000. Many of the marine stations are members of regional associations for marine stations (such as MARS, NAML, JAMBIO, TMN, AMLC, CARICOMP, PIMS, GOOS-Africa etc.).[7] A global body, the World Association of Marine Stations, was established in 2010.

7 MARS - European Network of Marine Research Institutes and Stations; NAML – National Association of Marine Laboratories; JAMBIO – Japanese Association of Marine Biology; TMN – Tasmania Maritime Network; AMLC – Association of Marine Laboratories of the Caribbean; CARICOMP – Caribbean Coastal Marine Productivity; PIMS - Perry Institute of Marine Science; GOOS-Africa – Global Ocean Observing System for Africa.



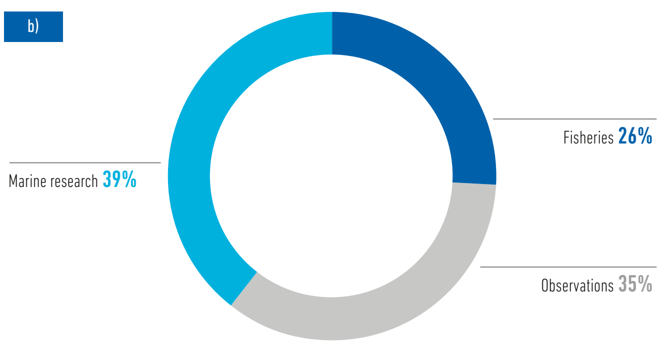


Figure 3.7. a) The relative proportion (%) of ocean research facilities/institutions associated with one field of science (fisheries, observations, ocean research) for 29 countries individually; b) The total number of institutions for 24 countries (as in Figure 3.7.a, excluding Canada, Germany, the Russian Federation, Spain and USA, which listed all institutions for one category). *Source*: GOSR questionnaire, 2015.

Table 3.2. Total number and proportion of marine stations in different regions.

Geographical location of marine station	Number of marine stations (and % of total)
Asia	179 (23%)
Europe	172 (22%)
North America	163 (21%)
Antarctica	86 (11%)
South/Latin America	81 (10%)
Africa	62 (8%)
Oceania	41 (5%)

Due to different definitions of 'field stations', the number of field stations in previously published compilations varied from 800 field stations, including hydro-biological stations (Hiatt, 1963; Inaba, 2015; Baker, 2015), to 260 marine stations (NRC, 2014). A study by Tydecks *et al.* (2016) counted more than 430 biological field stations including 50 marine stations. The different definitions of 'field stations' have complicated comparisons until now. The following global analysis provides information on 784 marine stations maintained by 98 countries (for definition see Chapter 2; Figure 3.8).

Table 3.2 and Figure 3.9 provide further details on the regional and national distribution of the marine stations. Most are located in the northern hemisphere, almost equally distributed among Asia (23%), Europe (22%), North America (21%), followed by Antarctica (11%), South/Latin America (10%), Africa (8%) and Oceania (5%). The USA alone operates 137 marine stations, accounting for more than 17% of the world total. Japan's marine stations mostly belong to universities and have limited permanent staffing (fewer than 10 scientists). Due to the unique status of Antarctica, the marine stations located in this region are maintained by approximately 30 countries as year-round or seasonal stations.[8]

3

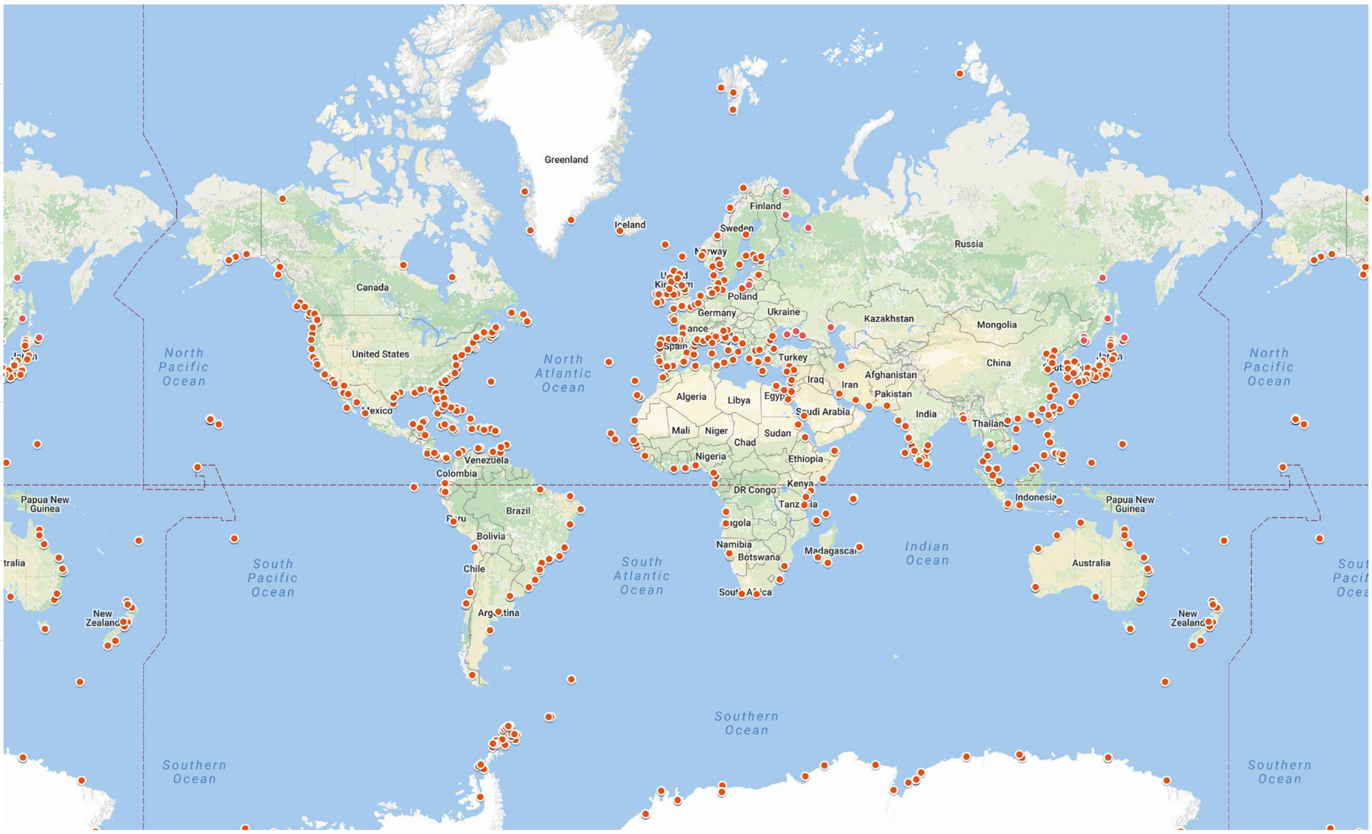


Figure 3.8. World distribution of marine stations. Data regarding marine stations were gathered from several sources and their locations were mapped using Google Maps.

8 https://www.nsf.gov/pubs/1997/antpanel/4past.htm

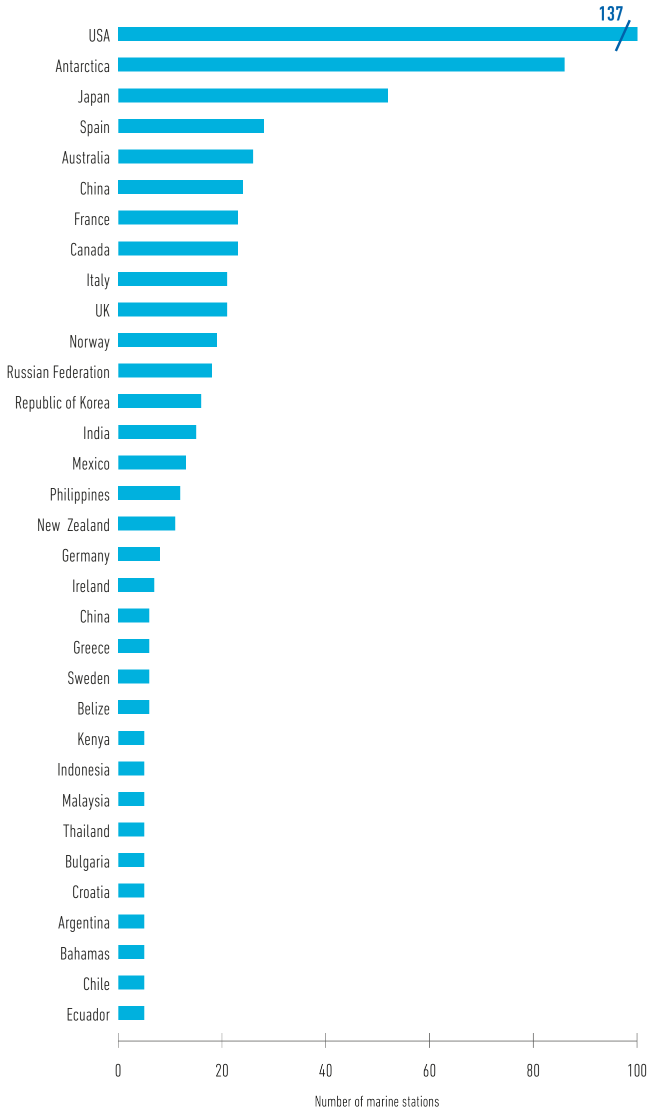


Figure 3.9. Number of marine stations per country. The marine stations in each country mapped in Figure 3.8 were counted and plotted in the order of counts (countries with > 5 marine stations).

3.4. Research vessels and other research infrastructures/ equipment

Continuous access to the open ocean, coastal zones and watersheds depends on novel infrastructure and technology, from sensors to research vessels to autonomous vehicles. Research vessels are an essential component of ocean research infrastructure as they provide access to both the open ocean and coastal areas. Evolving science needs, cost pressures and newer technologies, such as advances in autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs), have changed ocean science infrastructure. However, this has not lessened the reliance on well-equipped ships. In fact, research vessels are fundamental to deploy and recover new observing technologies and to explore the vast areas of the ocean poorly observed to date. Determining how to size the fleet (e.g. appropriate number of research vessels and their scientific research capabilities) is an essential exercise that should be carried out in order to utilize existing funding efficiently, to plan future investment, to match seagoing capacities with research demands, and to maintain or improve current capabilities.

3.4.1. Research vessels and ships partly used for ocean science

Information about research vessels was provided by 30 countries via the GOSR questionnaire. A total number of 371 vessels was reported, which cover 325 research vessels mainly used for ocean science and 46 vessels partly used for ocean science (Figure 3.10). The top ten countries are: USA (51), Japan (29), Germany (28), Turkey (27), Republic of Korea (26), Canada (20), Italy (20), France (18), Thailand (16) and Norway (15). The total number for the top ten countries (250) is higher than for all other countries combined (121 vessels).

Besides the data gathered through the GOSR questionnaire, OCEANIC and Eurofleets are international databases that contain compiled information about research vessels maintained (Figure 3.11). Differences between the numbers available from the OCEANIC database, EUROFLEETS and the GOSR could have resulted from the inclusion of research vessels < 10 m in length and ships that are not operational any more.

In general, the research vessel category applied for this report has four ship classes, primarily based on the length of vessels. The classification is consistent with that of the US Research

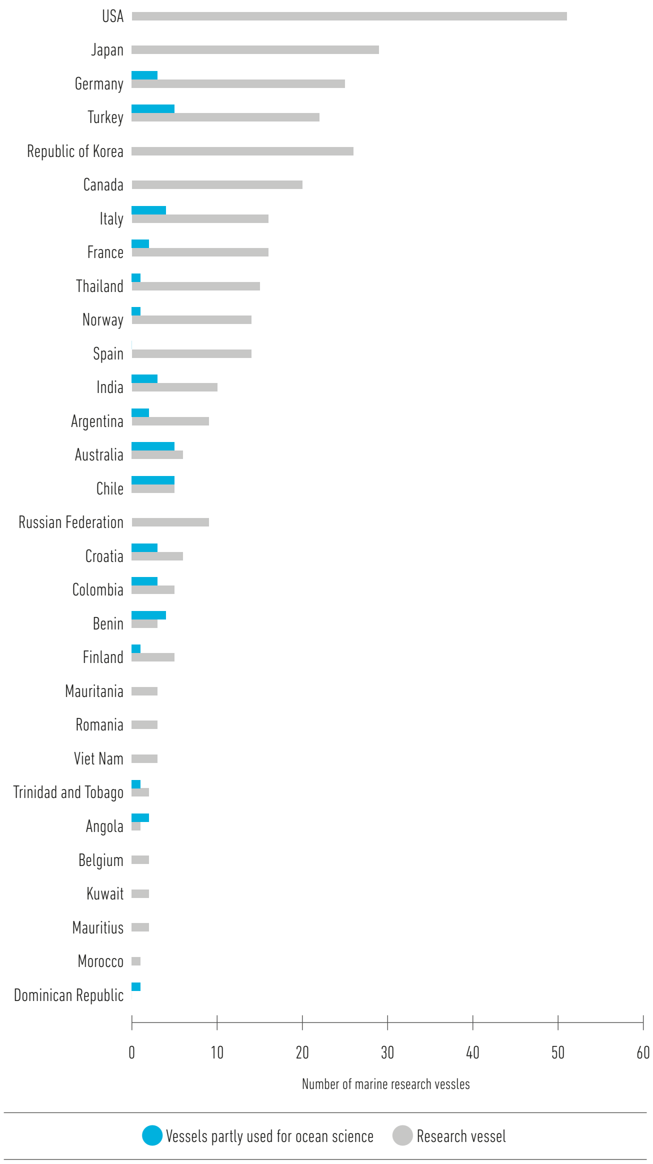


Figure 3.10. Number of nationally maintained research vessels. *Source*: GOSR questionnaire, 2015.

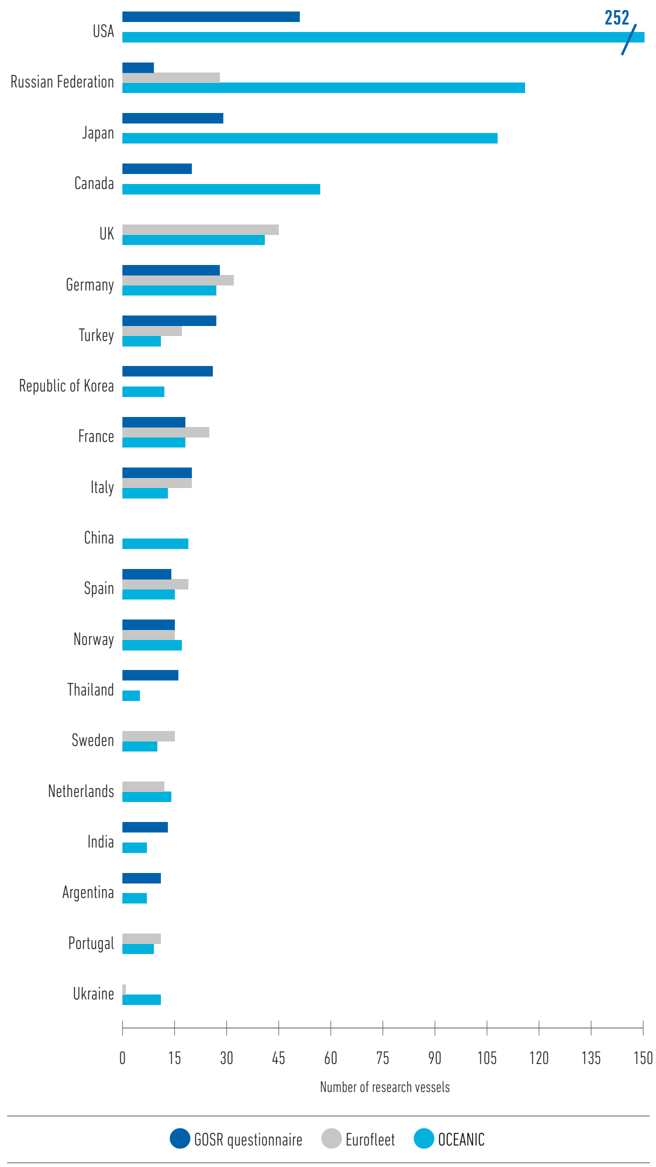


Figure 3.11. Number of research vessels maintained by top 20 countries (according to the OCEANIC database), results from three different sources: GOSR questionnaire, 2015 – dark blue; Eurofleet database, 2015—grey; OCEANIC database, 2015—light blue. (Note: data provided for the USA is restricted to Federal Oceanographic Fleet).

Vessel fleet operated by University National Oceanographic Laboratory System (UNOLS).[9]

- ≥ 65 m: Global vessels (large and operate on a multi-ocean basin scale)
- 55 m ≤ L < 65 m: International vessels (large enough to operate on an international scale)
- 35 m ≤ L < 55 m: Regional vessels (e.g. operate on a European regional scale)
- 10 m ≤ L < 35 m: Local and/or coastal vessels (for research only).

9 https://www.unols.org/

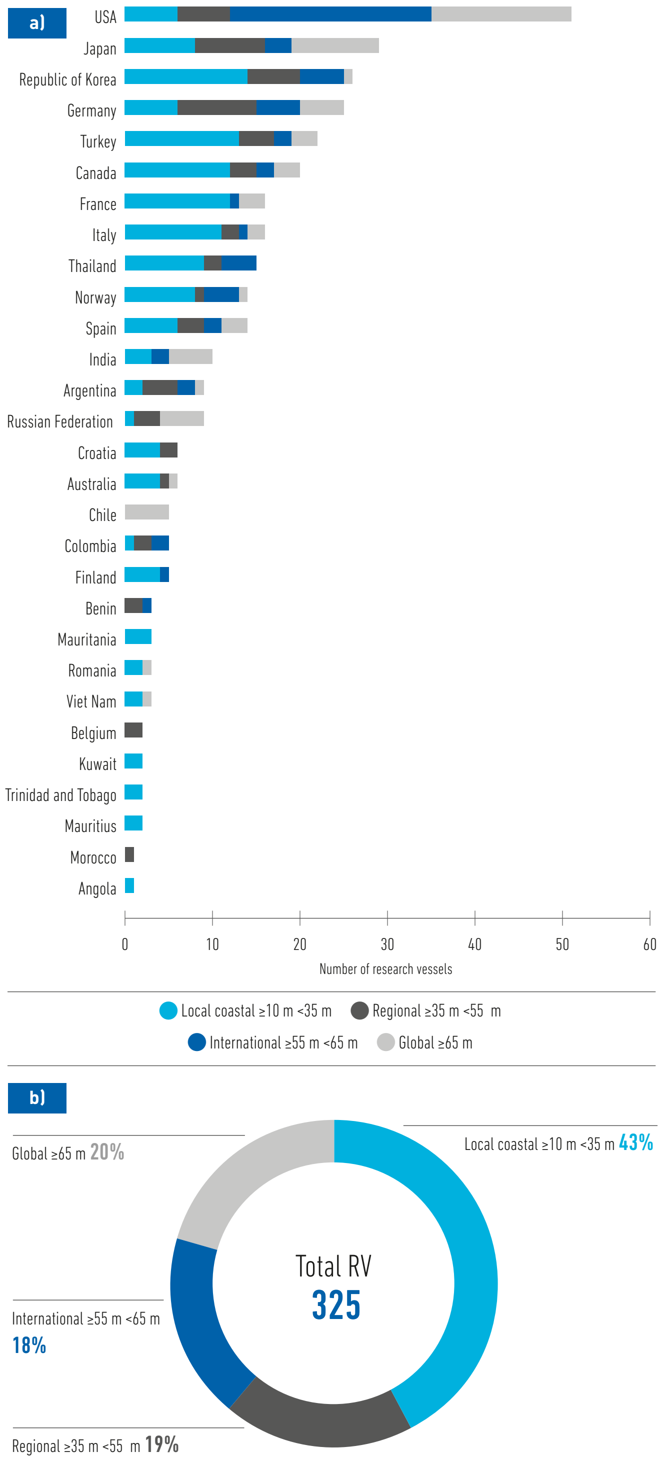


Figure 3.12. a) Number of nationally maintained research vessels (RV), classified in four different ship sizes: local/coastal ≥ 10 m < 35 m, regional ≥ 35 m < 55 m, international ≥ 55 m < 65 m, global ≥ 65 m. b) Relative proportion of the different ship sizes summarizing all research vessels, accounted for in a). *Source*: GOSR questionnaire, 2015.

Of the 34 GOSR questionnaire respondents, 20 countries provided information on research vessels primarily used for ocean science and with information on ship class. The comparative distribution of ships by country is illustrated in Figure 3.12, which shows that there are 325 research vessels operating in 29 countries.

Local and coastal research is the primary purpose of 43% of research vessels, spread over 29 countries. The proportions of research vessels operating at regional (19%), international (18%) and global scales (20%) are similar. Vessels used at the global scale are maintained by 17 out of 29 countries: Argentina, Australia, Canada, Chile, France, Germany, India, Italy, Japan, Norway, Republic of Korea, Romania, the Russian Federation, Spain, Turkey, USA, and Viet Nam.

Another indicator that provides useful information about the fleet of vessels supporting ocean science is the age of the ships. The OCEANIC database contains information in this regard, though it must be kept in mind that data from the GOSR questionnaire and this database differ significantly (Figure 3.11). In order to minimize potential biases associated with outdated data, the age class assessment of research vessels herein is restricted to ships ≥ 55 m (Figure 3.13).

There are 326 research vessels larger than 55 m registered on the OCEANIC worldwide database. More than one-third of these ships were built more than 30 years ago, while less than 4% were put into operation during the past ten years (Figure 3.13).

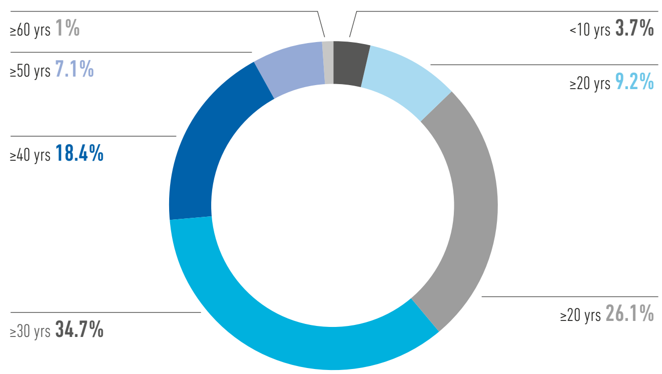


Figure 3.13. Proportion of seven age classes within the research vessel fleet for ships ≥ 55 m. *Source*: OCEANIC database, 2016.

A more detailed breakdown about the average age of research vessels at the national level is provided in Figure 3.14. Mexico, Australia, Canada, the UK and Greece have the oldest fleets. In contrast, the average age of research vessels in Norway, Bahamas, Japan and Spain is less than 25 years, suggesting new investments in the scientific research fleet. The investment into the renewal of ocean science equipment on board RVs can be significant, however this analysis was beyond the scope of this report.

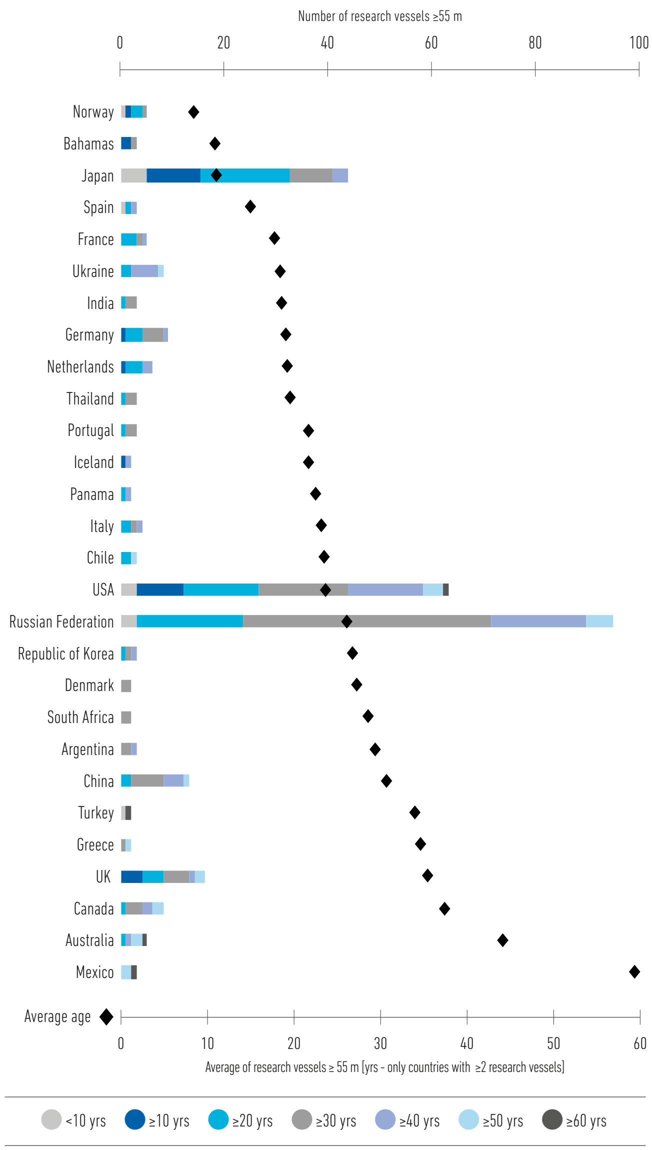


Figure 3.14. Stacked bar chart: Number of research vessels ≥ 55 m for countries with minimum two research vessels of this size, colour-coded age classes. Diamonds indicate the average age of all research vessels for the respective country. *Source*: OCEANIC database, 2015.

The ship time allocated for conducting national and international investigation was reported by 23 countries (Figure 3.15). The USA, Germany, France and the Republic of Korea are the top four countries in terms of days of investigation dedicated to international research on research vessels. The majority of ship time is dedicated to national research: Japan for example reported ten times more days for national research than international investigation, and Australia did not report any ship time used for international research. The Russian Federation, though maintaining the biggest research vessel fleet, reported in total only 529 days of ship time used for ocean science.

3.4.2. Other research infrastructure/equipment

Information about specific technical equipment used for ocean science was provided by 20 countries via the GOSR questionnaire. In total 1,392 devices (with per unit cost > US$0.5 million) were reported. The data based on this very rough classification suggests that of this equipment 74% was purchased over the period between 2009 and 2012, 14% between 2004 and 2008, 5% between 1999 and 2003, and 7% before 1999. Germany maintains the largest number of devices (396 items) followed by the Republic of Korea (172), Turkey (93), Canada (87) and India (83).

3.4.2.1. Moorings and buoys

Moorings and buoys are important to gather data on the state of the global ocean by providing continuous measurements of physical and chemical parameters. The Data Buoy Cooperation Panel (DBCP) was formed in 1985 as a joint body of the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO. It coordinates the operation of surface drifting buoys and tropical moored arrays.

The Argo profiling floats programme is coordinated by the Argo Project Office and the Argo Information Centre at JCOMM in-situ Observing Platform Support centre (JCOMMOPS). Such coordination and other activities allow JCOMMOPS to maintain real-time maps and statistics on the status of the ocean observing networks such as: DBCP, including drifting buoys,[10]

10 Drifting *buoys*: Surface Velocity Program (SVP) buoys, all different type of ice buoys placed on ice which move with ice packs.

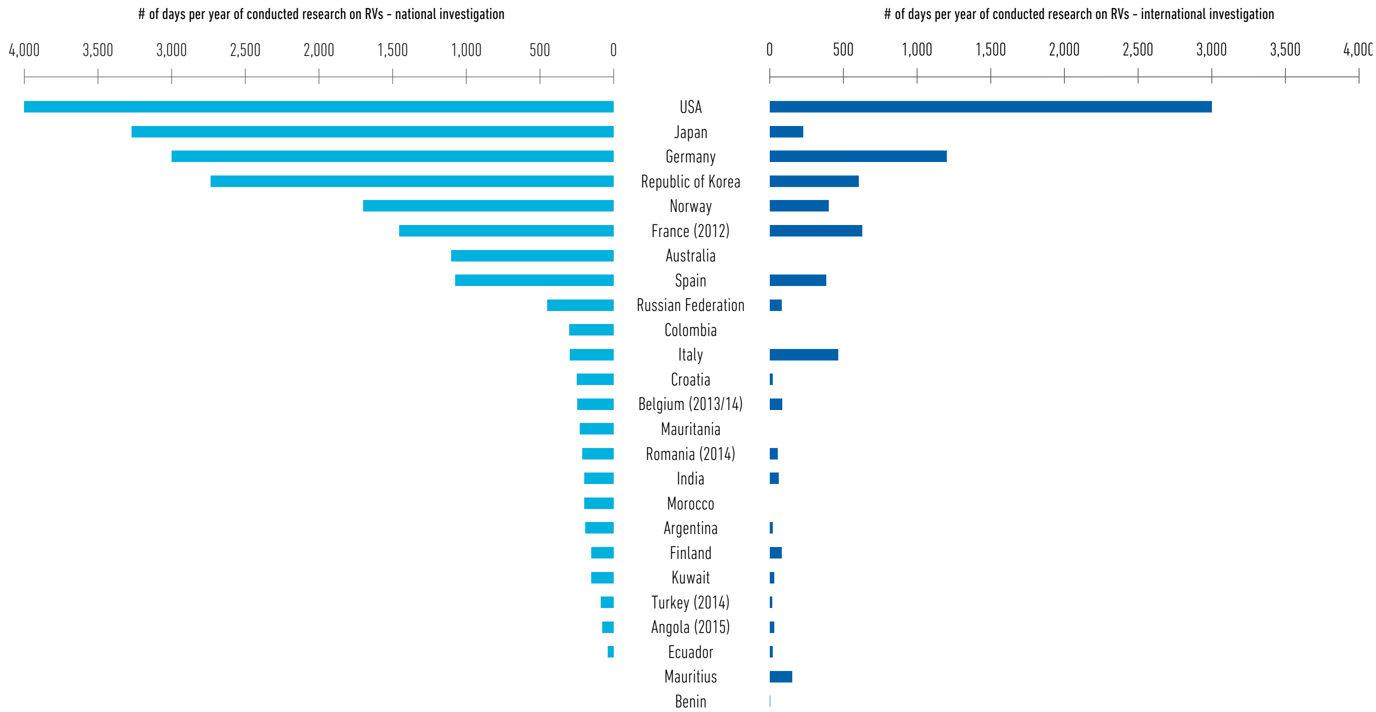


Figure 3.15. Number of days per year of research conducted from research vessels for national (left panel) and international (right panel) investigation by country (2013, or the last year with available data). *Source*: GOSR questionnaire, 2015.

moored buoys,[11] tsunameter buoys[12] and fixed platforms,[13] and the Argo network of sub-surface profiling floats.[14] The number and status of platforms, as well as operating countries, assessed in the DBCP, are presented in Figure 3.16. The total number of platforms (2,093) operational during the month of February 2016 comprise drifting buoys (1,536; other than Argo floats), coastal/national moored buoys (398), tsunameter (55) and fixed platforms (104). The USA operates 1,267 drifting buoys, followed by Europe (103), Canada (34), France (29) and Australia (18). The USA has the highest number (223) of coastal/national moored buoys, followed by France (22), Canada (20), India (19) and the Republic of Korea (17).

Argo is a model on how to share ocean science infrastructure. It has offered new ideas on (i) how to collaborate internationally, (ii) how to develop a data management system, and (iii) how to change the way scientists think about collecting data. Deployments began in 2000 and continue today at the rate of about 800 per year.[15]

There are 3,839 Argo floats listed as active and in operational condition.[16] The array of floats is presently provided by 29 countries. National contributions of floats to the Argo array vary from a single float (e.g. by Kenya and South Africa) to the USA contribution of 2,136, approximately 55% of the global total (March 2016; Figure 3.17). A primary focus of Argo is to document seasonal to decadal climate variability and to improve the predictability. Argo is part of the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS).

11 Moored Buoys: national/coastal moored buoys and tropical *buoys* moored as separate categories, including all surface buoys, which are moored to the sea floor. These buoys measure a number of atmospheric parameters (air pressure, air temperature, winds, waves, humidity) as well as sea surface (SST) and subsurface parameters (subsurface currents, subsurface salinity, etc.) in some cases.

12 Tsunameter buoys are systems with an anchored sea floor bottom pressure recorder (BPR) and a companion moored surface buoy for real-time communications. In their normal operation mode these buoys measure water column height.

13 Fixed platforms include platforms permanently fixed to the seabed, mobile offshore drill ships, jack-up rigs, semi-submersible platforms, floating production storage and offloading units (FPSO) and light vessels.

14 Argo is a broad-scale global array of more than 3,000 free-drifting profiling floats that measure the temperature and salinity of the upper 2,000 m of the ocean.

15 http://www.argo.ucsd.edu/About_Argo.html

16 http://www.jcommops.org

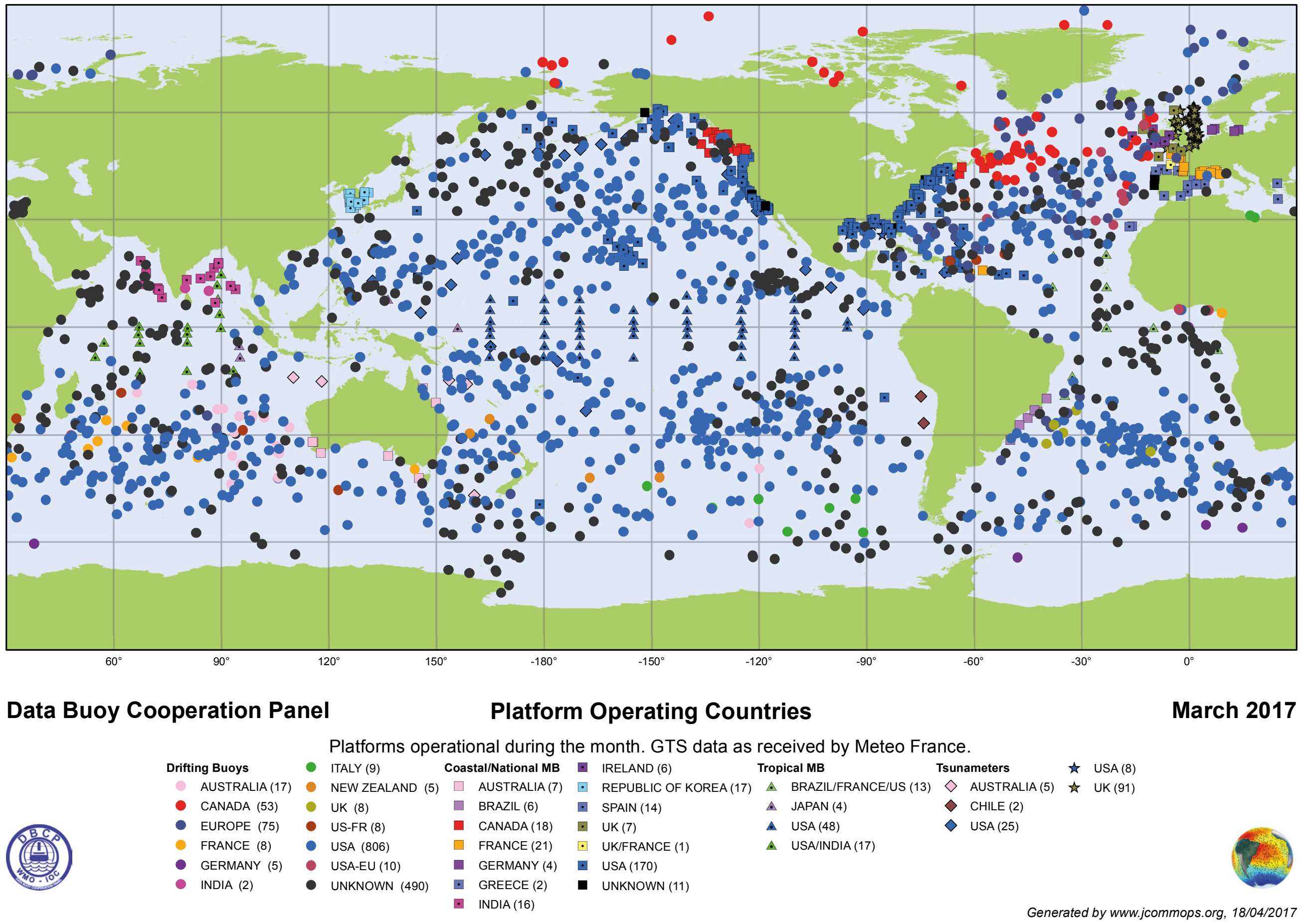


Figure 3.16. Map by operating country. *Source*: JCOMMOPS, 2017.

3.3.2.2. ROVs and AUVs

In addition to buoys and moorings, new marine research technologies include an array of 'vehicles'. A remotely operated vehicle (ROV) is an unoccupied underwater robot that is connected to a ship by a series of cables. These cables transmit command and control signals between the operator and the ROV, allowing remote navigation of the vehicle. A ROV may include a video camera, lights, sonar systems and an articulating arm. The articulating arm is used for retrieving small objects or samples, cutting lines or attaching lifting hooks to larger objects.

An autonomous unmanned underwater vehicle (AUV), commonly known as an unmanned underwater vehicle, is one of the technologies that can be used for underwater survey missions such as detecting and mapping submerged wrecks, rocks and obstructions that may be hazardous to navigation for commercial and recreational vessels. An AUV conducts its survey mission without operator intervention. When a mission is complete, the AUV will return to a pre-programmed location where the data can be downloaded and processed. An AUV operates independently from the ship and has no connecting cables, whereas ROVs are connected to an operator on the ship.[17]

Ocean gliders are one type of AUV that are used for ocean science. Since gliders require little or no human assistance while travelling, these little robots are uniquely suited for collecting data in remote locations, safely and at relatively low cost. Gliders may be equipped with a wide variety of sensors to monitor temperature, salinity, currents and other ocean conditions.[18]

ROVs and AUVs (including gliders) are becoming increasingly important to explore and investigate vast areas of the open ocean. They help to monitor the ocean more closely and to

17 http://oceanservice.noaa.gov/facts/auv-rov.html

18 http://oceanservice.noaa.gov/facts/ocean-gliders.html

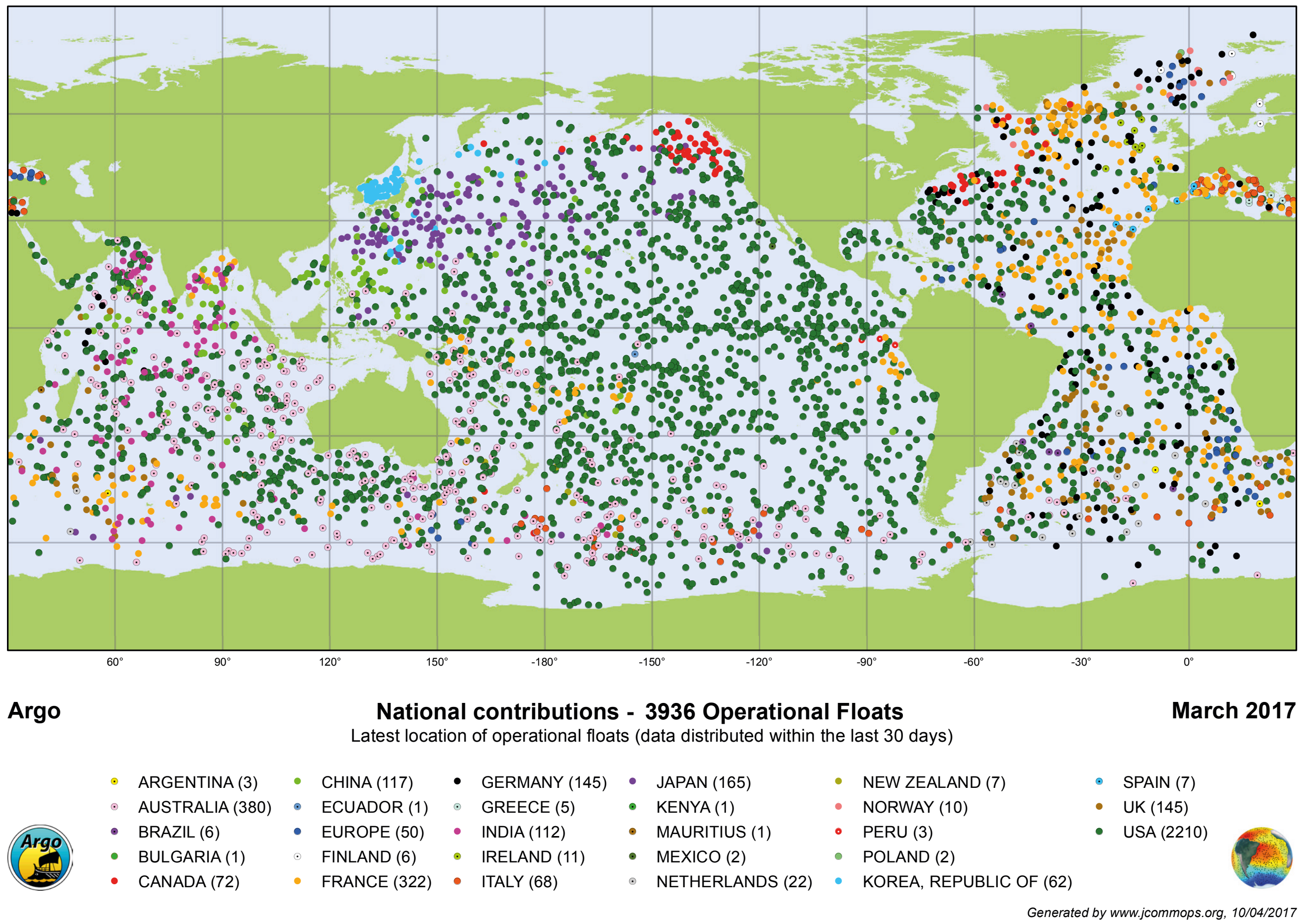


Figure 3.17. Map indicating the location of operational Argo floats in March 2016 (data distributed within the last 30 days) and list of national contributions. *Source*: JCOMMOPS, 2017.

fill knowledge gaps in the existing ocean observation data sets. During the past decade, the research application of AUVs has increased greatly, due to their unique capacity to carry sensors, such as for ocean acidification measurements and for characterizing carbon and nutrient cycles. The widespread application of unstaffed platforms is transforming oceanographic infrastructure. AUVs, including instrumented sea animals and gliders, are ideal platforms to use the newly developed small, low-power sensors for monitoring physical, chemical and biological indicators of dynamic variability and ecosystem variations in coastal and island settings.

Previous and ongoing undertakings to assess ROVs, AUVs and gliders[19] were used to confirm and to complement information provided via the GOSR questionnaire (Figure 3.18).[20] A total number of 339 pieces of equipment (ROVs, AUVs and gliders) was identified in 28 countries.

Portugal reported the highest number of ROVs, followed by the Republic of Korea, Greece, Norway, UK and USA. The highest number of AUVs are maintained in the USA (47), followed by the UK (22), the Republic of Korea (13), Norway (9) and Canada (8). The total number of ROVs, AUVs and gliders in USA (100), UK (46) and France (28) together are roughly the same as for the other countries combined (165).

3.4.3. Sustained ship-based measurements

Ocean time series measurements, in particular ship-based repeat measurements, are a type of observation method considered indispensable for helping to answer emerging scientific questions in ocean science and improving decision-making in ocean and coastal management (Edwards *et al.*, 2010). They provide research with the long, temporally resolved data sets and high quality information needed to characterize ocean

19 Gliders considered in a separate category to AUVs for the purpose of this analysis given their prevalence.

20 Global Inventory of AUV and Glider Technology available for Routine Marine Surveying—MREKEP/NERC—James Hunt, 2013, Eurofleets; http://www.eurofleets.eu/lexi/.

physics, climate and biogeochemistry. They make it possible to detect ecosystem variability and change. The International Group for Marine Ecological Time Series (IGMETS), an IOC-led effort, identified 341 marine ecological plankton time series globally (Figure 3.19).

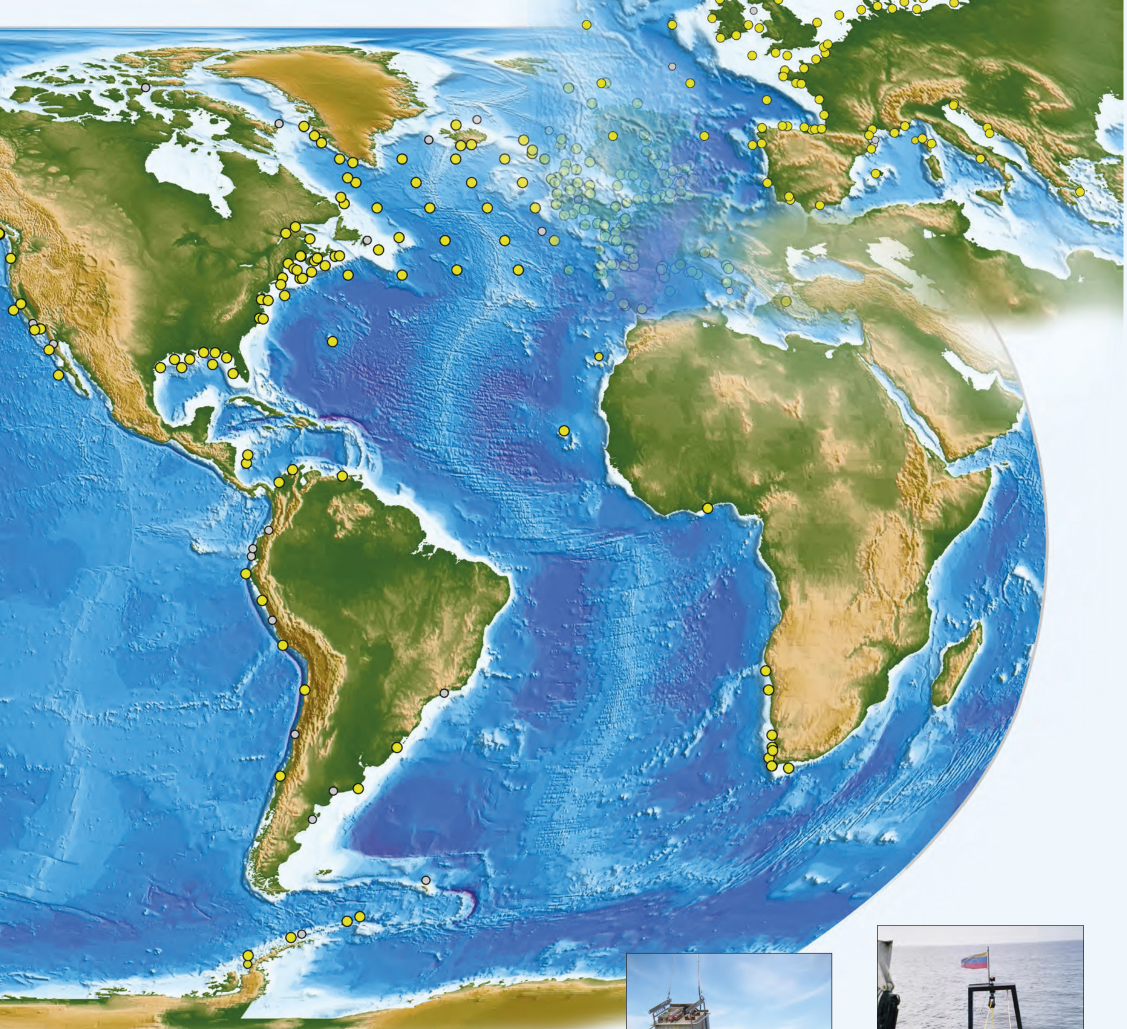
This compilation takes into account two types of ship-based time series. The first type includes water samples to determine chemical and other aspects of the physical environment, as well as some smaller plankton species, and net tows to identify larger species (> 50 μm). The second type of sampling to obtain data regarding the plankton community was conducted with a continuous plankton recorder (CPR), using an automated sampler and not individual net tows to preserve the plankton community. Figure 3.19 illustrates the number of ship-based time series for different time spans, highlighting time series using CPRs to describe plankton.

Figure 3.18. **a)** Number of ROVs operated or developed by country; **b)** Number of AUVs operated or developed by country; **c)** Number of gliders operated or developed by country; **d)** Proportion (%) of ROVs, AUVs and gliders at the global level compared to total number worldwide (345). *Sources*: GOSR questionnaire, 2015; Eurofleet, 2015; MREKEP/NERC, 2013.


DISCOVER OCEAN TIME SERIES
United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
IGMETS
KIOST
ICES CIEM
PICES
OCB
Key:
Marine ecological time series site for which data were provided and included in the International Group for Marine Ecological Time Series analysis.
Marine ecological time series site for which participation in the initial International Group for Marine Ecological Time Series analysis was not confirmed at the time of this map's creation.
© James R Wilkinson/SIO-CalCOFI
Crew of the NOAA ship Belle M. Shimada recovers the Bongo Net during a CalCOFI cruise.
© Digna Rueda
CTD sensor equipped with water sampling rosette deployed at the BATS station.
© Kirsten Isensee
WP2 plankton net deployed in the Baltic Sea.
© Bill Li
Chaetoceros decipiens.

Ship-based biogeochemical and ecological time series are one of the most valuable tools to characterize and quantify ocean ecosystems. These programmes continuously provided major breakthroughs in understanding ecosystem variability, allow quantification of the ocean carbon cycle, and help understand the processes that link biodiversity, food webs, and changes in services that benefit human societies. A quantum jump in regional and global ocean ecosystem science can be gained by aggregating observations from individual time series that are distributed across different oceans and which are managed by different countries. The collective value of these data is greater than that provided by each time series individually. However, maintaining time series requires a commitment by the science community and sponsor agencies.

The importance of continued sampling by existing marine time series is now highlighted by the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO). The International Group for Marine Ecological Time Series (IGMETS) seeks to aggregate time series dispersed around the world in an effort to augment the observing power to look at changes within different ocean regions, to explore plausible reasons and connections at a global level, and to highlight any locations of especially large changes that may be of special importance.



ific research vessel Veliger II returning from regular
ling at the Ubatuba station.

Limacina retroversa.

© Nancy Copley

Recovery of a multi-net for plankton analysis in the Baltic Sea during a cyanobacteria bloom.

© Kirsten Isensee

Sediment trap deployment at the CARIACO station.

©USF

Figure 3.19. Marine ecological time series identified by IGMETS (2015).

3

This data analysis includes information from time series stations maintained by 40 countries (Argentina, Australia, Belgium, Brazil, Canada, China, Chile, Colombia, Croatia, Denmark, Ecuador, Estonia, Faroe Islands, Finland, France, Germany, Ghana, Greece, India, Iceland, Ireland, Isle of Man, Italy, Japan, Latvia, Mexico, Namibia, New Zealand, Norway, Peru, Poland, Portugal, Republic of Korea, Slovenia, South Africa, Spain, Sweden, UK, USA and Venezuela).

Continued measurements of a broad set of parameters delivers the baseline information needed to detect the impact of slow onset threats to ocean health, but it also requires continuous financial commitment by countries. These investments differ between the northern and southern hemisphere, with more stations in existence in the northern hemisphere and in particular in the North Atlantic. Some ecological time series are maintained for more than 50 years, providing the information needed for climate models whose outputs are used in various marine science assessments (e.g. by the Intergovernmental Panel for Climate Change or ICES reports; Figure 3.20).

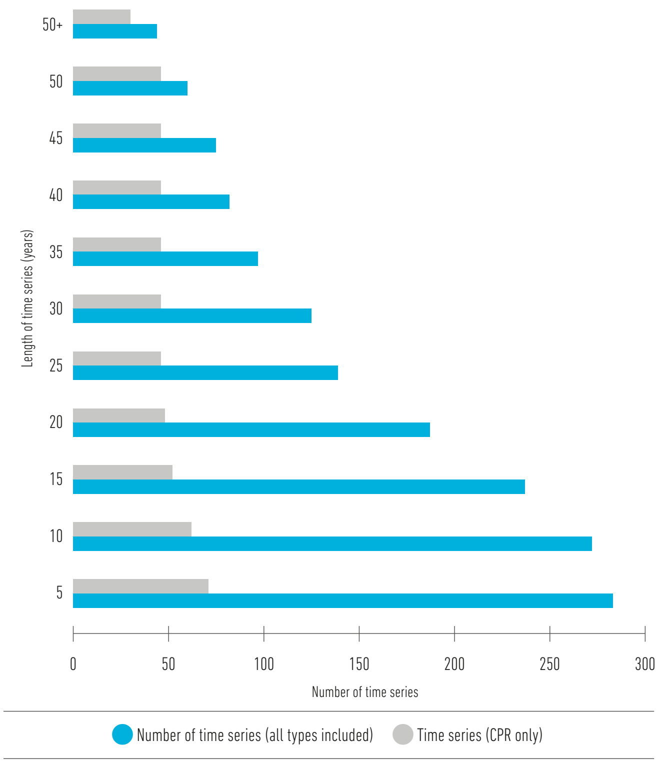


Figure 3.20. Histogram of IGMETS participating time series sorted by their span in years (status, 2012). The Continuous Plankton Recorder (CPR) time series are plotted separately, highlighting its significant contribution to the longer time spans *Source*: O'Brien *et al.*, 2017.

Another type of sustained ship-based observation, coordinated by the Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP), is a network of globally sustained hydrographic sections, providing data to global ocean/climate observing systems, including observations of physical oceanography, the carbon cycle, marine biogeochemistry and ecosystems. GO-SHIP provides approximately decadal resolution of the changes in inventories of heat, freshwater, carbon, oxygen, nutrients and transient tracers, covering the ocean basins from coast to coast and full depth (top to bottom), with global measurements of the highest required accuracy to detect these changes.

For the time period 2012–2023, 61 surveys are identified, most of them either completed or planned, while a few are yet to be confirmed (Figure 3.21). In March 2016, 44 cruises were confirmed. The different expeditions will be sponsored by at least 13 different countries: Australia (2), Canada (3), France/Spain (1), Germany (5), Ireland (1), Japan (9), Norway (2), South Africa (1), Spain (1), Sweden (1), UK (6) and USA (12).

3.5. Conclusions

Ocean science capacity, human and technical, depends on the financial support it receives. While Chapter 4 focuses more on the financial aspect, the analysis presented here in Chapter 3 gives a brief overview of infrastructure and some aspects of the currently available human resources (including gender information) for ocean science, national ocean science research institutions, related field stations, research vessels and some specialized technical infrastructure.

However, the data presented above can only give an approximation of the current situation and relies on the national reporting mechanisms in place. Technical capacity to prepare national inventories on ocean science capacity appear to be limited to a few countries only. The multidisciplinary nature of ocean science complicates such efforts. Future progress in this area depends heavily on the capacity of national, academic and federal capacities for marine research. Mapping technical and human capacities in ocean science are especially critical for SIDS, yet these statistics are not available due to constraints in the human, technical and financial resources required for generating this kind of information.

Between 28 and 30 countries, depending on the individual questions, submitted information regarding ocean science

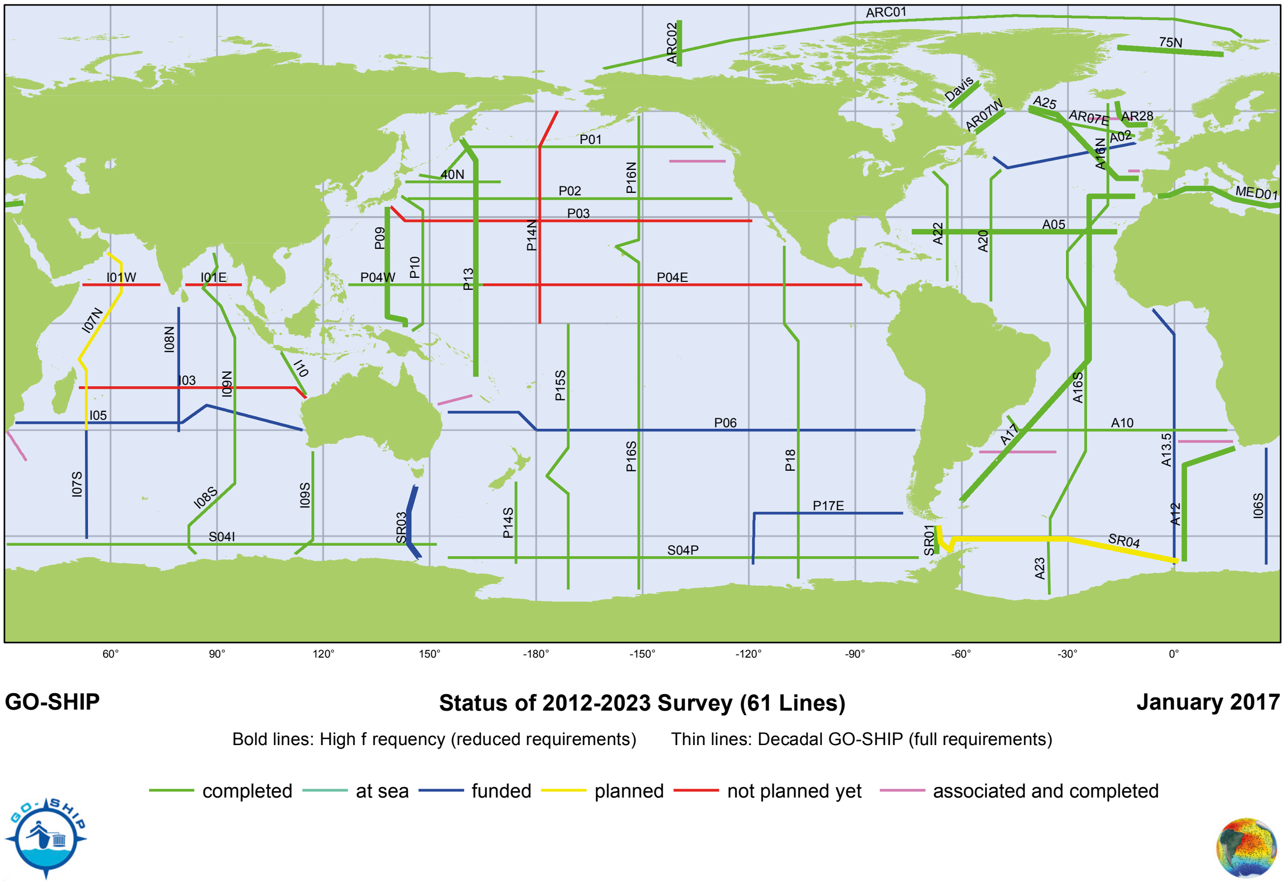


Figure 3.21. GO-SHIP Reference Sections (repeat hydrographic sections). *Source*: GO-SHIP, 2017.[21]

capacities via the GOSR questionnaire. In order to obtain a global overview, additional resources, including national and international reports and assessments, were consulted for the analysis.

Considerable differences exist in the total number of researchers per country. The counts differ by a factor of 1,000, clearly related to country size, length of coastline and economic importance of marine resources. However, calculations on the average number of marine scientists per million inhabitants also show high variations, with Norway having a strikingly high number with 364 researchers per million inhabitants, followed by Belgium with 74. The remaining countries only have between 1 and 33 researchers per million inhabitants. When looking at gender equality in ocean science, female scientists on average account for 38% of the researchers in ocean science, about ten percentage points higher than the global share of female researchers. However, the range across the different categories of ocean science stretches from 4% to more than 62% female participation, due to large regional differences as well as dissimilarities among the ocean science categories. Future compilations are envisaged to provide additional information regarding the education, skills, experience and professional level of human resources working in ocean science.

Without doubt, ocean science institutions and marine laboratories play a vital role in support of ocean research, including ocean observation. They are critical for several scientific questions, including studies of coastal food webs, ecosystem biodiversity and human impacts on coastal environments. Marine field stations and laboratories provide access to a range of environments, including coral reefs, estuaries, kelp forests, marshes, mangroves and urban coastlines. In total, the assessment

21 GO-SHIP http://www.go-ship.org/

presented here showed that there are 784 marine stations maintained by 98 countries.

Countries that invest in ocean science (Chapter 4) and publish in ocean science (Chapter 5) conduct their work mostly in highly specialized institutions. However, some of the countries that submitted information, via the GOSR questionnaire, about key governmental research institutions focusing on ocean science, listed a lower number of institutions than that obtained via the assessment of international conferences. The discrepancies might be the result of insufficient communication and reporting mechanisms between science and governmental institutions. The analysis of the countries' submission of numbers of ocean science facilities, when categorized in three groupings, showed the following results: general 'marine research' facilities comprise the highest percentage (54%), followed by observations (27%) and fisheries facilities (19%).

Continuous access to the open ocean, coastal zones and watersheds depends on novel infrastructure and technology, from sensors to research vessels to unmanned vehicles; 43% of research vessels in 29 countries are primarily operated for local and coastal research. The proportion of regional-scale research vessels (19%) is similar to that of international (18%) and global-scale research vessels (20%). However, it is not only the number of vessels which matters; the age of vessels is important to obtain a perspective of new investments supporting ocean science. Norway, Bahamas, Japan and Spain have the youngest research fleet with an average age of less than 25 years.

The development and deployment of new technologies and the expansion of ocean observation infrastructure is needed, such as ship-based time series, some of which provide data sets older than 50 years, including biological data sets or sustained hydrographic sections.

In summary, the human and technical capacities presented in this chapter complete the puzzle of ocean science, and each element is vital to advance and develop further. Human and technical capacity, together with long-term governmental and financial support, can create a favourable and productive environment for conducting ocean science. Such research helps the world to be better prepared to address challenges such as climate and ocean change and contribute to responsible and sustainable ocean management as a basis for a sound ocean economy.

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4

The funding for ocean science

4. The funding for ocean science

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4.1. Introduction

The ocean provides a broad range of services and goods. Scientifically based management actions will be required to guarantee that these benefits will be available to future generations. These actions include conservation and restoration of marine ecosystems, mitigation of human-induced stressors (e.g. climate change, ocean acidification, eutrophication, over-fishing) and adaptation to irreversible alteration of the coastal and open ocean. Eutrophication of marine waters, for example, already imposes high economic costs on commercial fisheries for some countries, such as the Republic of Korea and USA (OECD, 2012). Ocean science provides the basis to develop tools to address global challenges such as ensuring food security, demographic change (e.g. coastal constructions), global health and climate change. Given the breadth of challenges and beneficiaries, investment to enable knowledge-based decisions for the sustainable use of ocean resources will require a broad base, including different levels of government, private industry and local communities.

Sustained investment in research and development (R&D), including ocean research, remains essential to advance knowledge and to develop new technology needed to support modern economies. The ocean economy yields various benefits in terms of employment, revenues and innovation in many domains. Its current developments are largely based on decades of science and R&D investments by governments around the world. The OECD estimates, conservatively, that the output of the ocean economy was US$1.5 trillion (in value-added) in 2010 (OECD, 2016a), roughly equivalent to the size of the Canadian economy that same year. Under a business-as-usual scenario, the global ocean economy is projected to double in size by 2030 to reach a gross value added of around US$3 trillion, roughly equivalent to the size of the German economy in 2010 (OECD, 2016a). As another example, Australia's marine economy is projected to grow three times faster than Australia's gross domestic product until 2025 (AIMS, 2014).

Because of the many socio-economic domains benefitting from ocean science, financing a sustainable marine research infrastructure (Box 4.1) has become essential to address local, regional and global issues, e.g. ocean-climate interactions, ecosystem variability and tsunami-generating earthquakes and undersea landslides. Technical infrastructure also contributes to the training of students and early-career researchers, employs operators and technicians, and provides a platform for cooperation with private industry. Expenditures on ocean science are therefore also investments for the future as they are addressing important societal needs (JPI, 2014).

Funding for ocean science originates from a variety of sources, e.g. national, regional and international organizations, as well as directly or indirectly from the private sector, foundations, non-governmental organizations and even citizens via crowdsourcing. However, reporting mechanisms to obtain and compile funding on ocean science from all sources do not yet exist in most countries.

In this context, this chapter provides a general overview on funding sources and mechanisms for ocean science around the world. The first section discusses national expenditure on ocean science, with data from 29 countries, based on the first global endeavour to capture governmental funding of ocean science at national levels. The second section focuses on international/regional funding structures; the third section examines direct/indirect financial contributions to ocean science by the private sector, followed by a fourth section on philanthropic support for ocean science. The final section provides some forward-looking considerations.

4.2. National governmental funding for ocean science

National governmental funding for ocean science is usually part of the general expenditure for R&D. The OECD suggested that national governments will remain the main funders of public research for the foreseeable future (OECD, 2016a). Depending on national scientific priorities and research plans, the share that is invested in ocean science varies among countries and regions. The following analysis provides the results of the first international endeavour to capture governmental funding of ocean science at national levels. The information presented is based on the Global Ocean Science Report (GOSR) questionnaire (2015), which sought information on national expenditure on ocean science for the five-year time period 2009–2013. Based on the analysis of the questionnaire data received from 29 Member States, and despite some methodological and data collection constraints, some key trends in national investments in ocean science can be identified for the first time.

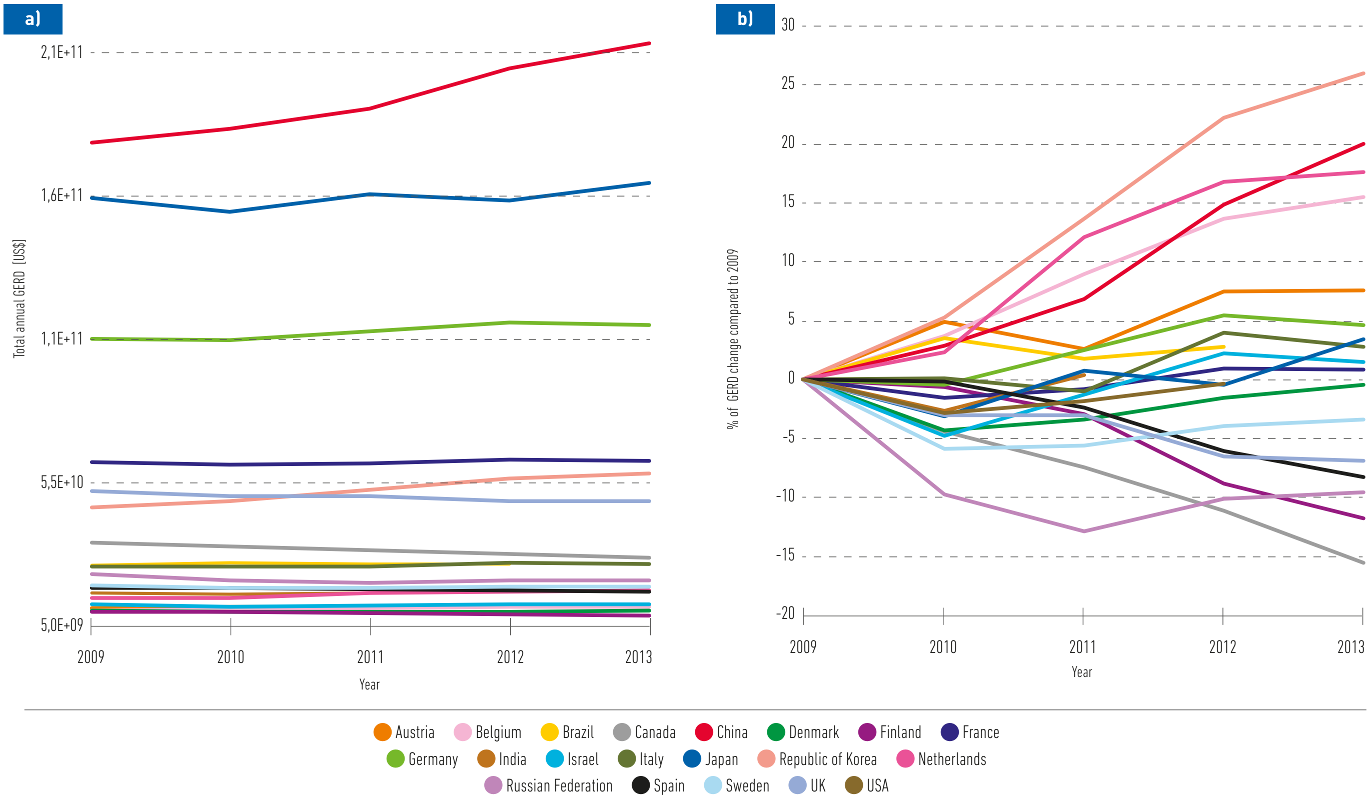

Figure 4.1. Changes in GERD 2009–2013 (US$): **a)** GERD of the top 20 countries with the highest financial support; **b)** % GERD of the top 20 countries with the highest financial support between 2009 and the respective year. *Source*: UIS, 2015.

From 2009 to 2013, year-on-year Gross Domestic Expenditure on R&D (GERD) showed great variability in several of the countries surveyed. While the Republic of Korea and China increased spending substantially (25%), countries such as Canada and Finland significantly decreased their national expenditure on R&D (Figure 4.1). Global R&D capacity has doubled in the last 15 years, a remarkable expansion driven by two important factors: 1) several emerging economies, such as China, have increased their R&D spending in past decades; and 2) industry expenditure on R&D has increased at a rate exceeding that of public R&D expenditure. Nonetheless, the challenges of slower economic growth and ageing populations will place considerable pressure on public spending in many countries over the next 10 to 15 years, with competition for resources from other sectors, such as health and pensions (OECD, 2016a). Indeed, the most recent data show the GERD decreasing as a proportion of overall Gross Domestic Product (GDP) in many OECD countries,[1] possibly a reaction of governments to pursue post global-financial-crisis austerity policies. Cutting national R&D expenditure is often seen as an easy way to make savings in difficult times. However, there is clear evidence that investment in R&D should be part of any national strategy for economic growth and job creation (AIMS, 2014; OECD, 2016a).

Long-term datasets on governmental funding of ocean science are not available for most countries. Gathering such data is fraught with difficulty, firstly because ocean science is rarely administered by a single government office or agency, responsibilities are often split among different sectors (e.g. fisheries, maritime/navigation and naval research, environment), and secondly because funding for ocean science might not be consistently categorized as such. Nevertheless, the data submitted through the GOSR questionnaire provide some information about the national resources dedicated to marine research. Notably, of the 29 countries that answered the questions related to national governmental financial resources allocated for ocean science, 8 are among of the top 10 publishing countries in ocean science (Chapter 5). Some of those countries that responded reported that there were no national funding strategies or resources for ocean science.

1 UIS, 2015

Based on results of the GOSR questionnaire, Figure 4.2a illustrates the annual expenditure of the 29 countries on ocean science from 2009 to 2013. For many countries, this was the first time the requested data were compiled. Given the novelty of this exercise, the information presented is not complete for all five years and does not always reflect the total national expenditure on marine research. For example, Germany provided a rough estimate for 2013, while Canada and Spain submitted the core funding allocated to their respective national oceanographic institutes DFO (Fisheries and Oceans Canada) and IEO (Spanish Institute of Oceanography, Spain).

Some countries, such as Norway, Turkey and Italy increased their funding for ocean science between 2009 and 2013; others, including Australia and Spain, reduced the national governmental funding significantly. In general, it appears that trends in GERD diverge little by country, whereas there was significant variation in expenditure for ocean science in some countries, e.g. Chile, Argentina and Japan (Figure 4.1b, Figure 4.2b). The available data indicate that 16 countries increased ocean science funding from 2009 to 2013, compared to 7 countries that decreased their support.

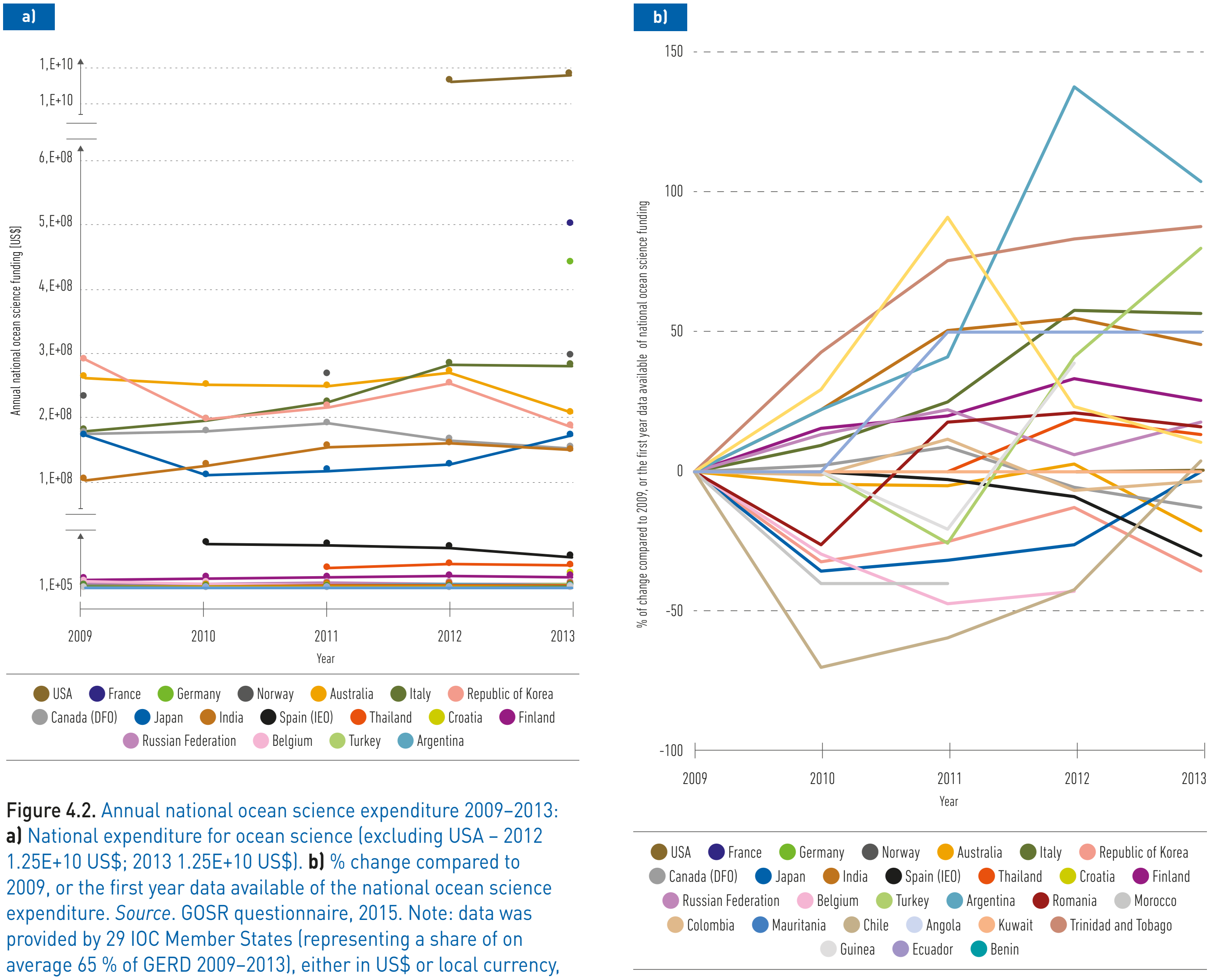

Figure 4.2. Annual national ocean science expenditure 2009–2013: **a)** National expenditure for ocean science (excluding USA – 2012 1.25E+10 US$; 2013 1.25E+10 US$). **b)** % change compared to 2009, or the first year data available of the national ocean science expenditure. *Source*. GOSR questionnaire, 2015. Note: data was provided by 29 IOC Member States (representing a share of on average 65 % of GERD 2009–2013), either in US$ or local currency, subsequently converted in US$ using exchange rates of May 2016.

Table 4.1. Average annual national expenditure 2009–2013 on natural science and ocean science, and annual ocean science expenditure as a percentage of annual natural science expenditure. Note: includes countries that provided data to the GOSR questionnaire and for which natural science funding data was also available. *Sources*: ocean science data: GOSR questionnaire, 2015; natural science data: UIS, 2015.

	Average annual national expenditure (2009–2013) natural science (US$ million)	Average annual national expenditure (2009–2013) ocean science (US$ million)	Average annual ocean science expenditure (% natural science expenditure)
Argentina	22.2	4.76	21.4
Croatia	159	22.0	13.9
Thailand	611	35.1	5.8
Trinidad and Tobago	5.3	0.27	5.1
Republic of Korea	7 720	228	3.0
Colombia	159	3.13	2.0
Romania	400	4.60	1.1
Chile	314	2.16	0.7
Kuwait	58.2	0.3	0.5
Turkey	1 250	4.83	0.4
Ecuador	65.5	0.13	0.2
Russian Federation	6 900	7.7	0.1
Average			**4.51 (± 6.62)**

Note: Data submitted via the GOSR questionnaire (2015) were either in US$ or local currency, subsequently converted in US$ using current exchange rates as of May 2016.

Few data about natural science funding were obtained to allow a comparison between total expenditure on natural science and ocean science. However, Table 4.1 shows that, where data are available, an average 4.5% of natural science funding was dedicated to ocean science, ranging from 0.1% in the Russian Federation up to 2% in Argentina. Unfortunately, data on natural science funding for countries that reported high national ocean science budgets, such as USA, France and Germany, are currently not available. For a more extensive and complete comparison, the GERD was used in Table 4.2.

Table 4.2 presents the percentage of national GDP allocated for R&D (2009–2013) and the percentage of R&D allocated to ocean science (2009–2013). The data illustrate that for many of the countries surveyed, R&D as a percentage of GDP was relatively high. However, only a few countries devote a high proportion of these funds to ocean science: Croatia, Norway, Thailand, Trinidad and Tobago, and USA. Science in general, and presumably ocean science as a subset of it, relies heavily on financial support not included in the national R&D expenditures.

Previous studies have shown that for the Group of 20 (G20)[2] the GERD was on average 2.04% of GDP in 2001; of this, 0.65% was spent by governments, 1.26% by the private sector and 0.13% by other sources (Steele, 2013).

National ocean science expenditures accounted for between < 0.04% and > 4% of GERD from 2009 to 2013 (Table 4.2, Figure 4.3), among the countries that responded to the GOSR questionnaire. For some countries, such as Norway, Italy and Turkey, a positive trend can be detected, indicating that an increasing amount of national R&D funding was allocated for ocean science from 2009 to 2013.

Some countries provided additional information about international and regional funding for ocean science (Figure 4.4). In general, national funding was responsible for more than 70% of the total budget for ocean science; only the Republic of Korea, Turkey and Chile indicated that international and regional funding accounted for higher percentages of the annual budget in certain years.

2 G20 members – Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russian Federation, Saudi Arabia, South Africa, Turkey, *UK* and USA, along with the European Union (EU).

Table 4.2. Percentage GERD of national GDP and percentage national ocean science expenditure of GERD for countries that provided information regarding ocean science expenditure via the GOSR questionnaire. *Sources*: UIS (GERD, GDP), 2015; GOSR questionnaire (ocean science), 2015, average non-weighted. Note: blue fields indicate a percentage higher than 1.5 and grey fields indicate percentages higher than 0.5.

	Percentage (%) GERD of GDP						Percentage (%) Ocean science expenditure of GERD					
Country	Average 2009-2013	2009	2010	2011	2012	2013	Average 2009–2013	2009	2010	2011	2012	2013
Argentina	0.52	0.48	0.49	0.52	0.58		0.16	0.11	0.14	0.15	0.23	
Australia	2.32		2.39	2.25			0.74		0.72	0.76		
Belgium	2.14	1.97	2.05	2.15	2.24	2.28	0.07	0.10	0.07	0.05	0.05	
Canada (DFO)	1.77	1.92	1.84	1.78	1.71	1.62	0.54	0.51	0.54	0.60	0.54	0.53
Chile	0.35	0.35	0.33	0.35	0.36		0.20	0.36	0.11	0.15	0.20	
Colombia	0.22	0.21	0.21	0.22	0.22	0.23	0.39	0.40	0.39	0.43	0.36	0.35
Croatia	0.78	0.84	0.74	0.75	0.75	0.81						4.73
Ecuador	0.38	0.39	0.40	0.34			0.03	0.02	0.03	0.05		
Finland	3.57	3.75	3.73	3.64	3.42	3.31	0.14	0.14	0.16	0.00	0.20	0.20
France	2.21	2.21	2.18	2.19	2.23	2.23						0.79
Germany	2.79	2.73	2.72	2.80	2.88	2.85						0.40
India	0.81	0.82	0.80	0.82			0.77	0.61	0.77	0.92		
Italy	1.24	1.22	1.22	1.21	1.27	1.26	0.88	0.69	0.75	0.87	1.04	1.04
Japan	3.36	3.36	3.25	3.38	3.34	3.47	0.09	0.11	0.07	0.08	0.08	0.11
Kuwait	0.14	0.11	0.10	0.10	0.10	0.30	0.16	0.16	0.18	0.19	0.19	0.06
Morocco			0.73						0.37			
Norway	1.66	1.72	1.65	1.63	1.62	1.66	3.18	2.69		3.28		3.58
Republic of Korea	3.74	3.29	3.47	3.74	4.03	4.15	0.44	0.62	0.40	0.41	0.44	0.32
Romania	0.46	0.47	0.46	0.50	0.49	0.39	0.50	0.47	0.35	0.51	0.54	0.65
Russian Federation	1.15	1.25	1.13	1.09	1.13	1.13	0.04	0.03	0.04	0.04	0.03	0.04
Spain (IEO)	1.31	1.35	1.35	1.32	1.27	1.24	0.28		0.37	0.37	0.36	0.28
Thailand	0.32	0.25		0.39						2.02		
Trinidad and Tobago	0.05	0.06	0.05	0.04	0.05		1.81	1.03	1.63	2.36	2.20	
Turkey	0.88	0.85	0.84	0.86	0.92	0.94	0.07		0.06	0.04	0.07	0.09
USA	2.78	2.82	2.74	2.77	2.81						2.55	

Note: Data for ocean science expenditure for Canada are only referring to expenditures devoted to the department of Fisheries and Oceans Canada (DFO) and data for Spain only reflect the national funds received by the Spanish Institute for Oceanography (IEO).

Currently, no information exists about the involvement of the private/business sector in terms of ocean science funding at the national level. From 2009 to 2013, the average GERD was 1.64%; however this varies widely across the world, with highest values in North America and Western Europe (2.39%) and low values in Central Asia (0.22%) as well as in the Arabic countries (0.26%).[3]

Previous assessments indicate that approximately 3% of R&D overall is funded by international organizations or foreign sources (Steele, 2013), much lower than what was obtained for some countries with regard to ocean science (average 8%; Figure 4.4).

3 Source: UIS,2015

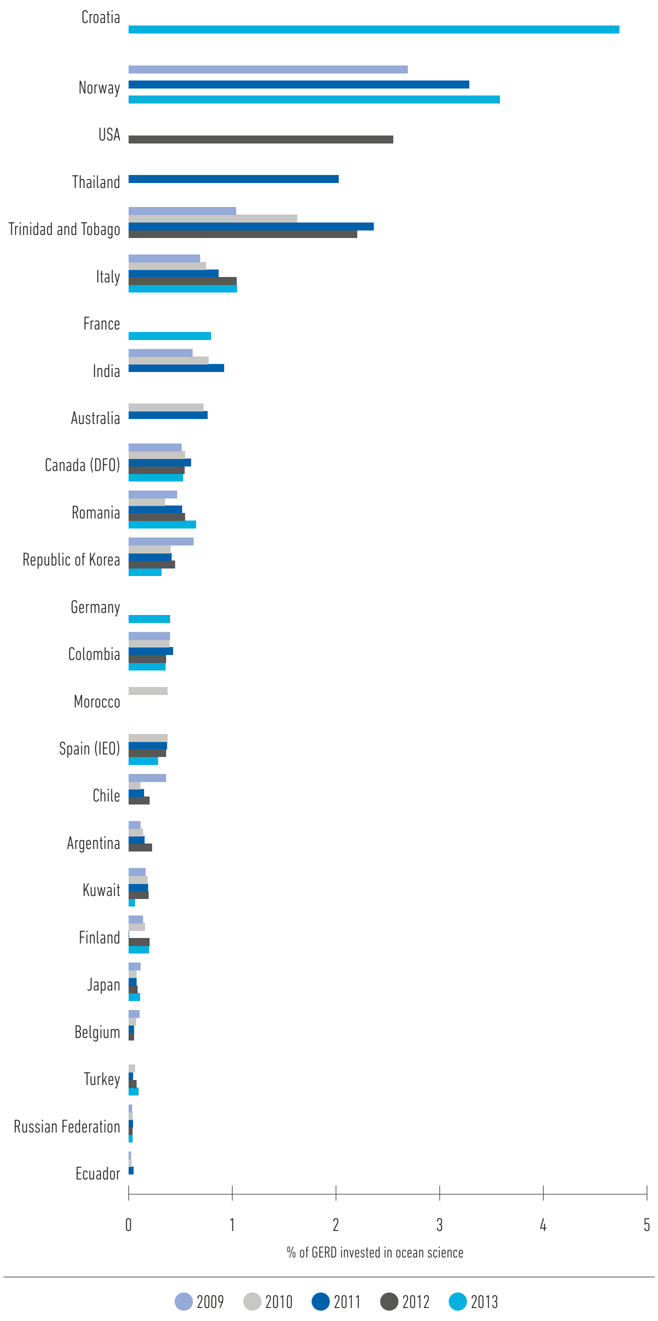

Figure 4.3. Percentage of national R&D expenditures invested in ocean science. Data from 25 countries that answered the GOSR questionnaire (Table 4.2). *Sources*: GOSR questionnaire (ocean science), 2015; UIS (R&D), 2015.

4.3. International/regional funding mechanisms used for ocean science

Different aspects of ocean science receive different levels of support by national, regional and international funding mechanisms. Funding varies over time and is often highly dependent on socio-economic needs, e.g. to inform management decisions. This section provides some insights into sources of funding for ocean science programmes at the international and regional levels. The analysis, while not comprehensive, show-cases examples, focusing on past European structural funds (Box 4.2) and funds provided by the Global Environment Facility (GEF) (Box 4.3). In general, these types of funds are restricted either by scope (e.g. fisheries, observation, capacity development), region or beneficiary (e.g. developing countries).

Structural funds are allocated in the European Commission to Member States or regions according to their average income per capita (European Commission, 2013). The decisions to allocate these funds to programmes/projects are taken by the Member States and regions themselves. The European Commission aims to reduce regional disparities in income, wealth and opportunities; Europe's poorer regions receive most of the support, but all European regions are eligible for European Regional Development funding (ERDF). The current regional policy framework is set for a period of seven years, from 2014 to 2020. A study commissioned by the European Commission has shown that many marine research infrastructures across Europe have been co-funded by structural funds in the past, in particular by the ERDF (European Commission, 2013). The European Maritime and Fisheries Fund (EMFF) 2014—2020 amounts to €6.4 billion; 11% of the EMFF budget is managed by the European Commission directly and 89% is administered by Member States in the framework of operational programmes. Under the current European Union (EU) Multi-Annual Financial Framework, the EU invests €70 million annually to support the Data Collection Framework, the EU-wide programme to collect fisheries data to underpin the long-term management of fisheries. This involves the understanding and monitoring of commercial species, dynamics of single stocks and mixed fisheries, and ecological modelling of regional basins. Another €71 million is earmarked to support implementation of the EU Blue Growth Strategy, designed to stimulate sustainable growth and job creation from seas and oceans, in areas such as maritime surveillance, improved knowledge of the seas and ecosystems, and enabling rational exploitation of new marine resources (e.g. energy, biotech) (European Structural and Investment Funds, 2015).

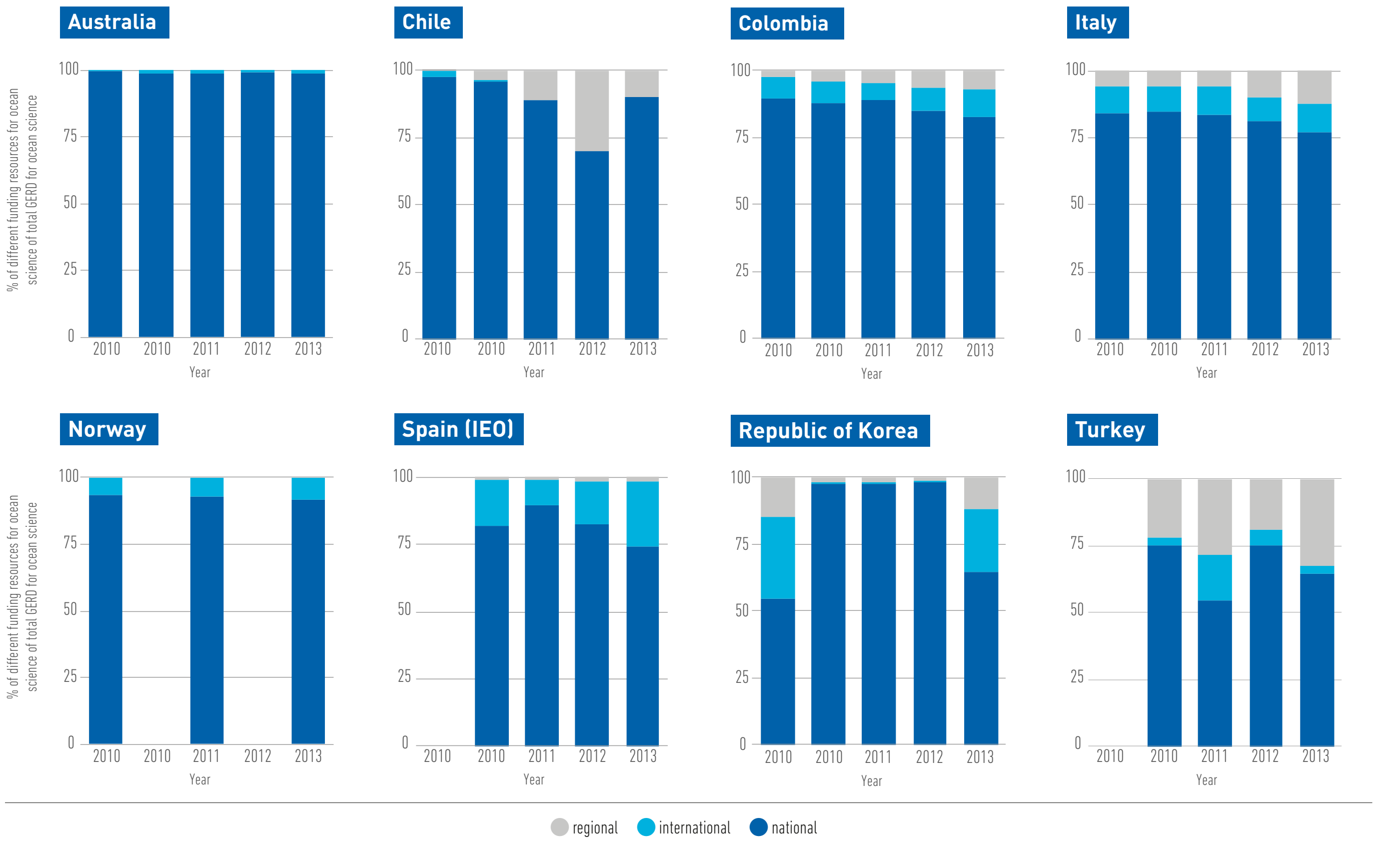

Figure 4.4. Proportion of regional, international and national funding resources for ocean science (2009-2013) for selected countries. *Source*: GOSR questionnaire, 2015.

Another type of structural fund supporting ocean science is provided by the GEF, established on the eve of the 1992 Rio Earth Summit. Through its strategic investments, the GEF aims to address the planet's biggest environmental issues. GEF is a partnership of agencies, including United Nations agencies, multilateral development banks, national entities and international NGOs. It is a financial mechanism for five major international environmental conventions: the *2013 Minamata Convention on Mercury*, the *2001 Stockholm Convention on Persistent Organic Pollutants* (POPs), the *1994 United Nations Convention to Combat Desertification* (UNCCD), the *1992 United Nations Convention on Biological Diversity* (CBD), and the *1992 United Nations Framework Convention on Climate Change* (UNFCCC). Its portfolio includes projects related to the preservation of threatened ecosystems in the ocean. The GEF funding mechanism is based on co-financing, which has resulted in an additional US$5.2 for every US$1 invested.[4]

Since its inception, GEF investments in the 'International Waters' focal area have surpassed US$1.15 billion. These funds have leveraged another US$7.7 billion from partners for marine-related projects and programmes. This investment has contributed to various marine environmental outcomes, including the creation of 4.1 million km^2 of marine protected areas. However, it is important to note that GEF investments can only be received by developing countries; developed countries are not eligible to receive financial support from GEF.

Science is an integral part of GEF projects, making it difficult to attribute the proportion of financial support of the total budget towards research-related activities. However, GEF is not itself a research programme and only funds research where it supports improved environmental management, mainly focused on developing countries (Cabanban and Mee, 2012).

4 Global Environment Facility (GEF). https://www.thegef.org

Box 4.1. Investments in national research vessel fleets

Several studies have documented the high investment required for marine infrastructure (in particular ships and marine observing platforms), including operations and maintenance, representing on average between 40% and 50% of the total funding for ocean science (JPI, 2011; Stemmerik, 2003). It was estimated that in the European Union, half of the national budgets for marine science are spent on operating and replacing marine infrastructure assets (European Science Foundation, 2007). This is becoming more and more challenging for agencies that support shipborne science, ship-operating institutions, and sea-going scientists, as the costs of operating and maintaining research vessels are constantly increasing (European Science Foundation, 2007; NRC, 2015).

Higher ship costs will almost certainly force significant changes in the size of the academic research fleet, as well as the use and scheduling of research ships. This issue has been raised by numerous committees, e.g. by University-National Oceanographic Laboratory System (UNOLS) of the United States, federal agencies and their advisory boards, and independent commissions (e.g. US Commission on Ocean Policy, 2004; Betzer *et al.*, 2005; McNutt *et al.*, 2005; Collins *et al.*, 2006; UNOLS, 2009; NRC, 2015).

The primary expenses of research ship operation are crew costs, fuel costs, maintenance and overhaul, technical and shore support, and consumables. As an example, for the UNOLS fleet between 2000 and 2008 (Figure 4.5.) crew and fuel costs were the two largest components of total research vessel operating costs, accounting for approximately 50% of total operating costs in this period (UNOLS, 2009).

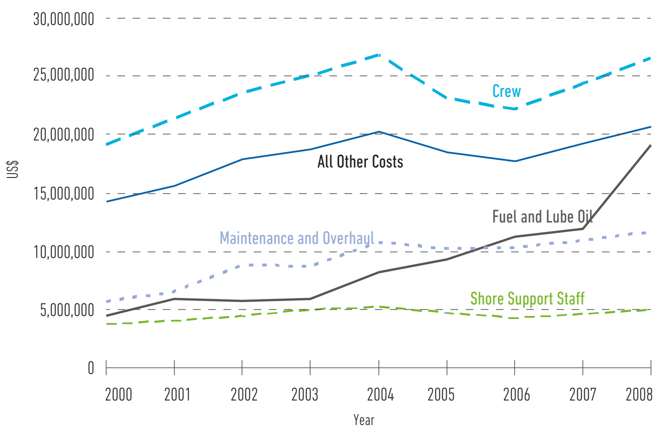

Figure 4.5. Major cost factors for the UNOLS fleet for the time period 2000–2008. The category of 'All other costs' includes food, insurance, equipment and supplies, travel, shore facility support, indirect costs, and miscellaneous costs. *Source*: UNOLS, 2009.

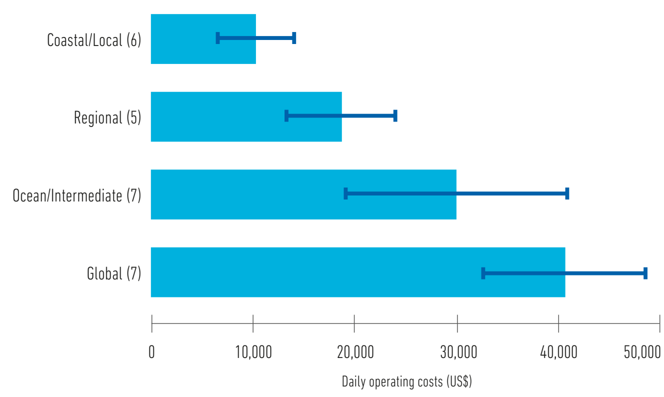

Figure 4.6. The average daily operating rate by UNOLS class, 2015. The number of ships in each class is in parentheses after the class name. *Source*: NRC, 2015.

Ship-dependent sampling, measurements and experiments are key components of ocean research, but other platforms and advancements in autonomous and remote sensing technology contribute significantly to the exploration of the many domains of ocean science (Chapter 6; Wynn *et al.*, 2014). This trend is expected to accelerate in order to get more data for less investment.

Ship data were not available from other countries at this time. Satellites are also an important infrastructure investment for ocean science, but gathering data on investment in satellites was beyond the scope of this report.

Depending on its size and area of investigations, a research vessel used for open ocean research costs between US$2.2 million and US$40 million (e.g. icebreaker vessel) per year (European Science Foundation, 2007; Stemmerik, 2003). Figure 4.6 illustrates the variation in the daily operating rate among global, ocean/intermediate, regional and coastal/local ships. The high daily operating rates for the global –and ocean – class ships indicate the substantial research funding required to undertake large oceanographic expeditions, especially for research beyond the coastal seas in the major ocean basins.

In general, the use of a research vessel requires a grant (for example, in the USA this may be funded by the National Science Foundation, NSF) to support the salaries, supplies, travel and equipment required to conduct science. It was reported that often projects require ship time but do not include it in the budget (NRC, 2015).

Box 4.2. European fisheries research

Science and technology can contribute in important ways to sustainable fisheries through the identification and monitoring of wild fish populations and traceability of fish and fish products. In recent years, some noteworthy innovations have been achieved in this respect, which have the potential to revolutionize wild fish stock management and make serious inroads into prosecuting and preventing illegal, unreported and unregulated (IUU) fishing activities (OECD, 2016b).This case study examines the important role that successive EU Framework Programmes (FPs) for Science and Technology have played in supporting fisheries research.

EU investment in fisheries research throughout the FPs steadily increased between FP2 and FP7, covering the period from 1988 to 2013 (Table 4.3). However, there was a notable reduction in funding for fisheries research under the FP7 programme (2007–2013). Fisheries research under FP7 received the lowest level of (0.21 %) relative to the total programme funding for any of the FPs. This was also reflected in the number of projects funded, which increased from FP3 to FP6, and declined again during FP7. The average investment per project slightly decreased from FP3 to FP4, remained almost unchanged in FP5 and FP6, and increased in FP7, thus suggesting larger research projects. Indeed, on average, FP7 fisheries research projects were more than twice the size of those in FP4 (Rodriguez, 2014).

It is possible to classify the EU FPs fisheries research projects according to the fisheries research area to which they most closely belong, depending on the main objective of the research project in question. Rodríguez (2014) used a six-part classification for fisheries projects based on a previous scheme by the FAO Advisory Committee on Fishery Research (FAO, 2002), as follows: fisheries management, interaction with the environment, fish biology, socio-economy and fisheries policy, fisheries technology and research infrastructures. Figure 4.7 illustrates the increased importance of socio-economic and fisheries policy projects and the reduced number of projects focusing on fisheries technology and fish biology from 1988 to 2013, indicating the societal shift to sustained utilization of natural resources.

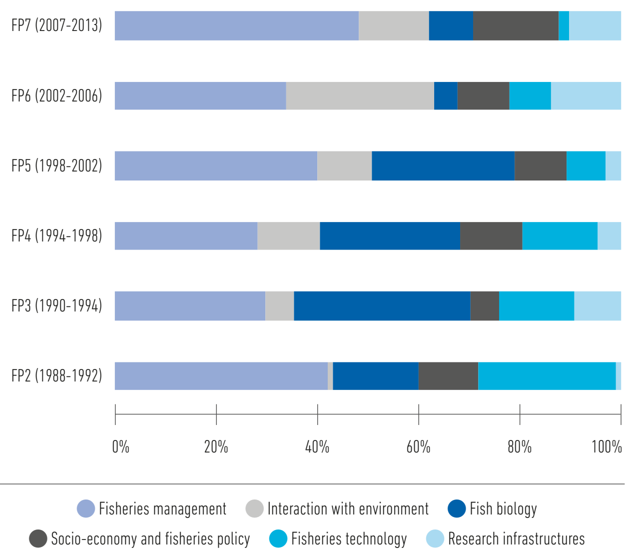

Figure 4.7. Proportion of main research areas of conducted EU Framework Programmes fisheries research projects (1988–2013). *Source*: Rodriguez, 2014.

Table 4.3. Budget allocation for EU fisheries research projects under FP2-FP7. *Source*: Rodriguez, 2014.

Framework Programme (FP)	EU FP research budget (€ millions)	EU fisheries research budget (€ millions)	% allocated to fisheries research	Annual allocation (€ millions)	Nº of fisheries projects	Average project duration (months)	Average project cost (€ millions)
FP2 (1988-1992)	5 357	15.14	0.28	3.03	65	27	0.23
FP3 (1990-1994)	6 600	22.76	0.34	4.55	30	31	0.76
FP4 (1994-1998)	13 100	48.16	0.37	9.63	67	34	0.72
FP5 (1998-2002)	14 960	76.17	0.51	15.23	63	36	1.21
FP6 (2002-2006)	17 500	92.49	0.53	18. 50	71	35	1.30
FP7 (2007-2013)	50 521	107.131	0.21	15.30	63	35	1.70
Total (1988-2013)	**108 038**	**361.79**	**0.33 (average)**	**14.47 (average)**	**359**	**33 (average)**	**1.01 (average)**

Box 4.3. Large Marine Ecosystems

GEF funding contributes to advance ocean science, particularly to identify knowledge gaps and to propose measures on how to address these gaps through international and regional collaboration. For example:

- The global ocean has been conceptually divided into 66 large marine ecosystems (LMEs), near-coastal areas where primary productivity is generally higher than in open ocean areas. To date, the GEF has supported projects aiming to contribute to sustainable governance of 23 LMEs in which multiple countries collaborate on strategic, long-term ocean governance of transboundary resources, including science.
- As of the end of 2016, the International Waters focal area has invested US$285 million, leveraging US$1.14 billion in financing from other partners in LMEs (GEF secretariat, 2016).
- The funding strategy for the future includes support of priority actions and investments within regional policy frameworks, in order to explore the potential of the ocean economy, including blue carbon restoration, marine spatial planning and economic valuation (GEF secretariat, 2016).

4.4. Funding of ocean science by the private sector: possible synergies

The private sector can act as a beneficiary of ocean science and can also contribute to directly fund relevant scientific and R&D programmes. As users and beneficiaries of ocean science, many marine industries use marine environmental data. This is the case for established industries like oil and gas industries, shipping companies, as well as newer high-growth industries like offshore wind generation and aquaculture, which invest considerable amounts in environmental impact and risk assessments (European Commission, 2013) and also generate and use marine data. A distinction should be made, however, between mature industries (e.g. oil and gas, shipping), and new industries. The offshore wind industry, in particular, is expected to invest hundreds of billions of dollars in the coming decades and is in strong need of marine data to reduce the risks and enhance the value of these investments. It is important that service and equipment providers are engaged at the outset of research planning and consideration should be given to market development where the private sector and other parts of the public sector do not yet have a strong role (McAleese *et al.*, 2013).

Box 4.4. Sir Alister Hardy Foundation for Ocean Science – combining national and private funding sources

In some cases, private funding can support ocean research. One example is the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), the international charity that operates the Continuous Plankton Recorder (CPR) Survey. The CPR is a plankton-sampling instrument designed to be towed from merchant ships on their normal routes. SAHFOS therefore relies heavily on the cooperation with 'ships of opportunity' utilizing both volunteer commercial and research vessels (26 ships in 2013) to collect measurements related to physical, chemical and biological oceanography and ecology through this programme.

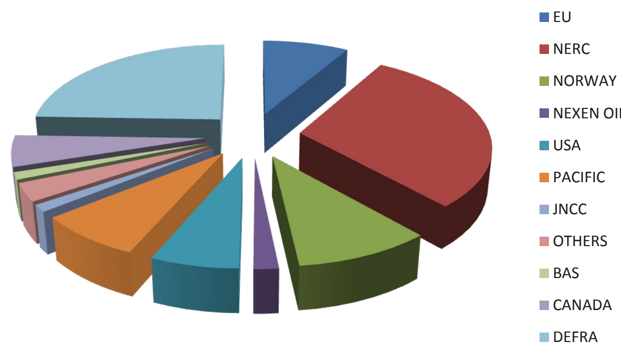

Figure 4.8. Principal sources of funding for SAHFOS in 2014.
Source: Johns and Brice (eds), 2015.

SAHFOS has been collecting data from the North Atlantic and the North Sea on biogeography and ecology of plankton since 1931 and more recently has expanded its work in other parts of the global ocean. While in the early times this foundation started with private funding, the work of SAHFOS, in addition to 'in-kind' funding of the ships of opportunity, is supported with direct funding from: UK Natural Environment Research Council (NERC), UK Department of Environment, Food and Rural Affairs (DEFRA), USA National Science Foundation (NSF), as well as *seven* other organizations* and companies including the Exxon Valdez Oil Spill Trust and Nexen Oil in 2014 (Figure 4.8). The total funding sources for 2014 were reported at GBP 1,558,537 (GBP 2,141,088 in 2013; GBP 1,758,543 in 2012) (Johns and Brice *(eds)*, 2014, 2015). Note: British Antarctic Survey, European Union, European Environment Agency, Dept of Fisheries *and* Oceans Canada, Institute of Marine Research Norway, Joint Nature Conservation Committee, North Pacific Research Board.

An example of 'in-kind' support provided by the private sector is that of the so-called 'ships of opportunity'. These are commercial vessels making regular transits on the ocean, which collect scientific data. As chartered research vessels are expensive and cruises are time-consuming, the use of volunteer vessels as well as oceanographic samplers while underway is a cost-effective way to cover vast areas of the ocean. Data collection from ships of opportunity, mounted with observation equipment, repeatedly traversing sailing routes contributes to the scientific knowledge of the ocean by increasing the coverage, frequency and repeatability of sampling and routine observations.

Examples include:

- the Sir Alister Hardy Foundation for Ocean Science (Box 4.4);
- automated instrument packages on ships of opportunity routes (Ferrybox) in the North and Baltic Sea as part of EuroGOOS; and
- the Ocean Exploration Trust, founded in 2008 by Dr Robert Ballard to engage in pure ocean exploration; many of its scientific expeditions are launched from its 64 m research exploration vessel (E/V) *Nautilus*.

4.5. Philanthropy: non-profit and private foundations/organizations

Philanthropy – the desire to promote the welfare of others, expressed especially by the generous donation of money to good causes – is becoming an increasingly important source of revenue to advance science. The awe-inspiring scale and beauty of the ocean can help attract philanthropic funding to support ocean science. Some specialist foundations focus on technology innovation to advance existing key oceanographic technologies, and to enable open and effective sharing of new technologies, scientific information and research outcomes among academic and broader communities worldwide. Foundations and philanthropies can augment national investments and stimulate new initiatives. Although public funding remains the dominant source of research funding, it is unclear how far or fast that balance might shift in the future or what a shifting balance may mean. Previous studies are rare, supporting the conclusion that a comprehensive assessment of the magnitude and impact of privately funded science, particularly ocean science, is needed, as public funding sources decline (Spring *et al.*, 2014).

The following examples of foundations that support ocean science not only stress the increasing importance of alternative funding sources, given highly competitive national science budgets, they also illustrate how investments in ocean science made by foundations have resulted in ground-breaking research, catalysed new collaborations and additional resources, and opened opportunities for long-term funding and projects in the past. Though the initial financial support is low compared to governmental expenditures (Figure 4.6), the value of this support is often leveraged by funding from other sources.

4.5.1. The David and Lucile Packard Foundation

Within its Conservation and Science programme, the Packard Foundation includes an ocean programme, which contains financial support for the Monterey Bay Aquarium Research Institute (MBARI) (Table 4.4).[5] MBARI is a not-for-profit organization conducting scientific research in marine biology, oceanography, underwater geology and other kinds of marine research and technology development, and educating the scientific community and the general public in regard to such research. In total, the Packard Foundation has invested more than US$1.6 billion in ocean science over the past 50 years, with the aim to close knowledge gaps and improve ocean health.

Table 4.4. Direct charitable expenses and programme operating expenses of MBARI (US$) donated by the Packard Foundation. *Source*: Packard Foundation.[5]

Year	2009	2010	2011	2012	2013	2014	2015
US$	50 189	52 162	53 229	52 554	51 404	50 336	51 861

4.5.2. The Gordon and Betty Moore Foundation

The Gordon and Betty Moore Foundation's Science Program seeks to advance basic science through developing new technologies, supporting research scientists and creating new collaborations at the frontiers of traditional scientific disciplines. One ocean science activity, the Marine Microbiology Initiative (MMI), seeks to gain a comprehensive understanding of marine microbial communities, including: their ecological roles in the oceans; their diversity, functions and behaviours; and their origins and evolution.[6] Since 2004, more than US$225 million has been spent within the framework of the MMI. Another area of high importance for the foundation is environmental conservation, more than US$250 million has been invested in a programme focusing on marine conservation supported projects and working groups since 2004.

5 David and Lucile Packard Foundation: https://www.packard.org/

6 Gordon and Betty Moore Foundation https://www.moore.org

4

4.5.3. Alfred P. Sloan Foundation

The Alfred P. Sloan Foundation committed US$78 million to support the Census of Marine Life, an international programme (1999 to 2010) to assess the diversity, distribution and abundance of marine life. The foundation supported 14 Census of Marine Life field projects, helped to assess current marine populations, created a network to predict the future of marine animal populations, developed the Ocean Biogeographical Information System (containing tens of million records on hundreds of thousands of marine species), and supported the Census's International Scientific Steering Committee and Secretariat, the US National Committee, and an Education and Outreach Network to increase the project's visibility and engage other nations and organizations. Two thousand seven hundred (2,700) scientists from more than 80 nations participated in the programme.[7]

The Ocean Biogeographic Information System (OBIS) was created as the data integration component of the Census of Marine Life.[8] OBIS has grown beyond its original scope and now integrates data from many sources, over a wide range of marine themes, from poles to the equator, from microbes to whales. It is now the world's largest online repository of geo-referenced biodiversity data. At its 2009 Assembly, the Intergovernmental Oceanographic Commission of UNESCO adopted OBIS as one of its programmes under the International Oceanographic Data and Information Exchange (IODE). With the support of policy makers and the nations it serves, OBIS continues to grow and thrive under IODE, remaining a permanent legacy of the Census of Marine Life collaboration (Chapter 6).

4.5.4. The Schmidt Family Foundation

The Schmidt Family Foundation works to advance the development of clean energy and support wiser use of natural resources. Within this framework, the Schmidt Ocean Institute was founded in 2009, providing opportunities for ocean science studies aboard the RV *Falkor* oceanographic research vessel. The Schmidt Family Foundation also supports the XPRIZE Foundation, which awarded The Wendy Schmidt Ocean Health XPRIZE, a US$2 million global competition that in 2015 challenged teams of engineers, scientists and innovators from all over the world to create new improved affordable pH sensor technology. Currently, the foundation is supporting the US$7 million Shell Ocean Discovery XPRIZE, inviting teams to advance deep-sea technologies for autonomous, fast and high-resolution ocean exploration.[9]

7 Alfred P. Sloan Foundation https://sloan.org/

8 OBIS http://www.iobis.org/

4.5.5. Prince Albert II of Monaco Foundation

In June 2006, HSH Prince Albert II of Monaco established a foundation with the objective to support the protection of the environment and the promotion of sustainable development, focusing on the Mediterranean basin, Polar Regions and Least Developed Countries. Since its establishment, 368 projects have been supported by the foundation with a total of €37.3 million. In 2015, the foundation committed €6.8 million to 27 projects; of this amount, €1.22 million (18%) was allocated to ocean science projects addressing issues such as ocean acidification and developing marine protected areas (Prince Albert II of Monaco Foundation, 2015).

4.6. Looking ahead

Ocean science relies on sustained funding, international collaboration and support from a variety of funding sources. The GOSR is the first global endeavour to capture governmental funding of ocean science at national levels. This first-ever assessment includes the contributions of 29 countries that responded to the GOSR questionnaire (2015) submitting information for the time period 2009–2013. Despite methodological and data collection constraints, some key trends in ocean science were identified.

Based on the results of the GOSR questionnaire, government funding for ocean science remains modest. Ocean science funding, as a share of national R&D funding, varies widely between countries from < 0.04% to 4%. Countries with the largest dedicated ocean science budget include USA, Australia, Germany, France and the Republic of Korea. Ocean science, like other scientific and R&D domains, is facing increased sustainability challenges in many countries. When examining trends over five years (2009–2013), ocean science funding has fluctuated by more than 50% in some countries (e.g. Argentina, Chile and Japan).

A growing number of commercial actors from diverse maritime sectors (e.g. oil and gas, offshore wind, aquaculture) have become direct and indirect beneficiaries of ocean R&D and

9 Ocean Discovery XPRIZE http://oceandiscovery.xprize.org/

observing programmes. In some countries, there may be potential to increase private investment in dedicated ocean research programmes (e.g. PhDs and postdoctoral researcher positions supported by private grants). As other sources of funding, non-profit institutions (including foundations and crowdfunding) are becoming new mechanisms to fund selected ocean science programmes. However, these sources remain negligible in most countries, with the bulk of funding for researchers still relying on grants from government agencies.

Looking ahead, pressures on public budgets for science and R&D may intensify in some countries, with implications for ocean science funding. To secure long-term institutional support, as well as to diversify sources of funding, ocean scientists may need to increasingly demonstrate the high and long-term societal and economic value of investing in ocean research. The ocean economy is already bringing many benefits in terms of employment, revenues and innovation across many domains. Its current development is based on decades of R&D investment by governments around the world. To ensure future environmental sustainability and economic growth, continuous ocean research supported by long-term public and private funding will need to be secured.

This chapter gives baseline information on ocean science funding that can be used as a starting point for more directed, tailored investment and new capacity development strategies, and to support the case for ensuring maximum impact of ocean research, for example through marine technology and knowledge transfer from government-funded marine and maritime R&D projects. Expanding the reach of the GOSR questionnaire to gather data from more countries would help to complete the picture of the ocean science funding landscape now and in the future.

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5

Research productivity and science impact

5. Research productivity and science impact

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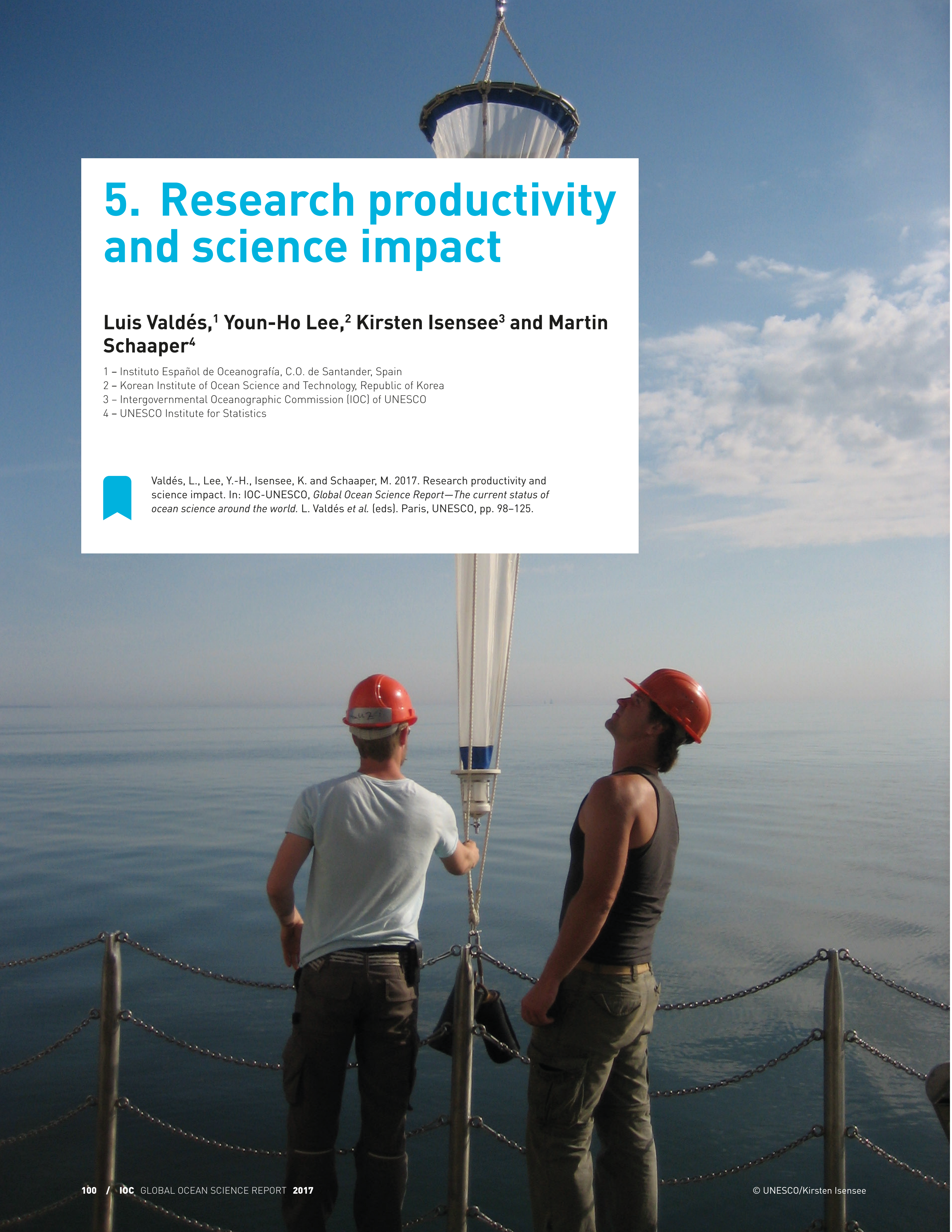

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5.1. Measuring global ocean science through publications

Some important measures of knowledge production, transfer and utilization can be derived from the scientific publications in which scientific knowledge is embodied. Bibliometrics is the application of mathematical and statistical methods to quantify published scientific literature (e.g. papers, books and documents) and create metrics and indices for reliable comparisons (Pritchard, 1969). It has become a generic term for a range of approaches directed at quantifying output levels, collaboration patterns and impact characteristics of scientific research (OECD, 2002, 2014).

The bibliometric literature recommends implementing a broad suite of metrics for a holistic understanding of the articles produced by an author, institution or country because each bibliometric indicator measures a different aspect of the underlying publication set (e.g. Martin, 1996; van Leeuwen *et al.*, 2003). A suite of metrics can therefore provide indications of – and credit for – a number of aspects of scientific publications. In the Global Ocean Science Report (GOSR), a suite of metrics was used to evaluate ocean science output in four categories: production; quality; topicality and collaboration. The production indicators attempt to measure research performance over specified periods of time. The quality indicators attempt to measure the impact of published literature to the broader scientific community. The topical indicators attempt to identify the major research areas pursued by nations consistent with research priorities and categories set by the United Nations Sustainable Development Goal 14 ('Conserve and sustainably use the oceans, seas and marine resources for sustainable development', (UNGA, 2015)) and blue growth (see Chapter 2 for 'blue growth' research categories). Finally, the collaboration indicators attempt to identify both the amount of knowledge published by international research partnerships and the major institutional and international connections showing how this knowledge is shared.

This chapter provides an overview of global ocean science output as measured by bibliometric indicators and describes trends and patterns following the metrics indicated above. Bibliometric data were compiled from scientific peer-reviewed articles[1] in Ocean Science[2] indexed in the Web of Science by Thomson Reuters and published over the past five years (2010–2014), comprising 372,852 articles.[3] Bibliometric data were produced on ocean science as a whole and for each of the categories of ocean science indicated in Figure 2.1.

5.2. Global analysis of research performance

5.2.1. Total scientific publication output: Overall figures

Table 5.1 shows the global performance of peer-reviewed ocean science literature between 2010 and 2014 by total publications and citation counts.[4] The total number of publications worldwide reached 372,852, whereas the number of citations in the same period was 2,206,429. Europe is the largest contributor in both publications and citations with a proportion of 33% of the world total publications, followed by Asia (28%) and North America (26%) (Figure 5.1).

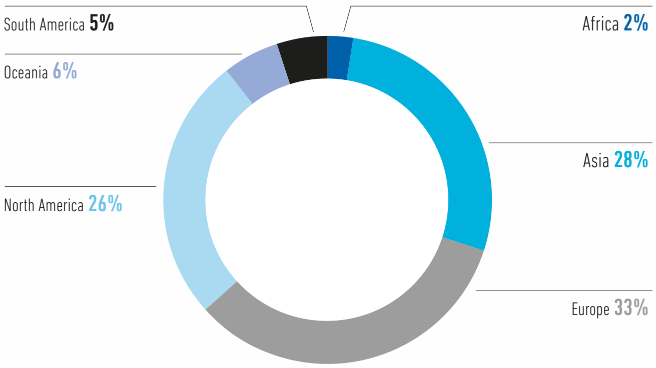


Figure 5.1. Proportion of global publication authorship by continent (Annex F).

The total number of scientific publications is an indicator of research output. The USA leads the world in ocean science research output (96,000 papers), followed by China (58,000), the UK (29,500), Germany (24,200), France (22,000), Canada (21,000), Australia (21,000), Japan (20,500), Spain (18,000) and Italy (15,000) (Table 5.1).

1 Peer review means that the science that is published has been subjected to independent scrutiny by qualified scientists, and thereby supports scientific quality and credibility.

2 Definitions for Ocean Science and the categories considered for the bibliometric analysis can be consulted in Section 2.1 in Chapter 2.

3 Articles printed in other languages than English were also counted if the keywords and/or the abstract were available in English. See Section 2.3.2 in Chapter 2 for a detailed explanation on the statistical methods.

4 The sum of national publications exceeds the world total due to double counts related to international collaboration.

The number of citations that a scientific publication receives is an indication of the use of this publication in subsequent scientific works. Therefore the ratio between publications and citations is an indication of the quality and impact of the national contribution to world science. Citation rates vary, research nations with the greatest publication output are not necessarily the most highly cited (Table 5.1, Figure 5.2). Generally, European and North America countries have a multiplying factor or impact factor (ratio of citations to publications) higher than countries from other parts of the world. Twenty countries show an impact factor higher than seven, eighteen of those are European and North America countries and only two (Israel and Singapore) are not. The extent to which a country is engaged in international collaboration influences its citation rates. Generally, publications that are co-authored by scientists from many countries are cited more often than publications for which all the authors are from the same country (Jarić *et al.*, 2012) (see also Section 5.3.1).

Table 5.1. Number of published papers and citations received by continent and country in ocean science for the period 2010-2014 (Annex F).

Continent	Country	Papers	Citations
World		**372 852**	**2 206 429**
North America		116 708	925 691
	USA	96 088	801 788
	Canada	21 073	175 076
	Mexico	5 278	21 445
	Cuba	345	1 607
	Panama	341	2 938
	Costa Rica	304	1 675
	Trinidad and Tobago	138	661
	Jamaica	81	471
	Bahamas	67	420
	Barbados	54	348
	Grenada	45	178
	Belize	27	220
	Guatemala	27	188
	Dominican Republic	21	51
	Honduras	20	112
	Saint Kitts and Nevis	18	51
	Haiti	17	110
	Dominica	9	134
	Saint Vincent and the Grenadines	5	21
	Antigua and Barbuda	3	19
South America		22 258	98 007
	Brazil	13 211	51 042
	Argentina	3 780	18 740
	Chile	3 577	20 541
	Colombia	998	4 619
	Venezuela	553	2 459
	Uruguay	442	3 613
	Peru	407	3 352
	Ecuador	280	1 584
	Bolivia	116	755
	Nicaragua	37	284
	El Salvador	23	135
	Guyana	18	36
	Paraguay	13	33
	Suriname	11	41

Table 5.1. *continued*

Continent	Country	Papers	Citations
Europe		149 642	1 033 199
	UK	29 472	271 018
	Germany	24 227	218 285
	France	22 078	196 093
	Spain	17 826	134 189
	Italy	15 083	106 016
	Norway	9 888	75 613
	Russian Federation	8 816	31 458
	Netherlands	8 780	82 639
	Portugal	6 606	43 963
	Sweden	6 377	59 111
	Denmark	5 794	55 114
	Switzerland	5 299	62 385
	Poland	5 041	21 650
	Belgium	5 011	42 834
	Greece	3 531	22 121
	Finland	3 114	26 942
	Austria	2 779	26 564
	Czechia	2 720	17 410
	Ireland	2 272	18 243
	Croatia	1 654	6 626
	Romania	1 652	5 191
	Hungary	1 045	6 007
	Estonia	904	5 771
	Slovenia	858	5 235
	Iceland	788	6 444
	Ukraine	715	2 939
	Serbia	686	2 608
	Bulgaria	677	2 586
	Slovakia	595	2 832
	Lithuania	551	2 077
	Latvia	211	555
	Luxembourg	205	1 375
	Monaco	193	2 192
	Malta	130	684
	Montenegro	130	636
	Albania	109	272
	Former Yugoslav Rep. of Macedonia	85	265
	Belarus	83	246
	Bosnia and Herzegovina	61	200
	Rep. of Moldova	23	62
	Liechtenstein	7	19
	Andorra	5	43
	San Marino	2	3

Table 5.1. *continued*

Continent	Country	Papers	Citations
Asia		123 769	597 174
	China	57 848	283 431
	Japan	20 516	117 333
	India	12 631	54 753
	Rep. of Korea	10 688	53 480
	Turkey	6 153	24 358
	Iran	4 437	16 148
	Malaysia	3 315	13 640
	Israel	2 397	17 881
	Thailand	2 323	11 904
	Singapore	2 307	16 935
	Saudi Arabia	1 831	11 084
	Indonesia	1 116	5 725
	Pakistan	1 113	3 956
	Viet Nam	946	3 715
	Philippines	730	4 240
	Bangladesh	632	2 749
	United Arab Emirates	453	2 499
	Oman	323	1 648
	Sri Lanka	276	1 685
	Cyprus	243	2 079
	Kuwait	227	733
	Jordan	221	821
	Iraq	199	642
	Lebanon	164	837
	Qatar	163	726
	Nepal	106	871
	Azerbaijan	86	213
	Georgia	86	296
	Mongolia	81	548
	Yemen	79	508
	Syria	78	361
	Lao People's Dem. Rep.	73	285
	Kazakhstan	72	252
	Armenia	70	305
	Brunei Darussalam	66	365
	Uzbekistan	60	248
	Cambodia	59	348
	Bahrain	43	207
	Myanmar	31	142
	Maldives	27	139
	Kyrgyzstan	26	210
	Tajikistan	18	39
	Turkmenistan	7	30
	Dem. People's Rep. of Korea	7	49
	Afghanistan	5	22
	Bhutan	4	34

Table 5.1. *continued*

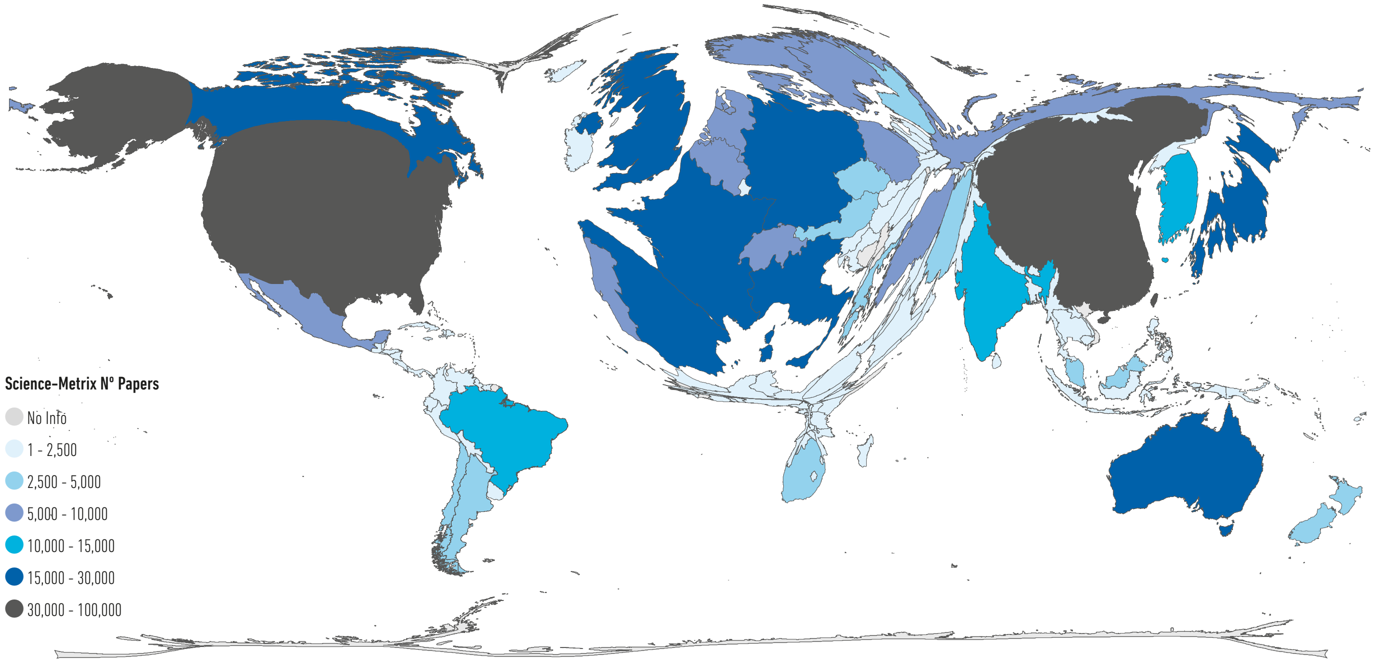
Continent	Country	Papers	Citations
Africa		11 472	60 648
	South Africa	3 979	26 526
	Egypt	2 063	8 234
	Tunisia	1 355	6 207
	Nigeria	604	1 670
	Morocco	545	3 151
	Kenya	542	3 920
	Algeria	493	1 775
	United Rep. of Tanzania	300	1 878
	Ghana	218	1 031
	Ethiopia	203	1 199
	Senegal	185	1 129
	Cameroon	167	723
	Uganda	154	915
	Madagascar	138	1 044
	Mauritius	100	655
	Zimbabwe	94	388
	Seychelles	88	609
	Benin	87	265
	Côte d'Ivoire	86	270
	Mozambique	82	751
	Libya	82	303
	Namibia	80	590
	Botswana	61	174
	Sudan	53	274
	Malawi	51	220
	Zambia	51	272
	Burkina Faso	50	328
	Cabo Verde	41	386
	Gabon	37	292
	Angola	33	133
	Congo	32	210
	Mauritania	31	177
	Niger	30	240
	Dem. Rep. of the Congo	29	260
	Mali	27	273
	Guinea	19	163
	Burundi	17	35
	Eritrea	16	161
	Rwanda	16	67
	Togo	15	48
	Swaziland	13	79
	Sierra Leone	10	95
	Chad	9	49
	Comoros	9	56
	Gambia	7	72
	Guinea-Bissau	7	49
	Central African Republic	5	31
	Djibouti	4	45
	Liberia	3	8
	Lesotho	3	13
	Sao Tome and Principe	1	6

Table 5.1. *continued*

Continent	Country	Papers	Citations
Oceania		25 072	205 383
	Australia	20 937	174 009
	New Zealand	4 818	40 114
	Fiji	155	846
	Papua New Guinea	68	724
	Solomon Islands	28	236
	Palau	26	130
	Vanuatu	24	162
	Cook Islands	20	147
	Fed. States of Micronesia	20	65
	Tonga	5	68
	Marshall Islands	5	35
	Tuvalu	4	7
	Kiribati	4	9
	Samoa	3	4
	Niue	2	6
	Nauru	1	4

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1% and HCP 10% (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)



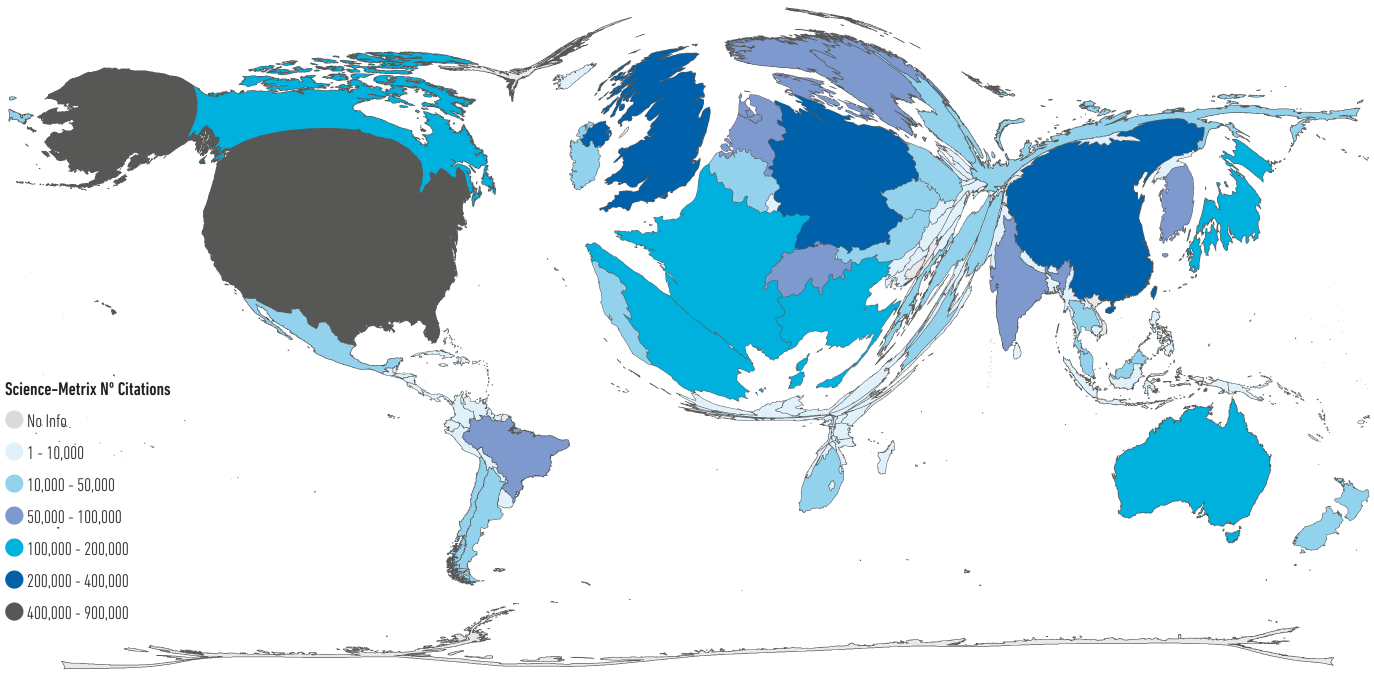


Figure 5.2. Publication and citation map of the world where the area of each country is scaled and resized according to the number of ocean science publications (top) or citations (bottom) received. Darker colours indicate more publications or citations (Annex F).

The research output of each country, in terms of the number of publications and the number of citations received, is illustrated in Figure 5.2. In these cartograms the geographic regions are deformed and rescaled in proportion to their relative research production[5] (by publications and citations). The heterogeneity shown in the comparison of both maps suggest asymmetries in the use and penetration of published science; a number of countries make a substantial contribution to research while others are less influential or have a negligible contribution. It is notable, however, that China, Brazil and India appear to have fewer citations than publications, indicated by the diminished relative size of the countries between the two indicators (Figure 5.2), whereas the USA, Germany, UK or France are more influential in terms of citations than publications.

5.2.2. Emerging scientific nations

The ocean scientific landscape is changing. Table 5.2 shows a selection of the top 40 ranked countries in terms of total number of publications as a function of time for three selected five-year periods: 2000–2004, 2005–2009 and 2010–2014. Although continuing to increase in absolute numbers of publications, the proportion of papers published by traditional scientific leaders (e.g. USA, UK, France, Germany and others) has been declining. Meanwhile, China has increased its publications to the extent that it is now the second highest producer of research output in the world. Brazil, India and the Republic of Korea are also increasing their share of research production, whereas Japan, the Russian Federation and the Netherlands dropped by four or five positions in the global ranking in the same period (Table 5.2).

5 Simple coloured maps can be misleading as the value assigned by classes of abundance gives an impression of a greater impact than in reality.

Table 5.2. Ranking of the 40 most publishing countries in Ocean Science for the periods 2000–2004, 2005–2009, 2010–2014 (blue - ranking upgraded, grey - ranking downgraded; Annex F).

2000–2004		
Country	**Rank**	**Papers**
USA	1	66 786
UK	2	19 323
Japan	3	16 469
Germany	4	14 099
Canada	5	13 535
France	6	12 727
China	7	11 213
Australia	8	10 094
Spain	9	7 916
Italy	10	7 888
Russia	11	6 175
Netherlands	12	5 021
Norway	13	4 928
India	14	4 104
Brazil	15	3 813
Sweden	16	3 798
Denmark	17	3 312
Rep. of Korea	18	2 905
New Zealand	19	2 843
Mexico	20	2 774
Belgium	21	2 615
Switzerland	22	2 339
Turkey	23	2 043
Portugal	24	2 011
Poland	25	1 984
Israel	26	1 962
Finland	27	1 961
South Africa	28	1 907
Greece	29	1 818
Argentina	30	1 693
Austria	31	1 364
Chile	32	1 327
Ireland	33	966
Czechia	34	960
Singapore	35	910
Thailand	36	743
Egypt	37	655
Malaysia	38	375
Iran	39	336
Saudi Arabia	40	208

Note: The selection of the top 40 countries is based on their output during the period 2010–2014

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

2005–2009		
Country	**Rank (Δ position)**	**Paper**
USA	1	81 723
China	2 (+5)	28 325
UK	3 (-1)	23 342
Japan	4 (-1)	19 336
Germany	5 (-1)	18 048
Canada	6 (-1)	17 646
France	7 (-1)	16 685
Australia	8	14 154
Spain	9	12 009
Italy	10	11 023
Brazil	11 (+4)	8 052
India	12 (+2)	7 600
Norway	13	7 134
Russia	14 (-3)	7 047
Netherlands	15 (-3)	6 443
Rep. of Korea	16 (+2)	5 865
Sweden	17 (-1)	4 666
Portugal	18 (+6)	4 367
Turkey	19 (+4)	4 314
Denmark	20 (-3)	3 922
Mexico	21 (-1)	3 805
Belgium	22 (-1)	3 668
New Zealand	23 (-4)	3 617
Switzerland	24 (-2)	3 533
Poland	25	3 502
Greece	26 (+3)	2 948
Argentina	27 (+3)	2 569
South Africa	28	2 525
Finland	29 (-2)	2 307
Israel	30 (-4)	2 197
Chile	31 (+1)	2 125
Austria	32 (-1)	1 948
Czechia	33 (+1)	1 798
Iran	34 (+5)	1 650
Thailand	35 (+1)	1 627
Ireland	36 (-3)	1 447
Singapore	37 (-2)	1 430
Egypt	38 (-1)	1 086
Malaysia	39 (-1)	924
Saudi Arabia	40	313

2010–2014		
Country	**Rank (Δ position)**	**Paper**
USA	1	96 088
China	2	57 848
UK	3	29 472
Germany	4 (+1)	24 227
France	5 (+2)	22 078
Canada	6	21 073
Australia	7 (+1)	20 937
Japan	8 (-4)	20 516
Spain	9	17 826
Italy	10	15 083
Brazil	11	13 211
India	12	12 631
Rep. of Korea	13 (+3)	10 688
Norway	14 (-1)	9 888
Russia	15 (-1)	8 816
Netherlands	16 (-1)	8 780
Portugal	17 (+1)	6 606
Sweden	18 (-1)	6 377
Turkey	19	6 153
Denmark	20	5 794
Switzerland	21 (+3)	5 299
Mexico	22 (-1)	5 278
Poland	23 (+2)	5 041
Belgium	24 (-2)	5 011
New Zealand	25 (-2)	4 818
Iran	26 (+8)	4 437
South Africa	27 (+1)	3 979
Argentina	28 (-1)	3 780
Chile	29 (+2)	3 577
Greece	30 (-4)	3 531
Malaysia	31 (+8)	3 315
Finland	32 (-3)	3 114
Austria	33 (-1)	2 779
Czechia	34 (-1)	2 720
Israel	35 (-5)	2 397
Thailand	36 (-1)	2 323
Singapore	37	2 307
Ireland	38 (-2)	2 272
Egypt	39 (-1)	2 063
Saudi Arabia	40	1 831

Portugal and Turkey have improved their standings and climbed into the top 20 in the period (2010–2014). Iran and Malaysia have also risen in the global ranking, climbing 13 and 7 positions respectively in the last 15 years. Meanwhile, publication share has declined for several countries, most notably for some European nations such as Finland and Ireland. Also, Israel and New Zealand declined in scientific performance.

Even maintaining a ranking position requires additional effort as countries have to increase their total publication output. For example, most European and western countries maintained a steady share of publications between 2000 and 2014, fluctuating only one or two positions up or down over the whole period. However, in order to hold their ranking all have increased the number of articles by around 35% for each of the periods considered.

In summary, China, Iran, India, Brazil, the Republic of Korea, Turkey and Malaysia show the strongest relative growth between the three periods indicated above. However, these countries – with the exception of China – are still far from the top positions, which continue to be dominated by the USA, Canada, Australia and European nations (UK, Germany, France, Spain and Italy).

The picture of scientific research is also starting to change across the Middle East, where there are a number of significant new commitments to marine science in countries such as Iran and Saudi Arabia. For example, Saudi Arabia has grown from 208 publications in the period 2000–2005 to 1,831 in the period 2010–2014, making it the fastest-growing country in terms of numbers of scientific publications in marine science in the world.

Similar trends were reported in other bibliometric analyses, such as fisheries science (Aksnes and Browman, 2015), physics (Wilsdon, 2008) or science overall (UNESCO, 2010, 2015; Royal Society, 2011). Countries such as China, Brazil, India, Turkey, Iran, Saudi Arabia and others have improved their overall scientific performance by declaring research a public priority, increasing their spending on R&D[6] at rates rivalling that of European countries (Wilsdon, 2008) and making significant investments in environmental technologies (which are relevant for global challenges such as climate change, water and food) (OECD, 2010).

6 China has heavily increased its investment in R&D, with spending growing by almost 20% per year since 1999 to reach US$368 billion PPP (Purchasing Power Parity) in 2014 (UNESCO Institute for Statistics database – accessed 7 March 2017– http://uis.unesco.org/en/country/cn?theme=science-technology-and-innovation) and India produces roughly 2.5 million graduates in IT, engineering and the natural sciences each year (Wilsdon, 2008).

5.2.3. Building science: economic and scientific wealth

The relationship between knowledge and wealth has been recognized since ancient times. Yet how this relationship works in the modern world is still a sensitive political issue; it is a widely accepted principle that in order to achieve long-term and sustainable economic growth, spending on education, research and development is essential to produce a substantial amount of innovative research.

To understand how this relationship works in ocean science, it is useful to compare the scientific efficiency (outputs – publications and citations – as a measure of returns on investment) relative to gross domestic product (GDP) and 'wealth intensity' indicators (GDP per person, percentage of GDP and investment in R&D). Table 5.3 shows the Pearson correlation coefficient (r^2) of the tested variables for the 40 nations in the comparator group of Table 5.2, and Figure 5.3 displays the data for the correlations indicated in grey in Table 5.3.

Table 5.3. Matrix of Pearson correlation coefficient (r^2) between different economic and bibliometric indicators. For more detailed information, the correlations highlighted in grey are displayed in Figure 5.3 (Annex F). *Source*: UIS (GDP), 2015.

	Publications	Citations	Impact (Cit/Pub)
GDP (country wealth)	0.952**	0.859**	0.001⁻
GDP per capita	0.016⁻	0.064⁻	0.717**
% GDP in R&D	0.952**	0.071⁻	0.318*
Expenditure on R&D	0.895**	0.859**	0.011⁻

Non-significant, *P<0.01, **P<0.001; economic indicators for 2013 (World Bank); bibliometric indicators for the period 2010–2014 (Science-Metrix).

Wealth intensity indicators (GDP, percentage GDP invested in R&D and spending on R&D) all have a positive correlation with total number of published documents. Countries with high levels of publication activity also have stronger national economies (i.e. GDP) and high levels of R&D expenditure.

National science citation intensity also correlates with national wealth intensity (GDP) and expenditure in R&D, but not with percentage GDP invested in R&D. This could be because if GDP is low, then even high percentages of GDP investment would result in only modest absolute investments in science. Therefore, real investment in R&D seems to be a much more appropriate comparative index for this analysis (even if we were not able to obtain the amount of expenditure on ocean research exclusively; see Chapter 4).

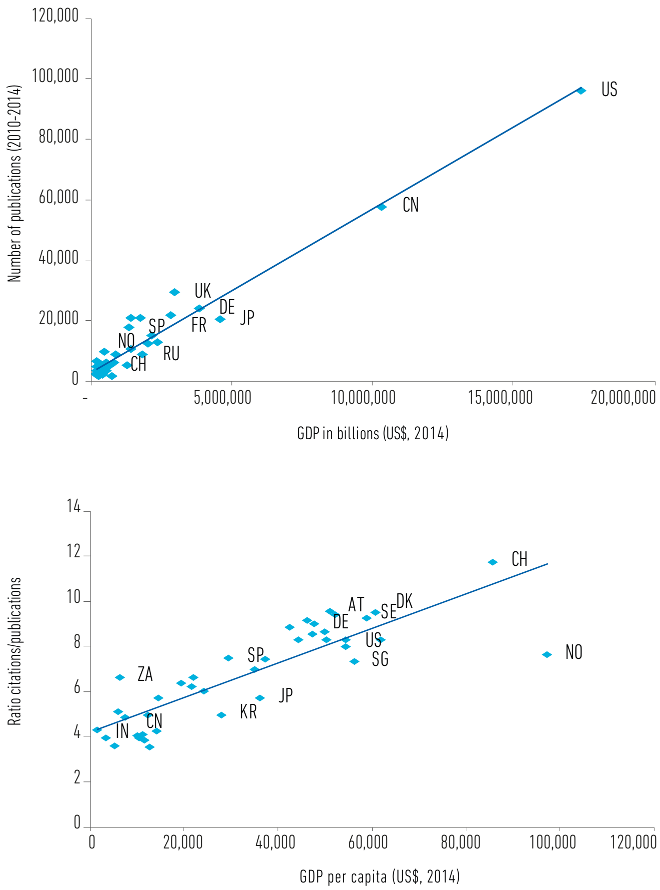


Figure 5.3. Comparison of economic and scientific wealth. Top: National science publication output versus national GDP as an indicator of national wealth intensity. Bottom: ratio of citations/national publications versus national GDP per capita as an indicator of individual wealth intensity. Data are shown only for the 40 nations in the comparator group (see Table 5.2; Annex F). Country codes are displayed according to ISO 3166 two-letter code, alpha-2. *Source*: UIS (GDP), 2015

Small or medium-sized nations with high GDP per capita have high citation impact (Figure 5.3). Sweden, Denmark, Austria, UK and especially Switzerland[7] perform strongly on this measure. At the other end of the scale, although China and India rank second and ninth in the world, respectively, in terms of total GDP, each has low GDP per capita and a modest citation impact.

There are several reasons relating scientific performance and economy. Firstly, those countries with better research and living conditions may be more appealing or competitive in attracting and retaining talented scientists. A report published by van Noorden (2012) indicates that 12% of scientists from China and 37% from India have migrated to the UK, USA and Australia. Moreover, many researchers and scientists from other Asian countries including Pakistan, Bangladesh and Jordan are also moving to other continents (van Noorden, 2012). Secondly, many research institutions in countries that were low in rankings, including those from Asia, Africa and South America have multiple 'missions' (e.g. assessment, management, education, reports), which are not all oriented towards scientific publications. Thirdly, outstanding achievements obtained by top researchers attract young talent; this causes a feedback process that draws young talent towards North America or Europe, whereas there may be less motivation for American or European researchers to move to other continents.

The reasoning presented here is not entirely new. Earlier work has provided evidence that excellent national research generates opportunities for innovation and ultimately for productivity and economic growth, as well as other societal benefits (i.e. the overall development of nations) (Bell et al., 2014). The relationship is quite straightforward: the more resources that are available per researcher the more likely research results will be produced that are regarded as seminal and cited accordingly.

A better understanding of the factors influencing the quantity and quality of research output is especially relevant for decision-makers, given that direct public funding through grants, subsidies and loans remains the primary form of support for ocean science R&D, with an increased focus on competitive and merit-based programmes (see Chapter 4). However, the most successful nations in terms of ocean science performance are those that facilitate more financial resources per researcher, which is a function of GDP per capita.

Overall, research performance increases with economic wealth. Investing a greater amount of GDP on R&D can generate strong research and technological capabilities and enhance overall scientific performance. The production of highly cited scientific articles having global impact is underpinned by a healthy scientific research environment (depending on recruitment and retention of top researchers, as well as access to equipment and facilities), and economic wealth.

7 Switzerland, although it is a landlocked country, has good performance in ocean sciences. This observation could be linked to the fact that a number of international geoscience organizations have head offices in the country in addition to the research in marine sciences from its academic institutions.

5.3. Research profiles

5.3.1. Patterns in national and regional specialization in ocean science by category

To enable international comparisons, governments, managers and scientists need an indication of disciplinary strengths and weaknesses of their national research profile based on reliable indicators. For this purpose we have disaggregated 'Ocean Science' into seven categories: 'Marine ecosystems functions and processes', 'Ocean and climate', 'Ocean crust and marine geohazards', 'Blue growth', 'Ocean health', 'Human health and well-being' and 'Ocean technology and engineering', plus one overarching topic: 'Ocean observations and marine data' (see Chapter 2 for details on the content of each category). As a metric for comparison purposes we have used the Specialization Index (SI), which gives an overview of a nation's research profile (or specialization) by comparing the shares of the categories of ocean science across a nation's total publications to the overall shares of each category for the world's total publications.

This national and disciplinary disaggregation process produces a substantial database, but it can be presented in a compressed form using spider or radial plots. The SI index for each category is normalized to that of the world in ocean science (World=1), which permits an easier comparison and a reference for visualization in the spider plots. Results in Figure 5.4 are given for the five continents (America is divided into North and South America) and for every nation accounting for at least 300 publications in the studied period (2010–2014), with the exception of Fiji Islands (155 publications, but still ranking #3 for Oceania).

In terms of the relative specialization of countries in scientific disciplines, Figure 5.4 reveals some marked asymmetries among countries. The traditionally dominant scientific countries (USA, UK, Germany, France, Canada and Australia) show a fairly well-balanced pattern, relatively uniform, in their individual research profiles with slightly higher values in 'Ecosystem functioning and processes' and 'Ocean and climate'. Japan and Russia are specialized in 'Ocean crust and marine geohazards' and China in 'Ocean technology and engineering'.

Over the past five years, several new trends have emerged in terms of national research priorities. Some of the data on scientific publications reflect these priorities but often the classification across disciplines is not detailed enough. For instance, blue growth has become an important topic but related research is spread across several sectors (tourism, aquaculture, fisheries, etc.). Some European countries seem to be specialized in this new ocean science category (e.g. Norway and Spain; which could be related to a focus on fisheries research). Whereas UK, Germany and France show strength in 'Ocean and climate', Russia, Italy and the Netherlands are important players in the category of 'Ocean crust and marine geohazards'.

By contrast, several countries in Asia (i.e. China, Republic of Korea and Iran) show stronger performance in 'Ocean technology and engineering' but poorer performance in 'Ecosystem functions and processes' and 'Ocean and climate'. Malaysia shows a strong specialization in 'Blue growth', 'Ocean health' and 'Human health and well-being'. India and Japan specialize in 'Ocean crust and marine geohazards' and are well-balanced across the other categories. Israel's scientific output shows a fairly well-balanced pattern across all categories.

Of the eight countries studied in Africa, six show very high SI values for 'Human health and well-being'; in contrast, there is a general lack of expertise in 'Ocean technology and engineering'. Kenya and Tanzania show the highest performance for 'Human health and well-being' and both are also strong in 'Blue growth'. Nigeria is most specialized in 'Ocean health' but also strong in 'Human health and well-being'. In contrast, Morocco is more visible in 'Ocean crust and marine geohazards' and is well-balanced in the other categories. South Africa shows a well-balanced pattern, relatively uniform in each research profile with slightly higher values in 'Ecosystem functioning and processes'. Egypt, Tunisia and Algeria are fairly strong in 'Human health and well-being' with Algeria also showing strengths in 'Ocean technology and engineering'.

In North America, 7 of 20 countries accounted for more than 300 publications in ocean science in the studied period and all of them performed well in 'Ecosystem functioning and processes'. USA and Canada are also specialized in 'Ocean and climate' and 'Ocean observation and marine data'. Mexico, Cuba and Costa Rica show above average performance levels in 'Human health and well-being' and for 'Blue growth'.

All eight countries compared in South America are particularly strong in 'Ecosystem functioning and processes', but weak (with the exception of Peru) in 'Ocean and Climate'. Peru and Ecuador also have good scores in 'Blue growth', 'Human health and well-being' and 'Ocean health'.

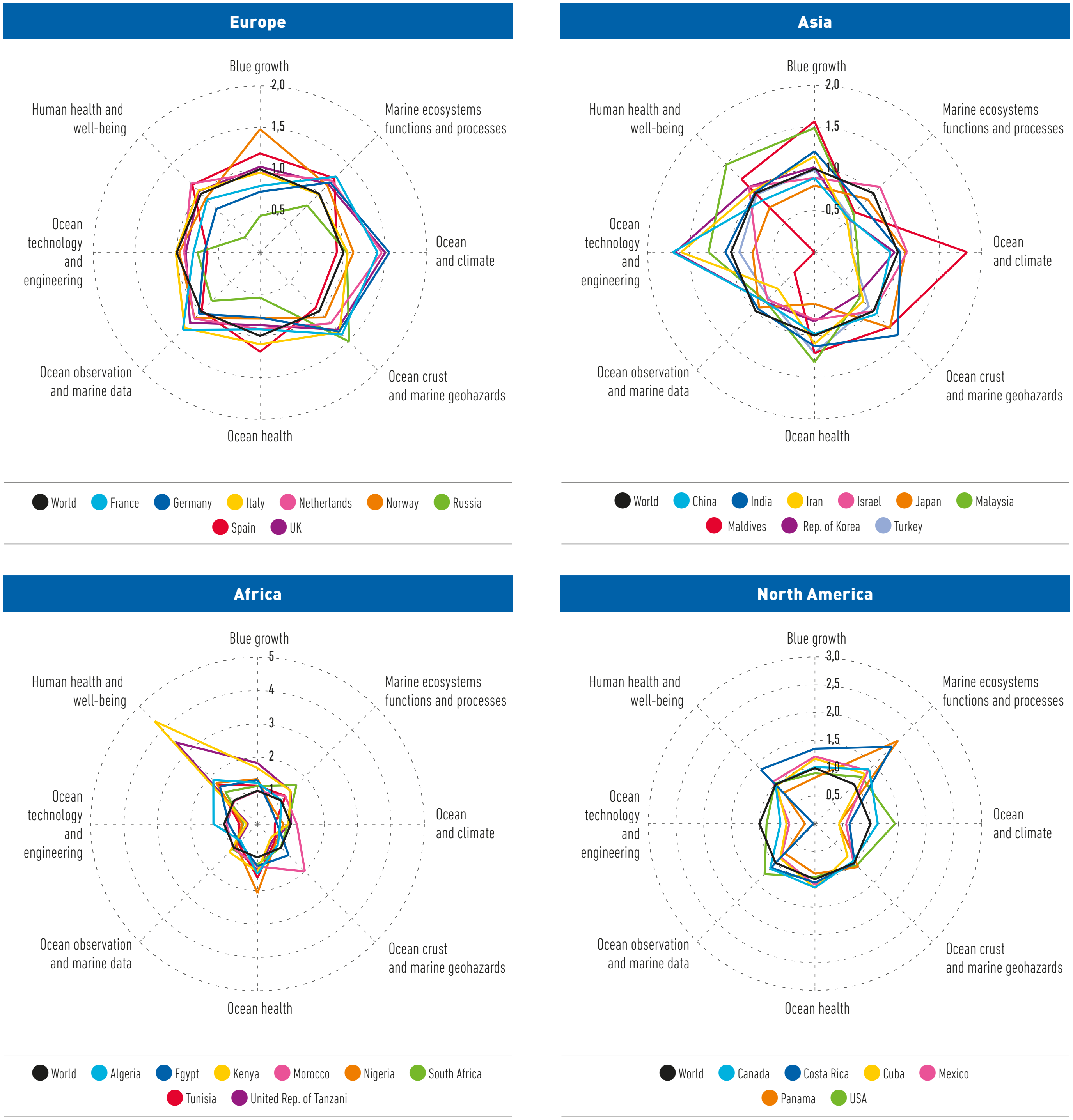


Figure 5.4. National strengths in different ocean sciences categories. Spider plots show the Specialization Index (SI) compared to the world (2010–2014) for the nations accounting for at least 300 publications in the studied period (note discussion on Fiji, under Section 5.2.1; Annex F).

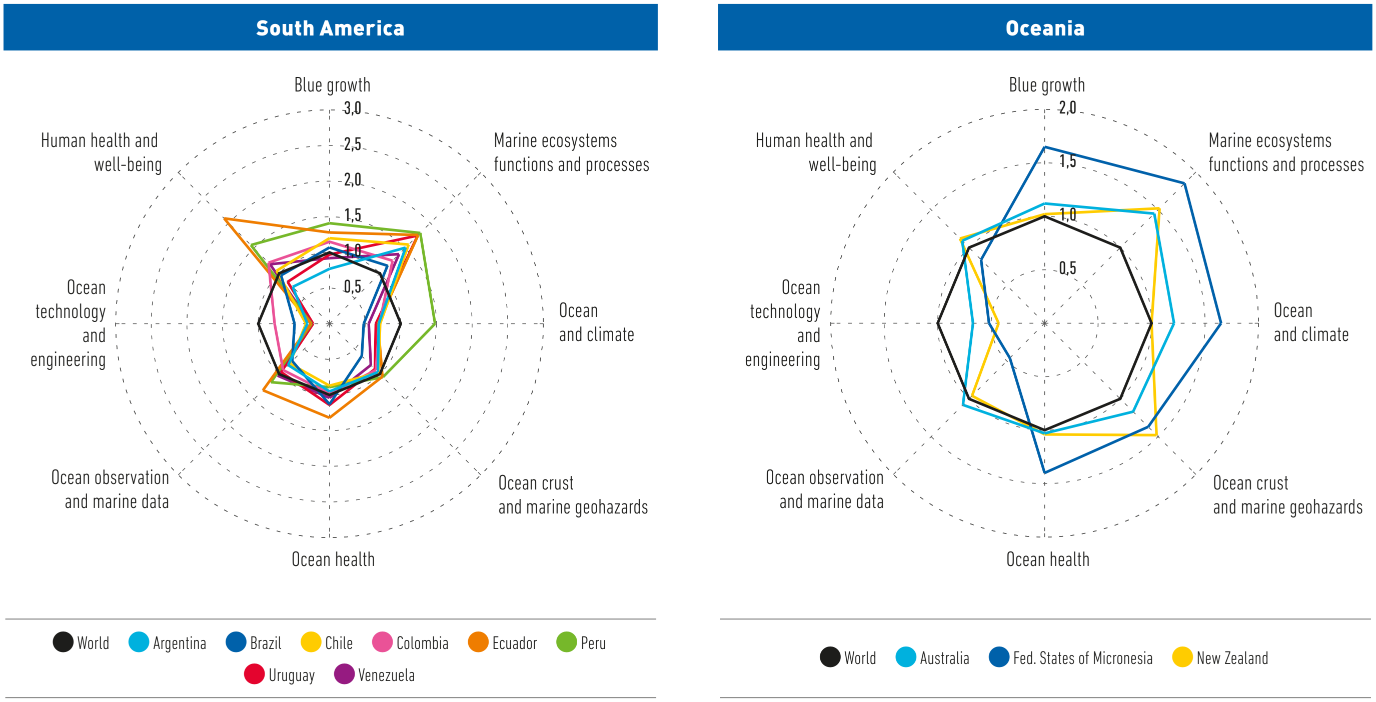


Figure 5.4. *continued*

Finally, in Oceania both Australia and New Zealand show a fairly well-balanced pattern for SI in each category. Australia seems more specialized in 'Ecosystem functions and processes' and 'Ocean and climate' than in other areas such as 'Ocean technology and engineering'. New Zealand is also weaker in 'Ocean technology and engineering' than other areas, such as 'Ocean crust and marine geohazards'. Fiji shows high performance in several categories, including 'Blue growth', 'Human health and well-being' and 'Ocean technology and engineering'; however it must be noted that these indices were calculated with a very low number of publications (155 documents) in the studied period. Furthermore, the main campus of the University of the South Pacific, (one of the major research institutions in the region) is located in Fiji but jointly owned by the governments of 12 member countries in the region.

The research publication profiles clearly illustrate the diversity that exists among countries and may reflect different scientific priorities and needs. This variation is usually not visible in aggregated analysis (e.g. if ocean sciences were subdivided into only three or four categories) and therefore this methodology is useful to obtain a clear overview of the different activities and profiles of countries and enable international comparison. The challenge is to use this information to transfer knowledge and technology and create new capacities, using the advantages of communicating in the common language of science, cultural similarities or geographic proximity.

5.3.2. National positional analysis in ocean science by category

In order to visualize the composite performance of countries we used the positional analysis, which combines three separate indicators (number of papers, specialization index, SI, and average of relative citations, ARC) to allow easy interpretation and comparison of the strengths and weaknesses of nations in each category of ocean science. The abscissa (horizontal axis) corresponds to the SI, the ordinate (vertical axis) to the ARC and the size of the bubble is proportional to the number of publications. The world level is situated on the axes; a bubble in the second and third quadrant is less specialized than the world average while a bubble in the third and fourth quadrant shows an ARC score lower than the world ARC average (see Section 2.3.2 in Chapter 2 for a more detailed explanation on the statistical methods). For ocean science overall, we compared the performance for the 40 nations in the comparator group of Table 5.2, and the results are shown in Figure 5.5. In addition —and to enrich the comparison in the different categories— we used the 40 highest publishing countries in each category and the results are presented in Figure 5.6 (in total for this analysis we compared 45 countries).

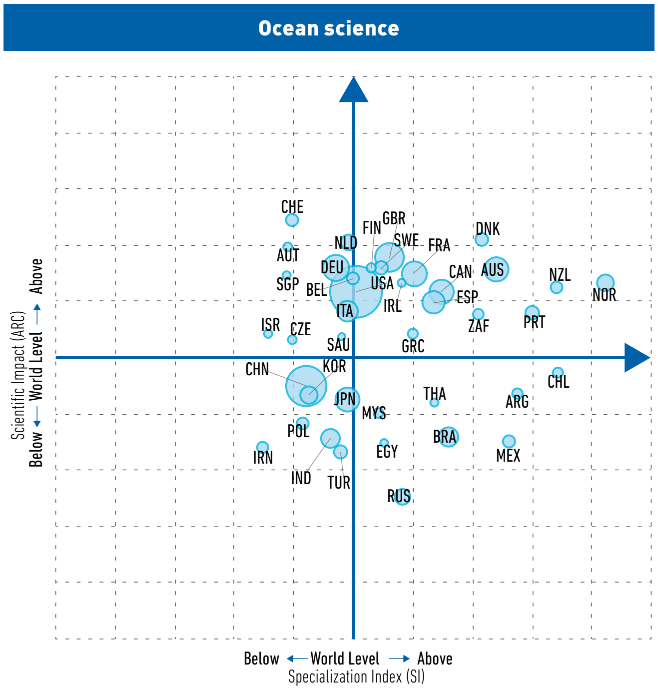


Figure 5.5. Positional analysis for the 40 countries included in the comparison group for ocean science output, 2010–2014. The size of the bubble is proportional to the number of publications for that country over the study period. (Country codes are displayed according to ISO 3166 three-letter code, alpha-3; Annex F).

The positional analysis for ocean science overall does not show much dispersion in nations' distribution in the plot, as most of them are grouped close to the centre of both axes (Figure 5.5). This is because this presents the average position of nations, and therefore we lose the perspective on an individual nation's contribution and specialization in each thematic category. This figure is useful to compare the relative position of the nations displayed in the plots shown in Figure 5.6.

The category 'Ecosystem functioning and processes' is likely the most classic research topic in ocean science and the distribution of the nations in the plot shows that the first quadrant is occupied by countries with a longstanding tradition in ocean science from North America and Europe plus Australia, New Zealand and South Africa (Figure 5.6). The second quadrant is mostly populated by Latin American countries (Brazil, Argentina, Chile and Mexico) which have high performance in terms of specialization but low penetration in citation rates. In the third quadrant we find most of Asian and Arab nations.

In spite of the similarity of research topics between 'Ocean and climate' and 'Ecosystem functioning and processes', which could produce a high autocorrelation in the analysis, the plots show few coincidences in the relative position of the countries, supporting the Global Ocean Science Report delineation of categories of ocean science. Most of the 40 analysed countries for 'Ocean and climate' are spread between the first and third quadrants (Figure 5.6). According to the results, none of the BRIC countries (Brazil, Russia, India and China) are particularly influential in 'Ocean and climate' research at a global scale. Also, Iran, Egypt and Turkey show lower performance in the positional analysis for this research category.

Regarding 'Ocean health', 30 of the 40 analysed nations show a specialization level above the world average, demonstrating good performance in research areas such as pollution, alien species and other impacts caused by anthropogenic activities. However, the countries with the highest SI values also show modest publication production, indicated by small bubble sizes (Figure 5.6). Most industrialized nations, where important chemical industries are based (such as Germany, Netherlands, UK, Switzerland, USA, Japan and China) rank below the world SI average in this category, although they produce abundant literature and some are among the most influential according to their impact rates.

The positional analysis for 'Human health and well-being' reveals that 39 of 40 countries have SI scores above or close to the world average. In fact, the distribution of the countries is displaced towards the right side, in the case of the third and fourth quadrants the bubbles are closer to the centre of the Y axis (Figure 5.6) than for any other category. Kenya shows the highest performance in SI and Tunisia, Egypt and Saudi Arabia also have high scores for SI. Kenya is also influential in terms of citations for this category.

The first and second quadrants for 'Blue growth' are populated by small and medium bubbles, perhaps because this is a new emerging area or because blue growth is a broad concept spanning several sectors. With tourism, aquaculture and fisheries part of blue growth, it is understandable that two well-developed but landlocked nations, Switzerland and Austria, show the poorest SI in this category (Figure 5.6). On the other hand, Romania shows the poorest performance in terms of ARC.

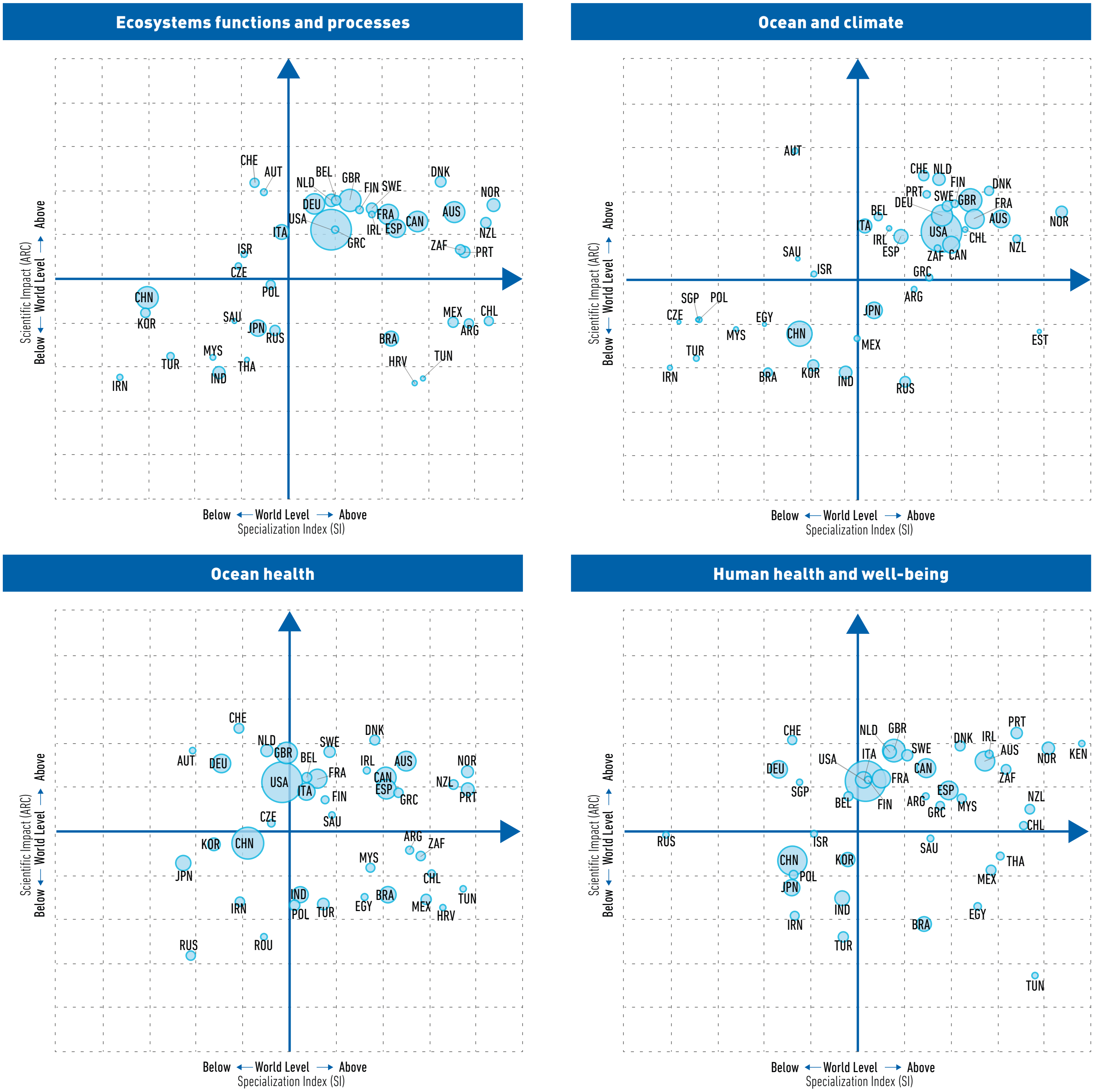
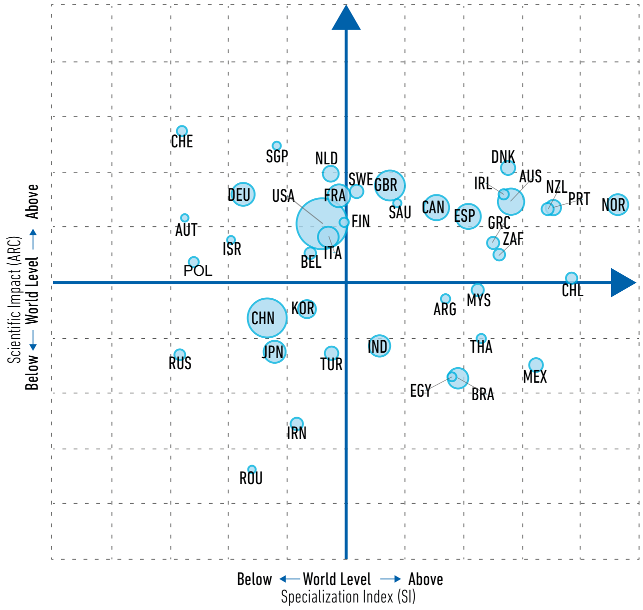
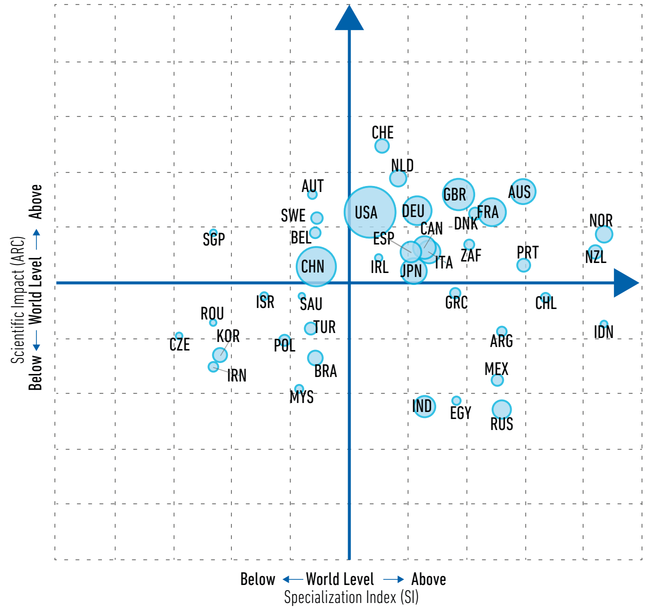


Figure 5.6. Positional analysis for the eight oceans science categories The size of the bubble is proportional to the number of publications for that country over the study period. (Country codes are displayed according to ISO 3166 three-letter code, alpha-3; Annex F).

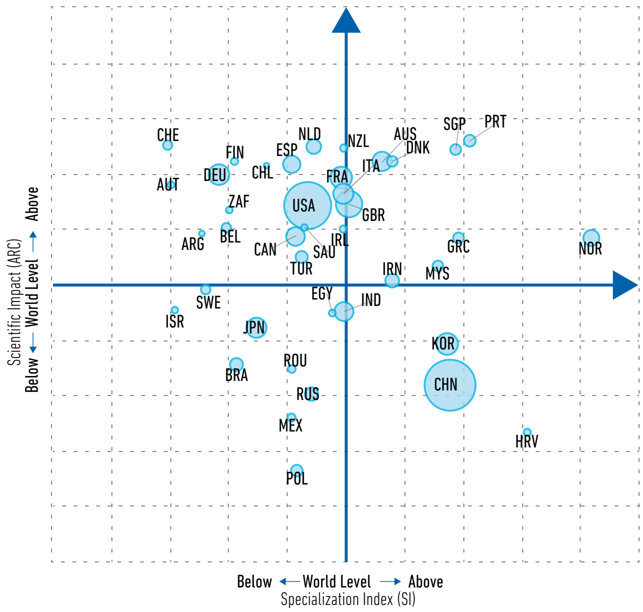
Blue growth



Ocean crust and marine geohazards



Ocean technology and engineering



Ocean observation and marine data

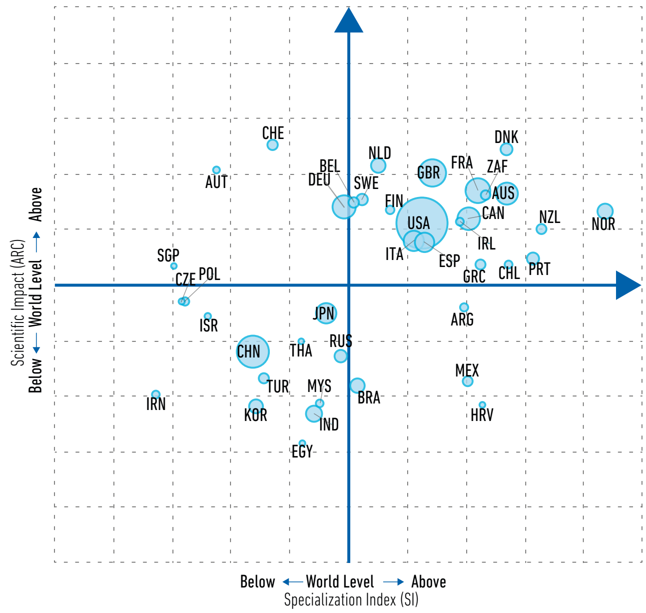


Figure 5.6. *continued*

In contrast to the previous category, the first quadrant for 'Ocean crust and marine geohazards' is populated by big bubbles, indicating higher total numbers of publications. Indonesia appears as the second nation with the highest SI. Chile, Japan and India are also above the world average. The Russian Federation, with a longstanding tradition in geology, is also well above the world average in SI in this category. It is noticeable that China gets its best score in terms of citation in this topic (Figure 5.6). All major scientific research nations, as well as most of the countries affected by tsunami events, are above the world average for both SI and citation impact, revealing a high interest for this research area.

There is a high expectation of new devices and equipment developed by 'Ocean technology and engineering' and many countries show good scores in average relative citations in this category. However, their performance in SI is quite low, for example, 18 countries occur in the second quadrant (Figure 5.6), making this plot distinctive among the eight categories compared in this analysis. Mirroring other areas of science and society, China and Korea get high scores in SI, but also Norway and other countries are above the world average in SI.

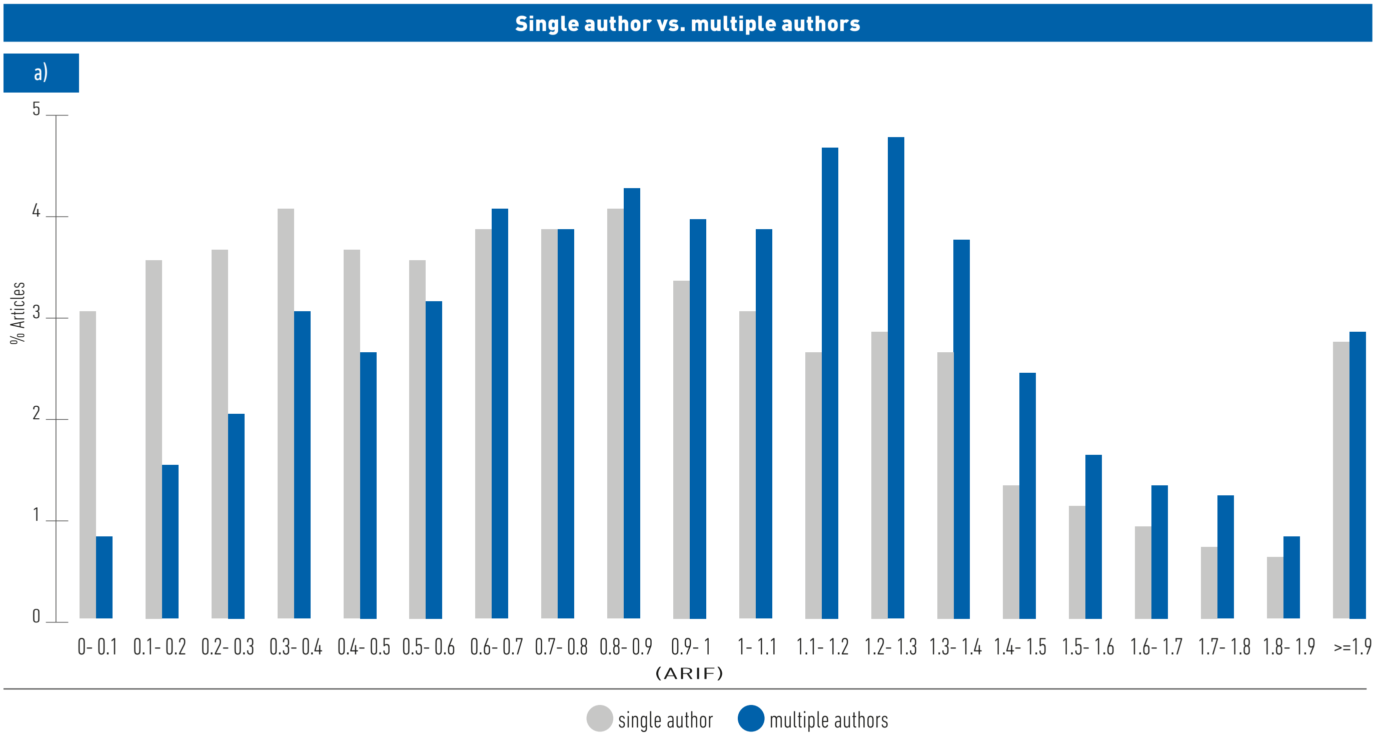
'Ocean observation and marine data' encompass – and are necessary for – all ocean science categories. The distribution of the 40 nations in the plot resembles the 'Ocean and climate' plot. This is likely to be because observation networks and big data sets are important for climate change science. Countries sharing equipment (e.g. satellites, Argo buoys or research vessels) and offering free access to their data collections appear in the first quadrant (see Chapter 3). It is perhaps understandable that landlocked countries such as Austria, Switzerland and Czechia, show poor scores in SI in this category (Figure 5.6), but they are still above or close to the world average relative citation index.

This analysis shows how nations are specialized in specific categories of research and, as there was no evidence of autocorrelation in the results, illustrates that the categorization used in this report is neither spurious nor overlapping. There are still elements for reflection - for example, the steady position that Norway shows in the first quadrant with high scores for both indices (SI and ARC) in each of the eight categories. Also, Switzerland shows a relatively steady position with high scores in ARC although its scores are below world average for SI (mostly appearing in the high part of the second quadrant in six of eight categories). It is also interesting to see how the USA (the largest bubble in this analysis) moves gradually from the first quadrant (in 'Observations and data', 'Ocean and climate' and 'Ecosystem functioning and processes') to the second quadrant (in 'Human health and well-being', 'Ocean health', 'Blue growth').

The weaker position of China, Republic of Korea, Japan, Brazil and Russia in this analysis – very often appearing in the third quadrant – could be explained by the fact that these countries produce over 70% of their overall publications from national researchers alone (Royal Society, 2011). Domestic collaboration is not as beneficial to citation impact as international collaboration (see Section 5.4).

5.4. Collaboration patterns and capacity development

Today, many scientific papers are co-authored, increasingly by researchers from different countries, which enable the ratios and routes of collaboration to be traced and quantified. Collaboration can be beneficial for several reasons. It provides a larger pool of available ideas (intellectual synergy), methods and resources, and allows cost sharing and time saving through division of labour (Katz and Martin, 1997; Leimu and Koricheva, 2005a). The degree of collaboration is also often taken into account when making funding, hiring and promotion decisions (Herbertz, 1995; Katz and Martin, 1997). Consequently, scientific collaboration is commonly considered a prerequisite of high-quality research. The number and multiplicity of connections have been favoured by the establishment of global programmes under the UN umbrella and international projects financed by international commissions, which have promoted international cooperation



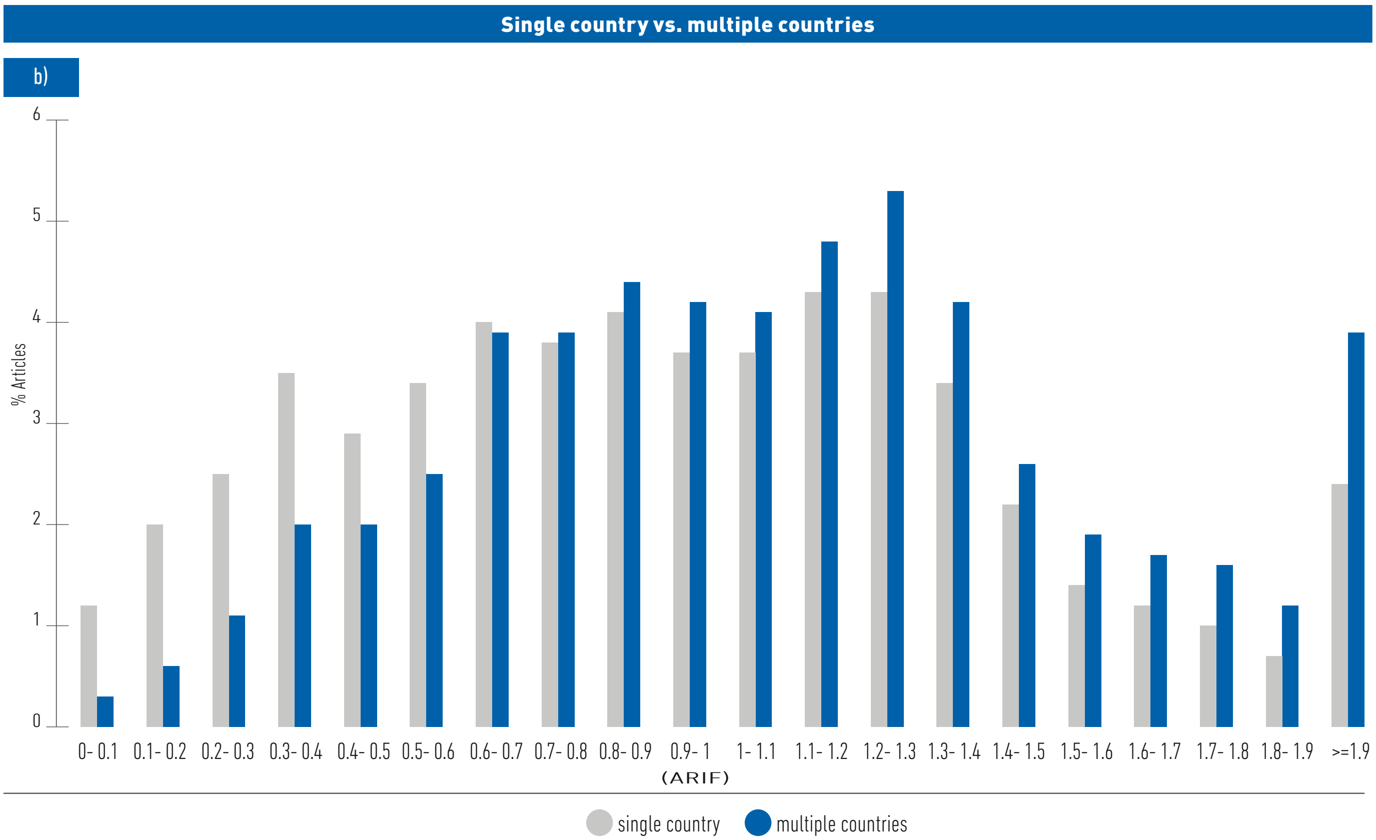


Figure 5.7. Comparison of scores in the average of relative impact factors (ARIF) in: **a)** articles produced by one single author (grey bars) versus multiple authors (blue bars); and **b)** articles produced by all authors from the same country (domestic, grey bars) versus multiple counties (international, blue bars; Annex F).

and connected researchers pursuing common scientific questions or interests from different parts of the world.

5.4.1. Scientific cooperation matters

The net value of collaboration is an issue under discussion, as the potential benefits may depend on the type of collaboration, the discipline and the country or countries involved. For example, international collaboration is generally considered to increase citation rates more than domestic collaboration (Narin *et al.*, 1991; Leimu and Koricheva, 2005b; Jarić *et al.*, 2012).

Despite the increasing emphasis placed on collaboration in scientific research, little is known about the extent of collaboration that occurs and whether or not a relationship exists between the degree of collaboration and the impact of a research study (Figg *et al.*, 2006). In order to illustrate how scientific cooperation matters in ocean sciences, two comparisons were carried out. Firstly, we determined the average of relative impact factors (ARIF) for articles signed by a single author versus papers published by multiple authors. Secondly, we classified collaboration as domestic in-house collaboration (all authors from the same country) versus international collaboration (authors from more than one country).

The effect of collaboration on scientific impact appears to be positive in both comparisons (Figure 5.7) as the scores for multiple authors and multiple countries (international cooperation), represented by the blue bars, are placed to the right side of the distribution, whereas the grey bars accumulate the higher scores on the left side of the plot.

Although it could be argued that the expected benefits of collaborative research in ecological sciences are relatively modest (Leimu and Koricheva, 2005a, 2005b), our analysis shows that the citation rates of ocean science papers are affected by the number of authors and their internationalization. The higher citation rates received by multi-authored papers might reflect the true benefit of multidisciplinarity of such articles or the advantages of division of labour. In addition, the larger the number of authors, the larger the network of scientists that might know one of them, increasing the probability that such papers will be brought to the attention of the citer through personal contacts (Bornmann *et al.*, 2012). Alternatively, the increase in citation rates with the number of authors might be related to an increased frequency of self-citations in the case of multi-authored papers (Herbertz, 1995).

The level of internationalization of science differs among regions and countries. According to the Royal Society (2011), China, Turkey, Taiwan (China), India, Republic of Korea and Brazil produce over 70% of their publications from national researchers alone. By contrast, small nations and less developed countries are collaborating at a much higher rate. Over half of the research published from Belgium, the Netherlands and Denmark in the period 2004–2008 was the product of multinational authorship.

In summary, collaboration is a means to spread efforts over different individuals and institutions, enhance intellectual synergy and allow resources to be shared. Collaboration is believed to be a highly effective tool for enhancing efficiency and productivity in scientific research because: (i) papers with many authors are most probably multidisciplinary papers, so that citations in various disciplines can be expected; (ii) the more authors a paper has, the larger the network in which the paper will become known through personal contacts; and (iii) each additional author increases the probability of self-citations (Bornmann *et al.*, 2012). The results of our study could encourage marine scientists to cooperate more in international research projects and to develop publication strategies that would increase their chances of achieving high citations without compromising the quality of the science produced.

5.4.2. Research neighbourhood

Knowing how scientific interactions vary with region and distance is valuable for practical reasons. For researchers, it might suggest how to choose collaborators in order to optimize the impact and visibility of their research. For institutions and governments, it might advise suitable allocations of funds for regional and international projects, in order to improve the scientific outcome for a given amount of resources (Pan *et al.*, 2012).

Figure 5.8 shows the collaboration network established in the top 40 most publishing countries in ocean science in absolute terms (Figure 5.8a), and also how this relates to the network of the top 40 most publishing institutions (Figure 5.8b). A European cluster dominates the centre of the country network (Figure 5.8a), linking with the USA, and also with Canada (via France) and Australia (via UK). The USA has a strong link

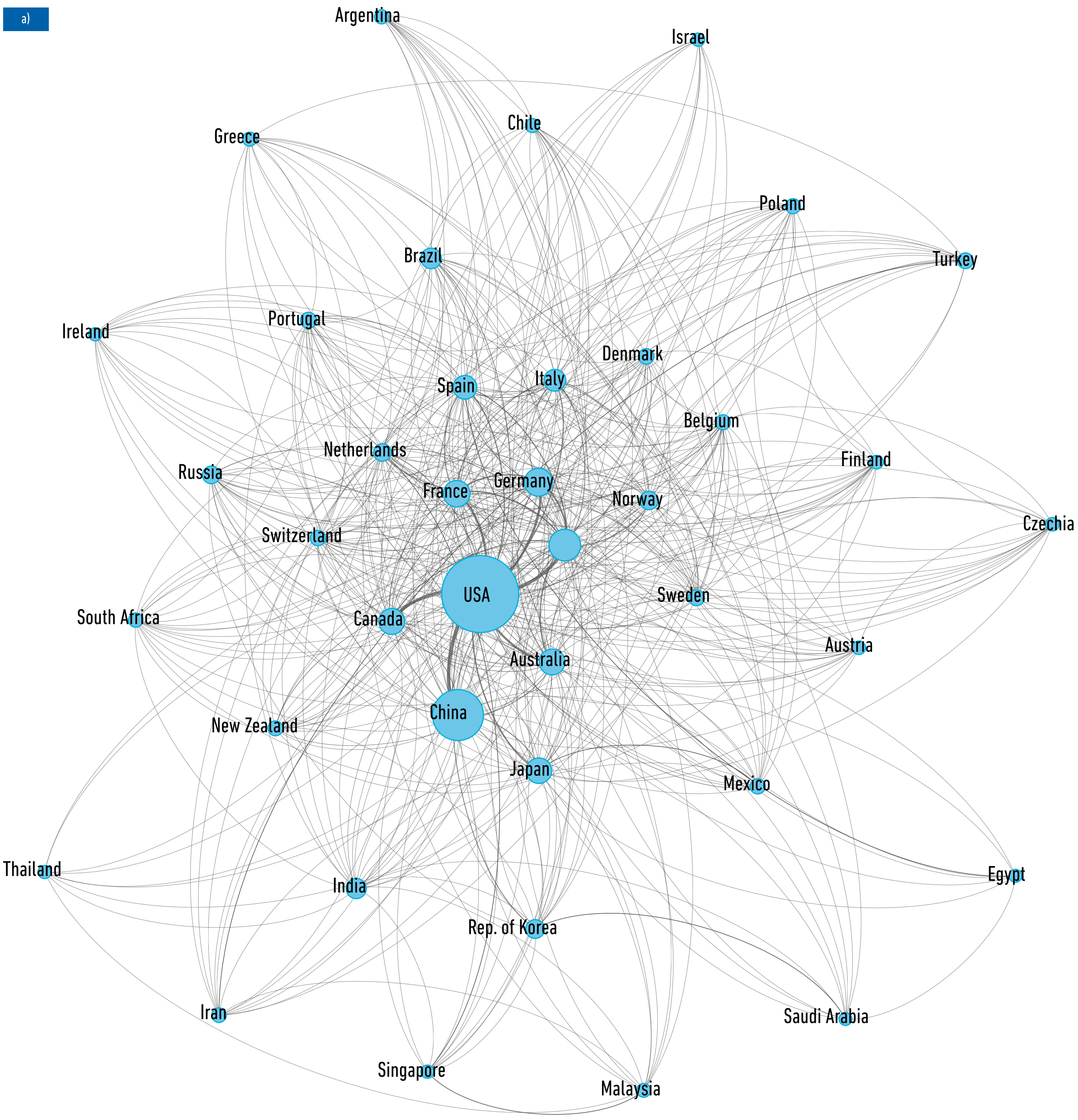


Figure 5.8a. International collaboration network of selected top publishing a) nations and b) organizations in ocean science, 2010–2014. The size of the nodes is proportional to the number of publications in ocean science and the thickness of the lines is proportional to the number of collaborations (co-authored papers). Nodes are arranged using an algorithm where linked nodes are attracted to each other while unlinked nodes are pushed apart (Annex F).

b)

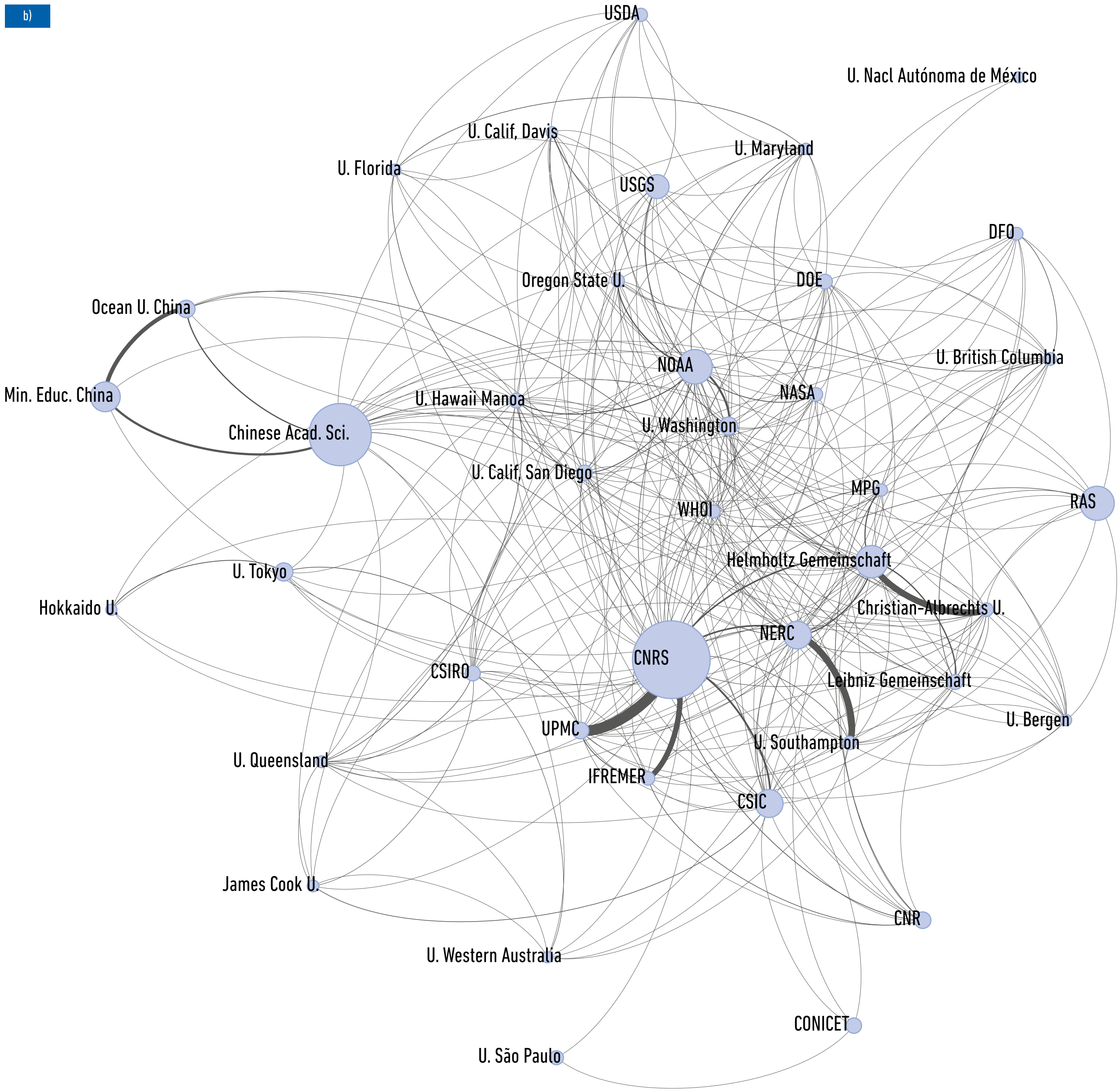


Figure 5.8b. *continued*

with Canada and also with China and, to a lesser extent, with Australia. In the periphery, weaker connections established between countries from different continents can be observed.

In terms of institutional collaboration, the largest nationally funded institutions dominate the landscape (Figure 5.8b). This is likely the result of different research models. The centre of the diagram is occupied by the European cluster composed of French organizations such as the Centre national de la recherche scientifique (CNRS), Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) and Pierre and Marie Curie University (UPMC), the Spanish Consejo Superior de Investigaciones Científicas (CSIC), the British Natural Environment Research Council (NERC) (all examples of a centralized model), and several German organizations (as an example of a decentralized model). A second cluster is made by US National Oceanic and Atmospheric Administration (NOAA) and several universities and other research organizations, including the Woods Hole Oceanographic Institution (WHOI), which has clear links with European organizations. A third large cluster is composed of several Chinese organizations; however, these do not maintain particularly strong links with the neighbours in the region (i.e. Japan, Korea). A fourth cluster is made up of Australian and New Zealand institutions, which are connected to both British and USA organizations. Canada's research structure is decentralized (composed of small organizations) with key collaborative hubs being Department of Fisheries and Oceans Canada (DFO) and the University of British Columbia. Apparently, Latin American institutions from Argentina (CONICET), Brazil (Univ. Sao Paulo) and Mexico (Univ. Nacional Autónoma de Mexico) have comparatively weaker international connections.

5.4.3. Opportunities to enable collaboration and promote excellent science

Multi-authored collaborations serve as a major opportunity for ocean science, as a wide range of competences and skills can be integrated to tackle difficult problems and improve the chances of success (Pan *et al.*, 2012). Indeed, the last decades have witnessed the formation of larger research teams supported by international programmes of the UN or by international commissions (see Chapter 7 for more information). Multi-institutional collaborations are more likely to lead to higher impact publications, especially if they involve different countries.

Geographic proximity is also likely to favour the process of giving and receiving credit for someone's work, expressed by paper citations. For most papers, one expects to find a diminishing probability of citation with distance, as new findings are typically more visible in the area where the authors operate (Van Noorden, 2010, 2012). In addition, collaboration patterns are likely to be influenced by results: while collaborating, scientists become more familiar with the scientific output of their co-authors, and then more stable collaborations are established and have a higher chance to be cited in the future. In turn, scientists who frequently cite each other's work have strongly overlapping research interests, and are more likely to become co-authors sooner or later. Therefore, citations and collaborations between distinct locations are highly correlated and it is good practice to improve scientific quality and transfer of knowledge and technology.

International cooperation enhances the flow of knowledge. It also helps to get a new result recognized by the scientific community in different geographical areas, which in turn may help to reveal how new scientific paradigms spread and get established.

The architecture of world science is changing with the expansion of global networks. These involve networks of individuals, communities of practice and groups, sometimes orchestrated and funded internationally or by cross-national structures such as the UN or the EU (Van Noorden, 2012). These global networks increasingly exert a significant influence on the conduct of science across the world and open new opportunities for collaboration and the promotion of excellent science.

When considering the motivations and benefits of international collaboration, the political and diplomatic dimensions also warrant reflection. Chapters 7 and 8 will explore the potential of scientific collaboration in greater detail.

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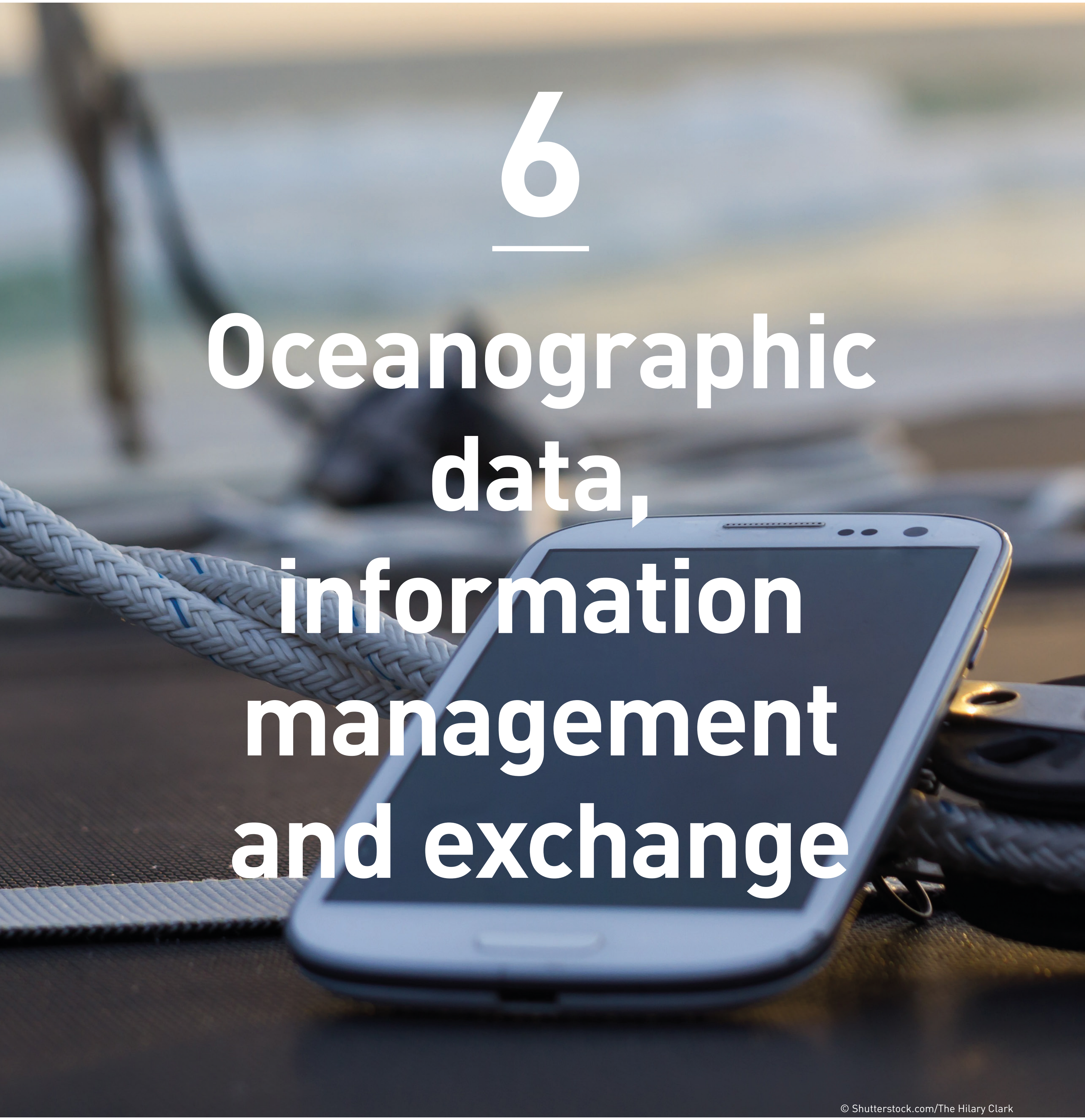

6

Oceanographic data, information management and exchange

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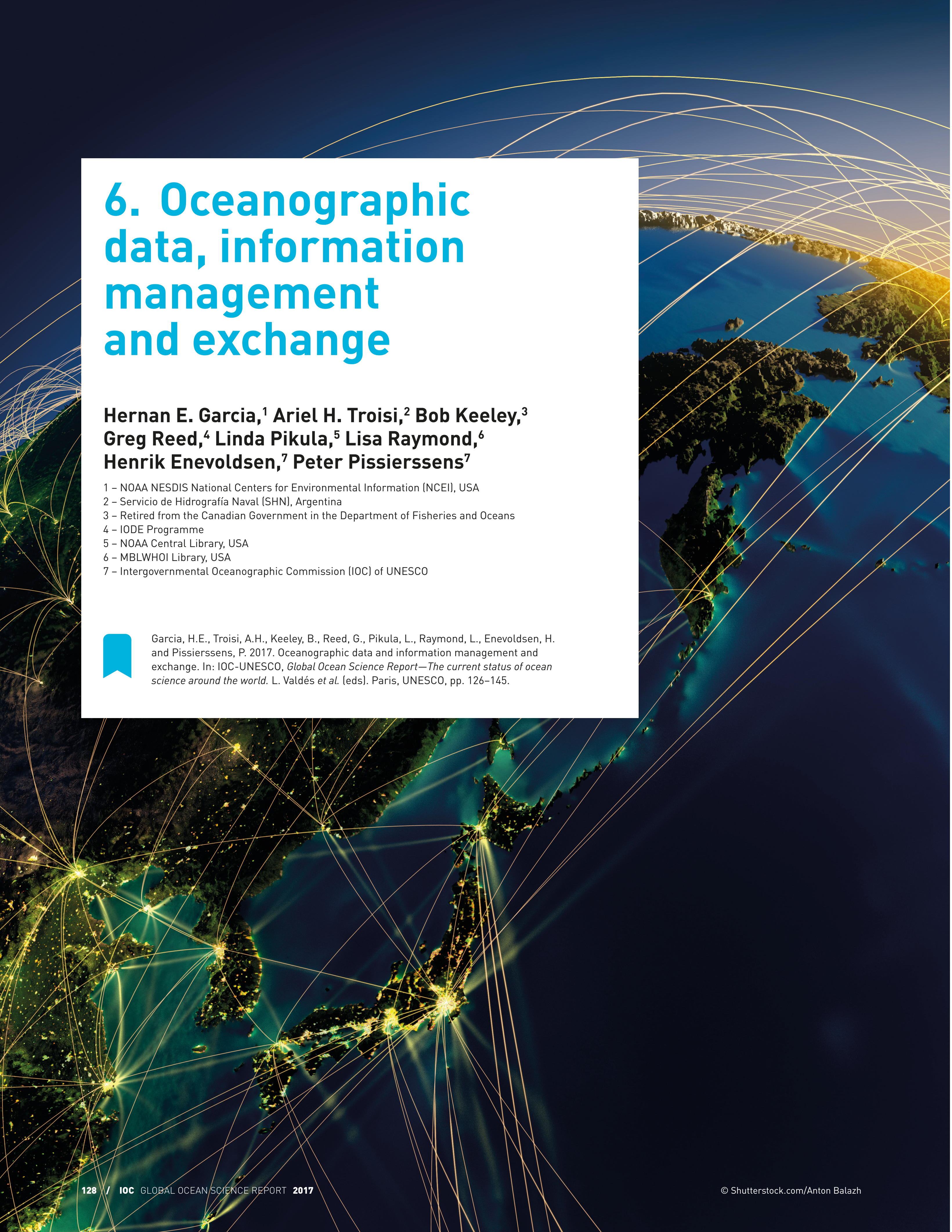

6. Oceanographic data, information management and exchange

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1 – NOAA NESDIS National Centers for Environmental Information (NCEI), USA
2 – Servicio de Hidrografía Naval (SHN), Argentina
3 – Retired from the Canadian Government in the Department of Fisheries and Oceans
4 – IODE Programme
5 – NOAA Central Library, USA
6 – MBLWHOI Library, USA
7 – Intergovernmental Oceanographic Commission (IOC) of UNESCO

Garcia, H.E., Troisi, A.H., Keeley, B., Reed, G., Pikula, L., Raymond, L., Enevoldsen, H. and Pissierssens, P. 2017. Oceanographic data and information management and exchange. In: IOC-UNESCO, *Global Ocean Science Report—The current status of ocean science around the world.* L. Valdés *et al.* (eds). Paris, UNESCO, pp. 126–145.

6.1. Introduction

To document and understand the dynamics and interactions of the world ocean in the context of the earth climate system, it is necessary to have access to relevant and timely oceanographic observational data and information. Documenting ocean mean-state and its variability has been a long-time goal of oceanographic science. A science-based, integrated approach to combine observations with appropriate data synthesis and modelling efforts enables informed decision-making in order to respond to and mitigate impacts of environmental change and improve resilience.

The global community has established the 2030 Agenda for Sustainable Development. In this framework, the Sustainable Development Goals (SDGs) adopted by the UN include a stand-alone goal for the oceans, SDG 14 'Conserve and sustainably use the oceans, seas and marine resources', as well as a goal for climate change, SDG 13 'Take urgent action to combat climate change and its impacts'. Other relevant agreements include the *Sendai Framework for Disaster Risk Reduction 2015–2030*, the *SIDS Accelerated Modalities of Action (SAMOA) Pathway* and the decisions adopted under the *1992 United Nations Framework Convention on Climate Change,* such as the *2015 Paris Agreement*. These agreements highlight the need for States to adopt scientifically sound and informed decisions, thus raising the need to collect, control, provide access to, and preserve data and information, as well as to exchange and implement best practices for data management.

In addition, the adoption by the UN General Assembly of Resolution 69/292 regarding the development of a new international legally binding instrument under the *1982 United Nations Convention on the Law of the Sea (UNCLOS)* on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction has prompted discussions at the international level on effective ways and means to access and use ocean data, including marine biodiversity data, information and products. In this context, the Ocean Biogeographic Information System (OBIS) has been recognized by States as a critical element to reach the proposed goals, being the most comprehensive gateway to the world's ocean biodiversity and biogeographic data and information required to address pressing coastal and world ocean concerns.

To characterize ocean variability, the international scientific community needs access to the most complete and reliable scientific databases of historical physical, chemical, geological and biological oceanographic observational data. The oceanographic data in these databases have been collected over time by different observing systems and for different purposes. Many global- to regional-scale surveys and time series of various water column variables have been carried out since the 1900s. Examples of international ocean observing programmes include the World Ocean Circulation Experiment (WOCE), the Argo Program, the Climate and Ocean: Variability, Predictability and Change (CLIVAR), and many others.

While ocean-observing systems provide access to a large amount of *in situ* data, the quantity of measured ocean Essential Climate Variables (ECV) as defined by the Global Climate Observing System (GCOS) varies considerably because these programmes are designed to sample certain variables only.[1] Some of these are part of the Essential Ocean Variables (EOVs) as defined by the Global Ocean Observing System. Some key EOVs are *in situ* temperature, salinity, ocean currents, nutrients, dissolved inorganic and organic carbon, inorganic carbon, dissolved gases such as oxygen, transient tracers, plankton, etc.[2] When these EOVs and other data are integrated into common data formats and quality-controlled databases, these have a significant impact on the development of valued-added scientific products. These databases are actively used for addressing a number of questions, ranging from diagnostic studies of ocean variability at multiple time and spatial scales to input for ocean data assimilation and numerical efforts to answer real world problems.

Regionally and globally, there is a diverse array of organizations, partnerships and programmes working with data and information compilation, sharing and management. The examples of organizations, partnerships and projects listed in Table 6.1 have diverse approaches and different degrees of open access to data. However, it reflects the widespread recognition of the importance and demand for ocean data and information management.

The International Oceanographic Data and Information Exchange (IODE) Programme of the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) has served a critical role in supporting the development of internationally recognized databases and projects, such as the World Ocean Database (WOD), the Global Oceanographic Data Archaeology and Rescue (GODAR), the Global Temperature and Salinity Profile Programme (GTSPP), the Underway Sea Surface Salinity Data Archiving Project (GOSUD), the International Quality Controlled

1 *GCOS* http://www.wmo.int/pages/prog/gcos/index.php?name=EssentialClimateVariables

2 GOOS EOVs http://goosocean.org/eov

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Table 6.1. Examples of the many organizations, partnerships and programmes working with ocean data and information management. Some of the organizations mentioned also operate globally. *Source*: IODE, 2017.

Region	Examples
Africa	PROPAO, IOGOOS, MESA, GOOS Africa, ODINAFRICA, MadaBIF, WIOMSA, UNEP clearinghouse mechanism, PIRATA, MOLOA, AWA, AfrOBIS.
South America including the Caribbean	CMA, CLME, SPINCAM, ODINCARSA, Caribbean OBIS, CPPS-OBIS.
Europe	ICES, HELCOM, SeaDataNet, EMODNet, Copernicus, Jerico, CAFF, EUROFLEETS, HAZADR, PERSEUS, MEDIN, GEBCO, GEOTRACES, GLOSS, Argo, AtlantOS, EMSO, IQUOD, OceanSites, IbiROOS, CoCoNet, Emblas, Black Sea SCENE, AORA, Caspinfo, WoRMS, OTN, LTER, LIFEWATCH, EMBRC, NAMMCO, ICCAT, MyOcean, SOOS, EuroGOOS, MedGOOS, EurOBIS, MedOBIS.
Asia/Pacific including North America and Oceania	UNEP/NOWPAP, GEOTRACES, ODIP, GOOS, NEAR-GOOS, ODINWESTPAC, WESTPAC, MOMSEI, WMO, IHO, PICES, ICES, SEAOBIS, J-OBIS, OBIS-USA.

Ocean Database (IODE-IQuOD) and OBIS. These international projects and associated databases have stimulated exchange of historical and modern oceanographic data. Further, these projects have promoted synergy, leading to the development of quality-control procedures and the integration of research-quality data at local, regional and global scales, resulting in a continuing increase of ocean data stored in these databases (Figure 6.1).

The main challenges and potential gaps facing the acquisition, management and exchange of data and information at this time are: (i) sustaining robust ocean observing systems that include EOVs; and (ii) ensuring that data collected by different countries are made accessible in an open and timely manner through robust databases using common data formats and metadata best practices – and served using inter-operable data delivery systems. Only in such an integrated and open data access framework is it possible to document regional to global climate-related events and inform society and decision-makers. At present, the Marine Climate Data System (MCDS) and Global Data Assembly Centres (GDACs) serve as data flow mechanisms to help integrate oceanographic data streams through enhanced coordination.

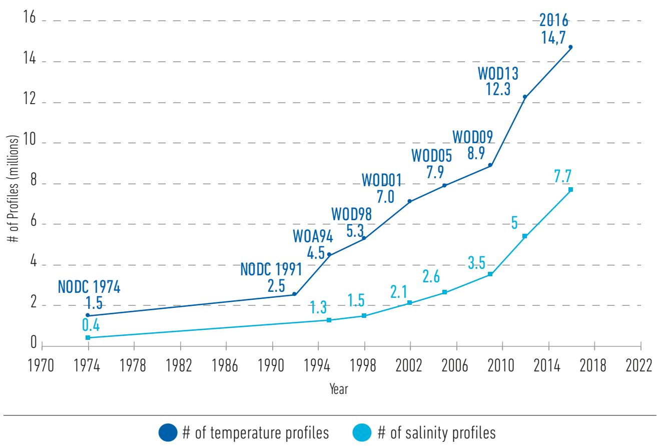

Figure 6.1. Increased ocean data sets, examples of temperature and salinity profiles stored in the World Ocean Database. *Source*: IODE, 2017.

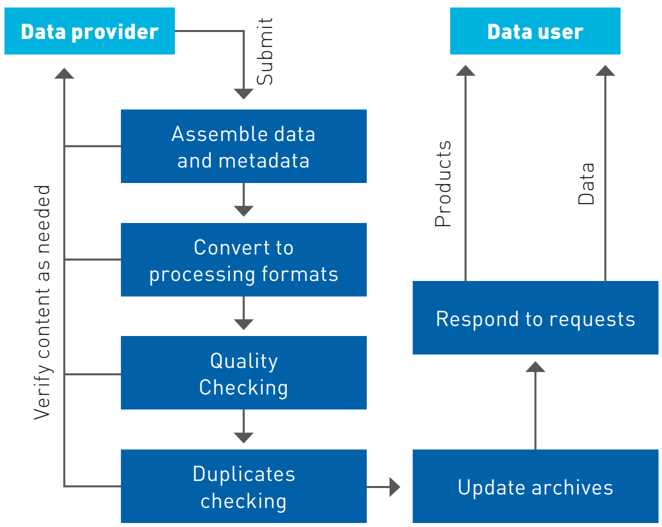

Figure 6.2. Data management processing chain. *Source*: IODE, 2017.

6.2. Data management

The term 'data management' encompasses a wide range of activities. It describes the activities to assemble data, the assessment of the quality and completeness of the data, the insertion of the data into a safe and secure long-term archive, and the dissemination of archived data to those who seek it (Figure 6.2; Austin *et al.*, 2016).

Raw data themselves, such as scientific measurements of sea-surface water temperature, are insufficient to ensure the applicability of those numbers to a particular problem. It is important that data managers also include information about how the data were collected. Information such as what instruments were used, including the precision of the instrumentation, the collection procedures, and when the data were collected, are vitally important. These are usually referred to as metadata, and their inclusion in data management procedures is crucial. Assembling both data and metadata requires a strong connection between data collectors and data managers.

Once data and metadata have been brought together in the hands of a data manager, the processing towards inclusion into the archive begins. There are many steps in the processing and these include verification that all data and metadata are complete. Questions such as 'Are all the units of the numbers reported?', 'Is the format of the data file fully explained?' and 'Are all the needed metadata present and clearly associated with the appropriate data?' need to be answered. After these questions are resolved, processing begins, usually to try to reassemble the data and metadata into data structures compatible with the way the archive is built. Of particular importance is the need to ensure that any unit conversions take into consideration changes in precision of the measured values. All of this must be done carefully to ensure no information is lost or degraded in the process.

After this, the data usually pass through a series of data quality checks that allow for the identification and flagging of incorrect data caused by instrument errors or incorrect handling of the instrument. These checks are designed to exploit known characteristics of the property being measured by the instrument employed. For example, water temperatures from a polar region are not likely to exceed certain values, and the significant number of decimals reported is dependent on the instrument resolution. Quality checks are often contained in a battery of tests, from simple checks (e.g. temperatures must fall within specified ranges) to more sophisticated comparisons (e.g. against ocean climatologies).[3]

An important consideration is verifying that data received by an archive has not already been stored in an identical or near identical form at an earlier date. Reasons for this occurring include: reprocessing by data providers; arrival of higher quality, delayed mode data versus real-time equivalents; and mistakes in sending data sets. Determining if data received has arrived at an earlier time is not a simple process, in particular because the newly arrived data may have changed values. It is not uncommon that resolution of this issue requires advice from data providers. Data and metadata verification sometimes leads to questions that have to be referred back to the data collector for resolution. This is an important step to ensure fidelity of the data placed in the archive.

The data archive step is usually straightforward once all of the above questions have been answered. The data structure of an archive is the complicated part. While in principle it is desirable for data to reside in a single archive, this is a challenge given the wide variety of data and metadata collected. It is more often the case that data are split into different types, with different data archive structures that reflect the characteristics of each type. This represents a tension, since when delivering data to a user, it is desirable to deliver whatever data are asked for, ideally in a single format or in as few different formats as possible. The objective is to make data processing as simple for the user as possible.

The main objective of data management is to ensure safe and long-term (i.e. eternal) storage of data and metadata so that present and future users are able to use all of the data that have been collected over time. Delivery of data and metadata is, therefore, a vital step. An archive must be able to respond in a timely way to requests for the data and information it holds, and to deliver these to a user in a way that is suited for their purposes. This is a great challenge. The data and metadata collected today are very diverse and there are greater demands for multi-disciplinary studies. In addition, the user community of an archive is not solely the same people who provide data; rather, the range of users includes scientists, engineers, a diverse range of other actors from public (e.g. policy-makers) and private sectors. The capacity of these different groups to handle digital data, especially in complex data structures, is also varied. An archive strives to support all of its users,

3 Climatologies are defined as the long-term averages of certain variables, often over time periods of 20–30 years.

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and so must have facilities to deliver both complete and comprehensive data sets to those with full data processing capabilities, as well as data sets filtered to meet the needs of users with lower processing capabilities. Any filtering applied must preserve the precision and other characteristics of the data and must ensure that any uncertainties associated with the data and metadata are also carried. This is vital so that all users have the opportunity to judge the appropriateness of the data received to the problem they are addressing.

Beyond delivering the data in digital form, archives also frequently choose to deliver other products. These can be maps of data availability, maps of measurements (for example sea-surface temperatures), statistical analyses of the contents of archives (such as error rates detected in processing), and so on. The type of products generated is usually determined by the number of times requests for such products are made and the operational reporting procedures of an archive (both to users and the governing bodies of an archive).

An effective data management team needs to include professionals who are well-connected to both data providers and users. Ideally, those working with data providers should have hands-on experience in the discipline related to the data received; they are known as subject-matter experts. Because of the diversity of data, it is not often feasible for all data expertise to be represented in data management teams. Therefore, data management teams need to develop strong relationships with data providers to learn from their experience and ensure that data management processes are appropriate for the type of data assembled. Data managers must also be able to talk with users, to understand the problem they are addressing, and to explain how archive contents may be brought to bear. Sometimes a user will ask for data, when a simple data product will meet their needs. A conversation with a user, before work begins, can help to tailor and deliver data or products to effectively meet a user's needs.

Of course, part of the data management team must be composed of computer experts, who maintain the data processing systems and write the necessary software for processing. The combination of computer expertise and subject-matter expertise in the design and building of data management systems is crucial.

As a term, 'data management' is compact and descriptive of what is required. But unpacking the elements of effective data management shows that there are many components and a great deal of expertise needed. All of this cannot exist without a stable environment of human and financial resources. A long-term archive by definition exists over lifetimes. Well-functioning data management and archive systems provide the baseline measurements for climate and trend analyses.

6.3. International cooperation on oceanographic data/information management and exchange

6.3.1. The International Oceanographic Data and Information Exchange Programme (IODE)

The IOC was established in 1960.[4] It promotes international cooperation and coordinates programmes in marine research, services, observation systems, hazard mitigation, and capacity development in order to understand and effectively manage the resources of the ocean and coastal areas. Nowadays, IOC is the recognized United Nations mechanism for global cooperation in the study of the oceans (UN DOALOS, 2010). Almost immediately after the creation of IOC, the IODE programme was established in 1961, *'to enhance marine research, exploitation and development, by facilitating the exchange of oceanographic data and information between participating Member States, and by meeting the needs of users for data and information products'*.

The main objectives of the IODE Programme are to: (i) facilitate and promote the discovery, exchange of, and access to, marine data and information, including metadata, products and information in real-time, near real-time and delayed mode, through the use of international standards, and in compliance with the IOC Oceanographic Data Exchange Policy for the ocean research and observation community and other stakeholders; (ii) encourage the long-term archival, preservation, documentation, management and services of all marine data, data products, and information; (iii) develop or use existing best practices for the discovery, management, exchange of, and access to marine data and information, including international standards, quality control and appropriate information technology; (iv) assist Member States to acquire the necessary

4 IODE (International Oceanographic Data and Information Exchange) http://www.iode.org/index.php?option=com_content&view=category&id=5&Itemid=89 *(Accessed 20 November 2016).*

capacity to manage marine research and observation data and information and become partners in the IODE network; and (v) support international scientific and operational marine programmes, including the Framework for Ocean Observing for the benefit of a wide range of users.

The IODE network has successfully managed to collect, control the quality of, and archive millions of ocean observations, and makes them available to Member States. The IODE data centres have a mandate to manage all ocean-related data variables including physical oceanography, chemical, biological, etc. In addition, IODE collaborates closely with, and services the needs of, the other IOC and related programmes such as Ocean Sciences, Global Ocean Observing System (GOOS), Marine Spatial Planning (MSP), Integrated Coastal Area Management (ICAM), and the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), among others. Another major and long-term commitment of the IODE Programme is the long-term accessibility and archival of oceanographic data, metadata and information to safeguard present and future holdings against loss or degradation.

From the start, the IODE Programme has focused on the building of a global community of national data centres, each established and maintained by IOC Member States. The number of such National Oceanographic Data Centres (NODCs) has grown steadily since 1961 to the current total of 65. In addition to the data management facilities at NODCs, the number of research groups, projects, programmes and institutions that manage their own data and provide their own – often online –data services, increases. The IODE network welcomes these new data centres as Associate Data Units (ADUs), of which 20 have been established since 2013. For more than 50 years now, the IODE programme has built not only a network of data centres but also a wide variety of specialized databases.

It should also be noted that there does not exist any formal education related to oceanographic data management. The IODE Programme has developed an active training programme over the past decades to address this gap. Today, IODE operates its OceanTeacher Global Academy programme that provides continuous professional development for staff of the data centres associated with the IODE network.

In addition to the intergovernmental global network of oceanographic data centres established under the auspices of IODE, regional and national data centres developed their own networks. The following sections describe two of these networks: SeaDataNet (the European network of national data centres, Section 6.3.2) and the Australian Ocean Data Network (Section 6.3.3). The activities of the Ocean Data Interoperability Platform are also briefly reviewed (Section 6.3.4). The platform promotes the development of a common framework for marine data management to facilitate the discovery and access of marine data through national, regional or international distributed ocean observing and data management infrastructures.

6.3.2. SeaDataNet

SeaDataNet is a European distributed infrastructure operated by the NODCs and marine information services of the major research institutes from 34 coastal States bordering the European seas. The SeaDataNet infrastructure provides harmonized discovery services and access to ocean and marine environmental datasets, managed in over 100 distributed data centres, as well as a range of metadata services, tools and standards that have been widely adopted across Europe. SeaDataNet has developed, and maintains, a set of common standards for the marine domain, which include:

- metadata profiles of the ISO 19115 standard for datasets and research cruises;
- metadata formats for data collections, research projects, monitoring programmes and networks and organizations;
- controlled vocabularies for the marine domain, with international governance, user interfaces and web services;
- standard data exchange formats for download services; and
- standard quality control procedures.

The SeaDataNet infrastructure comprises a network of interconnected data centres and a central portal providing users with a unified and transparent overview of the metadata and controlled access to the large collections of datasets, managed by the interconnected data centres. The Common Data Index (CDI)[5] data discovery and access service provides online access to more than 1 million datasets through a portal interface for requesting access, and if granted, for downloading datasets from the network of distributed data centres. SeaDataNet has also developed a set of dedicated software tools and online services for sharing metadata and data resources across its infrastructure. Common software tools are made freely available to data managers and end-users for data and metadata editing, conversion, analysis and interpolation.

5 http://seadatanet.maris2.nl/v_cdi_v3/search.asp

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SeaDataNet has defined a data policy that aims to strike a balance between the rights of investigators and the need for widespread access through the free and unrestricted sharing and exchange of data, metadata and data products.[6] The final goal of this policy is to serve the scientific community, public organizations and environmental agencies, and to facilitate the production of advice and status reports by stating the conditions for data submission, access and use. The policy applies to data managed by SeaDataNet partners for providing access to data managed across the distributed systems. The data policy is consistent with national and international policies and laws and is intended to be fully compatible with the European INSPIRE Directive.[7]

The next phase will be the SeaDataCloud project, which aims to advance SeaDataNet services and increase their usage, adopting cloud and HPC technology for better performance in cooperation with EUDAT, the network computing infrastructure developing and operating a common framework for managing scientific data across Europe.

6.3.3. Australian Ocean Data Network

The Australian Ocean Data Network (AODN) is an interoperable online network of marine and climate data resources, administered by the Integrated Marine Observing System (IMOS),[8] a national collaborative research infrastructure supported by the Australian Government and led by the University of Tasmania in partnership with the Australian marine and climate science community. The aim of the AODN is to make marine data, from publicly-funded projects as well as data from private industry and not-for-profit organizations, accessible and freely available over the internet. These data cover a wide range of ocean environment parameters, including data collected from ocean-going ships, autonomous vehicles, moorings and other platforms. The scope of observations geographically covers Australia's coastal, continental shelf and open oceans across disciplines (physical, biogeochemical and biological).

The objectives of the AODN are:

- to populate the AODN with publicly funded data and to make these data accessible to a wide community; and
- to encourage and develop the culture of data sharing across the marine science community of Australia.

The primary access point for search, discovery, access and download of data collected by the Australian marine community is the AODN portal, which is the single access point for marine data published by AODN contributors.[9] The marine data collections published in the AODN portal are wide-ranging, and all data collections can be downloaded through the user interface and are freely available to the public. The infrastructure of the portal follows international standards and agreements for data and metadata formatting, discovery and sharing. The portal incorporates a catalogue of metadata, a search interface driven by facets utilizing controlled vocabulary terms, and a map interface that can be used to interact with AODN datasets and offers data download in a number of formats.

The AODN has developed a data policy, which is aimed at making marine data available through the AODN Portal. The AODN does not generate any original data itself but is focused on publishing third party data. A condition of participation in the AODN is that all data provided is freely accessible at no charge to third parties. All data provided to the AODN must be adequately documented with metadata and arrangements made for data to be held by the custodian organization or an alternate organization for long-term access. The data policy recommends that all data be licensed through an appropriate open access Creative Commons license, preferably the 'By Attribution' (CCBY) licence. Data products have been developed using observations made available through the AODN partners. One example is the Australian Shelf Seas Atlas,[10] comprising a collated database of *in situ* salinity and temperature observations from coastal and shelf waters around Australia, collected over the 20-year period between 1995 and 2014, which have been assembled into a single data collection. These data have been supplemented by data from the World Ocean Database.

6.3.4. Ocean Data Interoperability Platform

SeaDataNet and the AODN, together with the IODE, partner in the Ocean Data Interoperability Platform (ODIP),[11] a project that aims to promote the development of a common framework for marine data management to facilitate the discovery and access of marine data through the development, implementation, population and operation of national, regional or international distributed ocean observing and data management

6 http://www.seadatanet.org/Data-Access/Data-policy

7 http://inspire.ec.europa.eu/

8 http://imos.org.au/

9 https://portal.aodn.org.au/

10 https://imos.aodn.org.au/imos123/home?uuid=f9b50e93-df47-4317-8f1f-f3ed2fed7093; https://imos.aodn.org.au/imos123/home?uuid=0a21e0b9-8acb-4dc2-8c82-57c3ea94dd85

11 http://www.odip.eu/

infrastructures. ODIP aims to leverage existing marine data infrastructures to establish a common global framework for data management that will potentially overcome many of the barriers to the sharing of marine data. ODIP aims to build consensus, trust and cooperation between partners in order to have a coordinated approach towards the harmonization of the marine data management infrastructures that can be applied and adopted globally.

In summary, regional and national networks make an important contribution to their respective communities, as well as contributing to the broader international community through the IODE network of NODCs.

6.4. Marine information management

6.4.1. From data to research knowledge

IODE Marine Information Managers (MIMs) are essential partners in the research management and the scholarly communication life cycle; they play an increasingly collaborative role with data collectors and managers. There are many significant trends developing in information management, which can provide support to data managers and scientific authors in creating knowledge. IODE, through its MIMs, leads projects and products, is assisting in this process and implements new technologies and tools. The terms of reference for IODE National Coordinators for Marine Information have been adopted by the IODE Committee.[12]

Many MIMs are involved in research data and others need instruction in data literacy. They are collecting, organizing and exploiting information, data, expertise and other knowledge assets, which are held within their organizations, ensuring that these assets remain available for future use. On an international scale, networks of MIM centres are collaborating to produce products and services to strengthen our global understanding of ocean processes and conditions. Marine information management is a vital process in the ocean knowledge cycle.

The users of marine information include research scientists, policy-makers and students at all levels, educators, industry and businesses. MIMs interact with marine data managers to deliver information products in a variety of online media formats. The data may be repackaged in the form of websites, regional repositories of stored and accessible scientific research publications, images, data, online catalogues of specialized collections, digitized collections of scientific studies that may be otherwise difficult to find, electronic citation databases, and internet bibliographies. MIMs establish national and international standards to disseminate this information, and they form groups of networked individuals and professional societies to collaborate on new products, training courses and technology for the delivery of marine and atmospheric information.

In the past, library collections were based on physical items on a shelf. Electronic publications allow for wider access to the scientific literature, but spiralling costs make it impossible for many libraries to subscribe to everything researchers want. IODE compiled the OpenScience Directory,[13] which provides a list of free or low cost e-journals for developing countries and also funds membership for some Member States in the International Association of Aquatic and Marine Science Libraries and Information Centers (IAMSLIC) that supports the Z39.50 Distributed Library and Interlibrary Loan Program, thus expanding timely access to science publications for Member States.

The journey of marine libraries from analogue to digital is enhanced by the international 'open access' movement. Open access is the free, immediate, online availability of research articles combined with the rights to use these articles fully in the digital environment. Open access is a much-needed modern update for the communication of research that fully utilizes the internet for the purpose for which it was originally built, i.e. to accelerate research free of many restrictions on use (copyright and licence restrictions). Open access can be applied to all forms of published research output. Although electronic journals and online library catalogues have existed in marine science libraries for many years, the 'Open Access repository' or 'Institutional Repository' (IR) has now been designated as one method to fulfil governmental, funder and national mandates to provide free and open access to the results of funded research. Subject repositories, such as OceanDocs[14] and other institutional repositories developed by Member States, play an auxiliary role in making publications accessible. IODE has developed standards for best practice for data publication and guidelines for data centres and librarians with e-repositories (Leadbetter *et al.*, 2013).

12 http://www.iode.org/nc-mim

13 http://www.opensciencedirectory.net/

14 http://www.oceandocs.org/

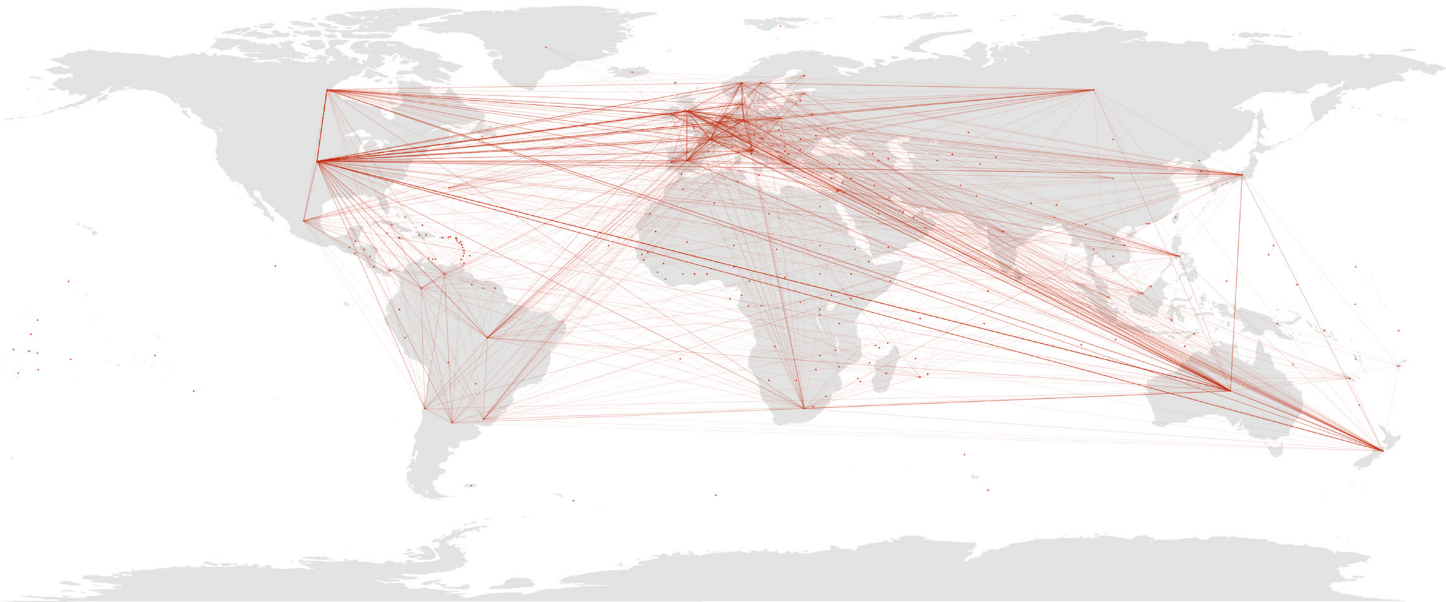

Figure 6.3. Connections of the co-authors' country affiliations of about 500 publications that cited OBIS and that are recorded in Web of Science (over 1,000 OBIS –cited papers are listed at http://www.iobis.org/library, maintained with support from the library of the Flanders Marine Institute). Data points without connections represent single authored papers. *Source*: OBIS, 2017 bibliometric data set at http://www.iobis.org/library and Web of Science.

General trends in marine information management include open access, interoperability of systems, increased emphasis on international collaborations and the development of networks. The development of collaborative networks has been recognized as important to accelerate the pace and progress of scientific scholarship which has long been a goal of IOC in general, and IODE specifically. OceanExpert[15] provides a networking tool utilizing personal, persistent identifiers, which can link to a scientist's career publications, activities, scientific events and institutions. The increasing use of persistent identifiers and linked data will likely have a significant impact on the type of future services offered by MIMs. IODE also participates in initiatives such as the Research Data Alliance (RDA), ensuring that the marine science community is associated with the development of international data standards and best practices for MIMs.

New technologies are enabling more sophisticated analysis of research outputs. Performance metrics (e.g. bibliometrics) for research data and publications measure the impact of scientific research on individual, institutional, national and international levels (Chapter 5). These studies are often carried out by advanced academic and research organization libraries. Utilizing visualization techniques, collaborative networks are shown on an international level. The example shown in Figure 6.3 illustrates the numerous connections among scientists who formed collaborations, which led to the production of scientific articles citing OBIS. It is notable that there are not only North-North but also North-South and South-South connections. Through open access to data, OBIS provides equitable access and benefits to research and enhances international collaboration.[16]

A significant barrier has been the wide variation in best practices and standards between and within disciplines. IODE addresses this need through the development of the OceanDataPractices platform[17] and the OceanKnowledge Platform Pilot Project.[18] These are excellent examples of IODE trying to apply interoperability and standards to their products and projects. UNESCO, IOC and IODE projects and products make marine information openly and freely accessible.

15 http://www.oceanexpert.net/

16 The contribution of OBIS to marine scientific research has been recognized by the UN General Assembly (see for example: A/RES/69/245).

17 http://www.oceandatapractices.net/

18 http://www.iode.org/okn

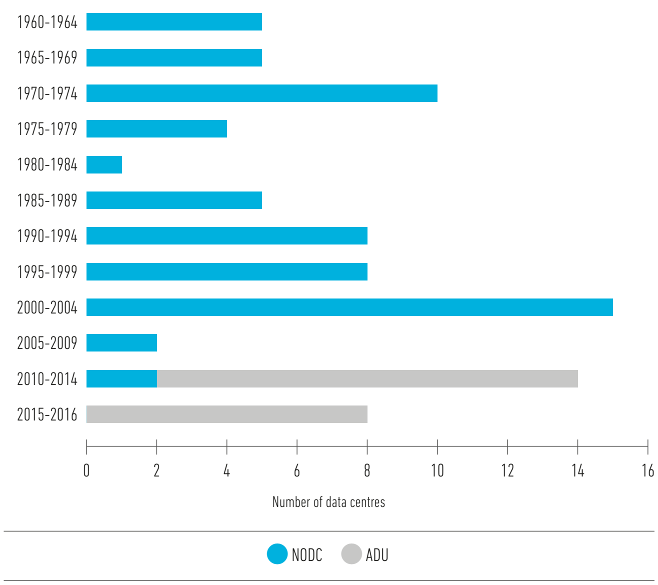

Figure 6.4. Number of IODE NODCs/ADUs created between 1960 and 2016 (NODCs shown in blue; ADUs shown in grey). *Source*: IODE, 2017.

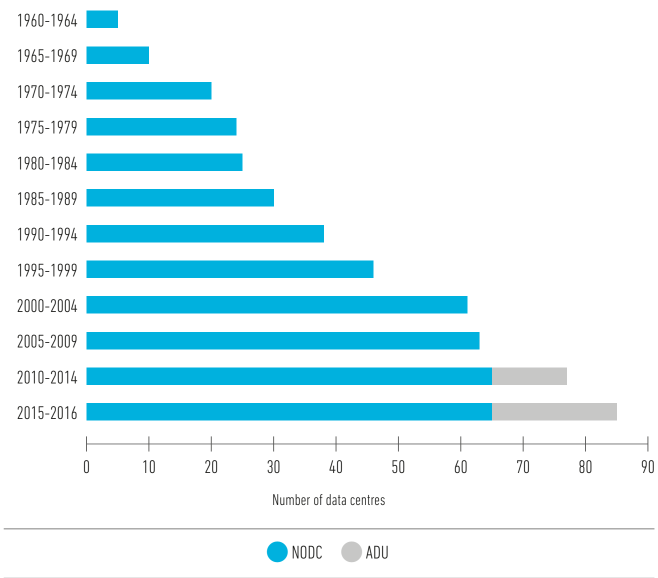

Figure 6.5. Cumulative number of IODE NODCs/ADUs created between 1960 and 2016 (NODCs shown in blue, ADUs shown in grey). *Source*: IODE, 2017.

The OceanTeacher Global Academy[19] utilizes open source software to store courses in marine data and information management along with other marine science topics. These resources can help MIMs and data managers provide services that rely less on traditional collections and more on knowledge creation and new information products.

A potential gap is the need for resources to support data literacy and the hesitation of librarians to participate in the data movement. The principles and values of the field of library and information science bring a unique and necessary perspective to the evolving data science discipline. Learning resources, such as '23 Things: Libraries for Research Data—Research Data Sharing Without Barriers',[20] can assist MIMs with incorporating data management into their practice of information services. Increased collaboration with data managers is recommended.

6.5. National capacity assessment for data and information management

The IODE is the global data centre network that deals only with oceanographic data management and exchange. However, oceanographic research centres, projects and research groups are increasingly managing and disseminating their own data. The IODE network has therefore started inviting these additional entities to join the IODE network as ADUs.

6.5.1. IOC Member State participation in international oceanographic data exchange

To achieve the objectives of IODE, the IOC Member States, under the IODE Programme, have established a global network of NODCs and, since 2013, ADUs (including OBIS nodes).

Figure 6.4 and Figure 6.5 show that there have been two peak periods in the establishment of NODCs: 1970–1974 and 2000–2004. The latter was due to the Ocean Data and Information Network for Africa (ODINAFRICA), a project funded by the Government of Flanders (Kingdom of Belgium); which operated between 1997 and 2014 and was instrumental in developing oceanographic data and information capacity in

19 http://classroom.oceanteacher.org/

20 https://www.rd-alliance.org/23-things-libraries-research-data-rdas-libraries-research-data-interest-group.html

Africa. The possibility for projects, programmes, institutions or organizations to establish ADUs as from 2013 has increased the number of data centres by 30% (from 65 to 85), thereby demonstrating the increasing capacity of entities other than NODCs to manage oceanographic data.

The data presented here are based upon responses to an online survey carried out between 24 June and 19 September 2016 among the IODE community (IODE national coordinators for data management, IODE national coordinators for marine information management, IODE Associate Data Unit contact points). Out of 114 contacts, a total of 76 (67%) responded. Of these respondents, 47 belong to an NODC, 17 to an ADU or OBIS regional node and 17 are marine librarians. Note that some institutions host both a data centre and a marine library.

In order to enable distinguishing regional differences, the results provided combine the responses received from NODCs and ADUs (n=57) and are grouped into four regions (Annex G). Note that for some of the countries there was more than one respondent.

6.5.2. Cooperation with other data centres and IOC programmes

Globally, the large majority of data centres are involved in national, regional and global collaborative activities (Figure 6.6). The main regional initiatives in Latin America involving cooperation on data and information management includes the Caribbean Marine Atlas (CMA), the Caribbean Large Marine Ecosystems (CLME), the South-East Pacific Data and Information Network in support to Integrated Coastal Area Management (SPINCAM), and the Ocean Data and Information Network for the Caribbean and South America Regions (ODINCARSA).

In Africa, there is a high percentage of regional collaboration through ODINAFRICA as well as through regional Large Marine Ecosystem (LME) projects such as the GCLME and the CCLME. Specific initiatives for Africa also include PROPAO, IOGOOS, MESA, GOOS Africa, MadaBIF, WIOMSA, UNEP clearinghouse mechanism, PIRATA, MOLOA, and AWA.

In the Asia/Pacific region, there are also a number of specific organizations and initiatives involved in cooperation on data and information management, including the UNEP/NOWPAP, GEOTRACES, ODIP, GOOS, NEAR-GOOS, ODINWESTPAC, WESTPAC, MOMSEI, WMO, IHO, PICES and ICES.

The investment by the European Commission in regional ocean data projects such as SeaDataNet, EMODNET and ODIP but also collaboration in ICES, HELCOM, EuroGOOS and MedGOOS, is clearly seen in its high percentage of regional collaboration. Other key initiatives in Europe include Copernicus, Jerico,

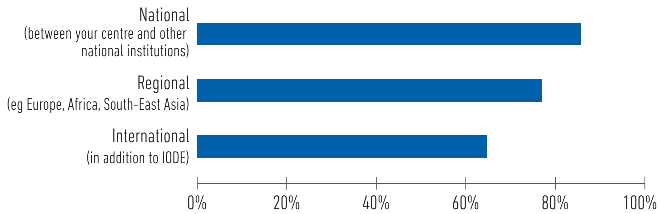

Figure 6.6. The percentage of national data centres involved in three types of collaboration: national, regional and international. *Source*: IODE survey, 2016 (answered by 57 focal points).

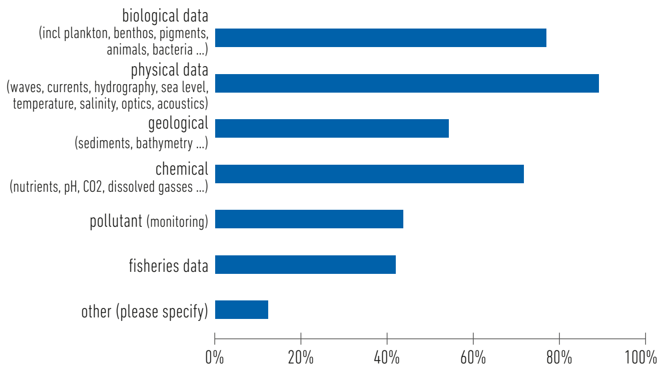

Figure 6.7. Observational data types regularly collected and managed by national data centres as a percentage of respondents. *Source*: IODE survey, 2016 (answered by 57 focal points).

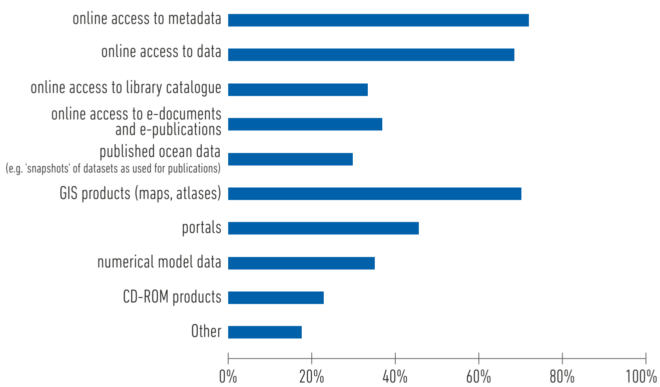

Figure 6.8. The data and information products provided to clients by data centres as a percentage of respondents. *Source*: IODE survey, 2016 (answered by 57 focal points).

CAFF, EUROFLEETS, HAZADR, PERSEUS, MEDIN, GEBCO, GEOTRACES, GLOSS, Argo, AtlantOS, EMSO, IQUOD, OceanSites, IbiROOS, CoCoNet, Emblas, Black Sea SCENE, AORA, Caspinfo, WORMS, OTN, LTER, LIFEWATCH, EMBRC, NAMMCO, ICCAT, MyOcean, and the SOOS.

6.5.3. Oceanographic data types managed by NODCs

Overall, the IODE data centres mostly manage physical data, followed by biological data and chemical data (Figure 6.7). Less than half of the centres collect data on marine pollutants and fisheries.

However, at the regional level there are differences in which data types are handled at NODCs or ADUs. In Latin America, Europe (including the Russian Federation) and Asia/Pacific, there is a fairly equal coverage of physical, biological and chemical data but a lower coverage of geological and geophysical data, except in the Asia/Pacific region. In Africa, biological, physical and fisheries data dominate the activities of data centres, while geological, chemical and pollutant data are less important currently. Similarly, Latin American data centres reported little work conducted with pollution data.

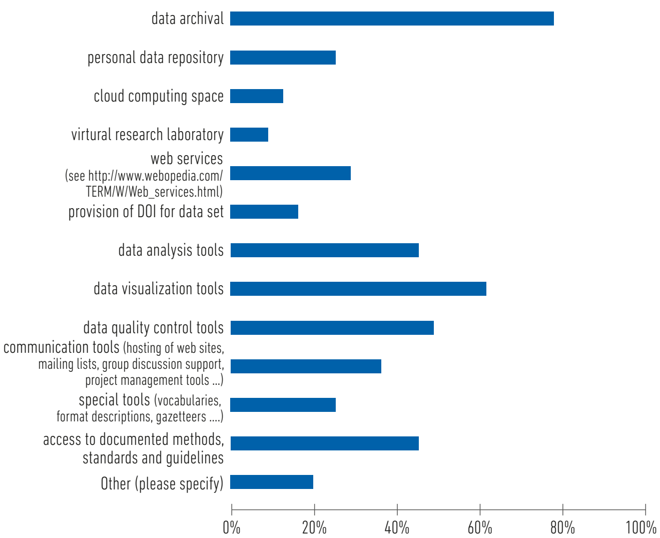

Figure 6.9. Services provided by data centres to clients as a percentage of respondents. *Source*: IODE survey, 2016 (answered by 57 focal points).

6.5.4. Services provided by NODCs and ADUs

The data and information products provided to users by data centres also vary among NODCs and ADUs, with the top three products globally being: (i) online access to metadata; (ii) provision of GIS products; and (iii) online access to data (Figure 6.8). Regionally, all regions show the highest percentages in the provision of online geographic information system (GIS) products. Giving access to metadata and data is one of the biggest services delivered by data centres in Europe (including the Russian Federation) and Asia/Pacific. Generally, providing open access to oceanographic/ocean data is becoming standard practice, however only few data centres in Latin America and Africa report this as one major activity. A similar pattern can be observed for numerical model data, which is also reflected in that only Africa relies strongly on dissemination of data on CD-ROM.

Globally, the top three services provided by data centres to clients are: (i) data archival; (ii) data visualization; and (iii) data quality control tools (Figure 6.9). The least provided services include virtual laboratory, cloud computing space and provision of DOIs for data sets.

At the regional level, NODCs and AUDs in all four regions report the provision of data archival services as one of their main data management activities. Only Latin America shows a slightly below-average percentage (Figure 6.10). However, looking at data visualization, 100% of Latin American data centres provide this service which, in contrast, is only rarely performed by African data centres. Similarly, the offering of data quality control tools by data centres located in Africa is lower than other regions.

The clients and end users of data, products or services provided by data centres are diverse and represent many sectors of society, reflecting the broad relevance of oceanographic data and information to the economy, research, public administration and businesses, in particular. Globally, the core users of data, products or services are national and international researchers, as well as the general public, followed by policy-makers and the private sector, according to the results of the IODE survey (Figure 6.11). The regional analysis does not reveal any significant differences between the regions in terms of user audiences, except for Asia/Pacific where national researchers are the top clients.

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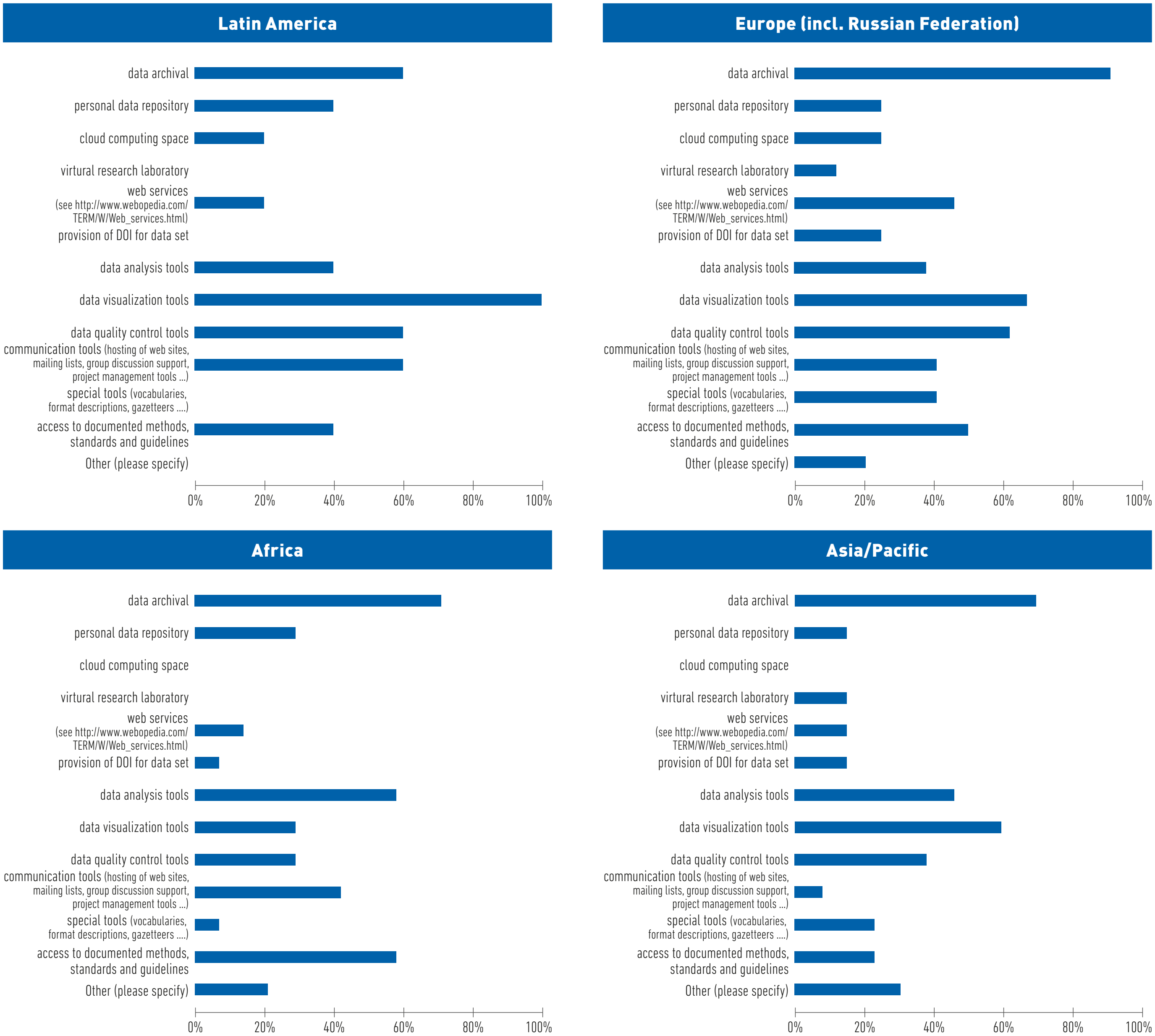

Figure 6.10. Services provided by data centres to clients as a percentage of respondents per region. *Source*: IODE survey, 2016 (answered by 57 focal points).

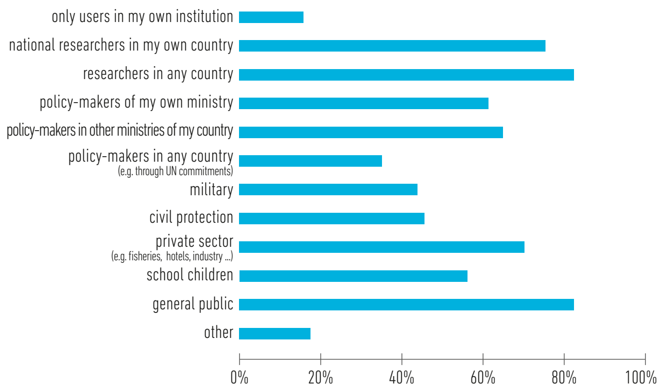

Figure 6.11. Clients and end-users of data, products or services provided by data centres. *Source*: IODE survey, 2016 (answered by 57 focal points).

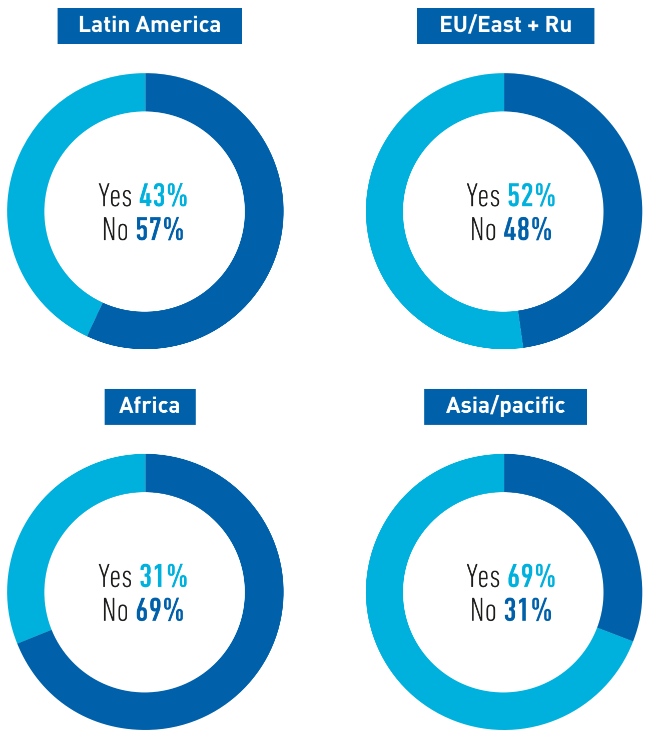

Figure 6.12. Illustration of how many of the data centres surveyed have a national data policy on the management and sharing of data. *Source*: IODE survey, 2016 (answered by 56 focal points).

6.5.5. Data policy and data access restrictions

Defined national policies for data storage and sharing is one indicator of the priority given to ensuring that oceanographic data and information is stored, shared and used (Section 6.1). Globally, there is a balance between countries that do – or do not – have a national data sharing policy.

The regional analysis, however, shows a significant difference, with 69% of Member States in the Asia/Pacific region having a national data sharing policy, compared to only 31% of Member States in Africa (Figure 6.12).

Overall, data sharing and open access to data is a core component of international and regional oceanographic data and information management systems. It is a prerequisite for most of the societal groups presented in Figure 6.11 to have access and to make use of data, data products and services. The extent to which this is possible depends on national data being shared with little or no restriction. Globally, 63% of data centres restrict access to 'certain' data types and 40% apply a restriction during a certain period of time (Figure 6.13).

The regional analysis reveals that all respondent Latin America data centres restrict access to data, while the data centres, which do not apply any restrictions, make up from 10% (Europe, including the Russian Federation) to 35% (Africa; Figure 6.14). The practice of geographic restrictions is predominately practised by data centres located in Asia/Pacific and Latin America. Restrictions during a certain time period are also common in the Asia/Pacific region.

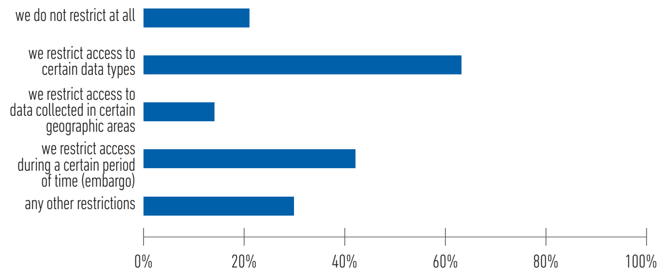

Figure 6.13. The percentage of data centres which restrict/do not restrict access to data. *Source*: IODE survey, 2016 (answered by 57 focal points).

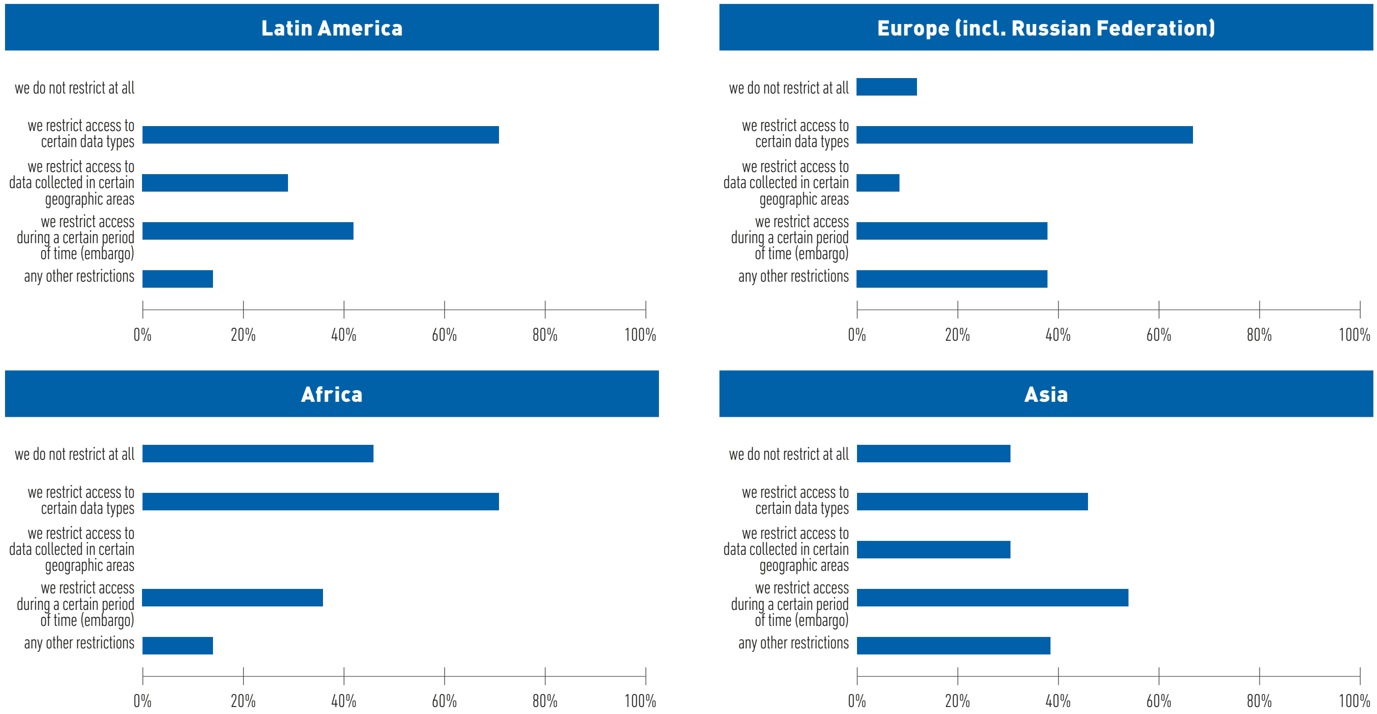

Figure 6.14. The percentage of data centres which do/do not restrict access to data by region. *Source*: IODE survey, 2016 (answered by 57 focal points).

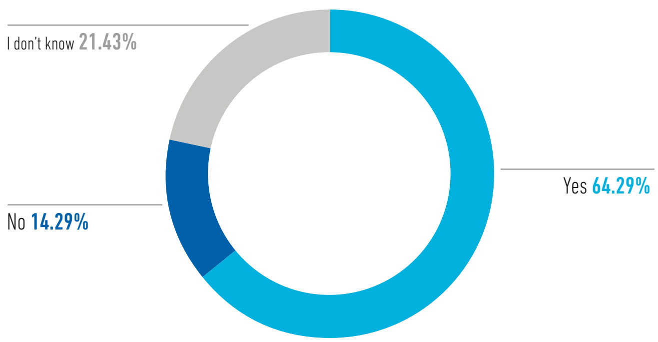

Figure 6.15. The distribution of data centres that do or do not apply the IOC Oceanographic Data Exchange Policy adopted as Resolution IOC-XXII-6. *Source*: IODE survey, 2016 (answered by 56 focal points).

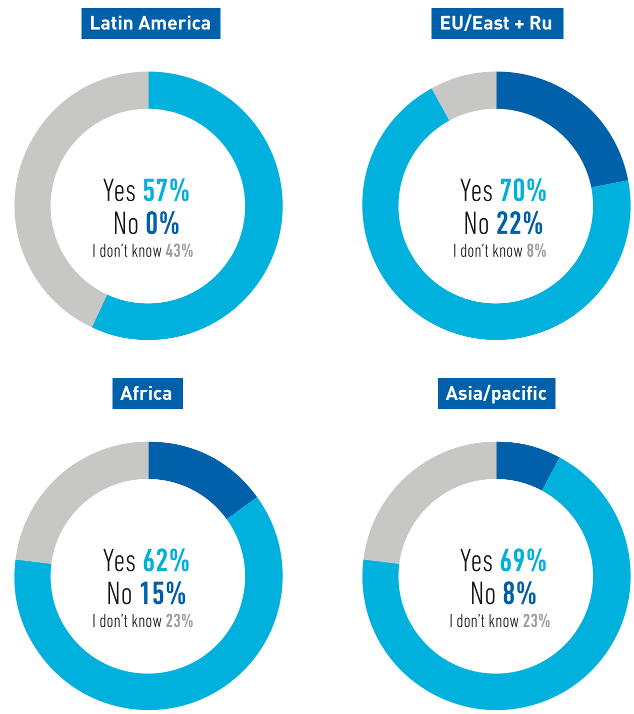

Figure 6.16. Distribution of data centres that do or do not apply the IOC Oceanographic Data Exchange Policy by region. *Source*: IODE survey, 2016 (answered by 56 focal points).

The timely, free and unrestricted international exchange of oceanographic data is essential for the efficient acquisition, integration and use of ocean observations gathered by the countries of the world for a wide variety of purposes, including the prediction of weather and climate, the operational forecasting of the marine environment, the preservation of life, the mitigation of human-induced changes in the marine and coastal environment, as well as for the advancement of scientific understanding that makes this possible.

Recognizing the vital importance of these purposes to all humankind and the role of IOC and its programmes in this regard, IOC Member States agree to an IOC policy for the international exchange of oceanographic data and its associated metadata. Globally, 64% of the IODE data centres apply the IOC Oceanographic Data Exchange Policy, but 21% indicated in the survey that they did not know if their Member State applied the IOC Oceanographic Data Exchange Policy (Figure 6.15).

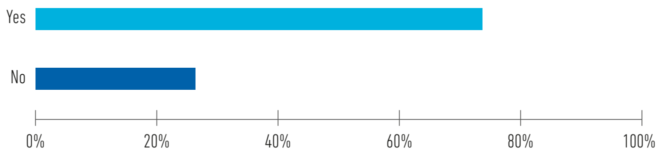

Figure 6.17. Illustration of whether data and information from data centres are contributed to international systems or not (i.e. data actively sent or made available to, for example, world data centres, global data assembly centres or other such international systems). *Source*: IODE survey, 2016 (answered by 57 focal points).

The regional analysis shows the highest application of the IOC data policy in data centres located in Europe (including the Russian Federation) and Asia/Pacific, followed by Africa (Figure 6.16). Latin America data centres show low awareness of the application of the policy in their data centres.

6.5.6. Data sharing with other networks

Another way to illustrate the extent of data sharing is to look at whether data and information from data centres are contributed to international systems, in terms of data actively sent or made available to, for example, world data centres, GDACs or other such international systems. The survey showed that, globally, the majority (74%) of data centres actively cooperate and share information/data with other international systems and networks (Figure 6.17).

However, there are significant differences from region to region with respect to if and how data and information are shared among the international or regional data systems. The European data centres are the most active in sharing data with other systems and networks, whereas Africa reported little data sharing with larger data systems (Figure 6.18). Global systems, such as OBIS, Global Biodiversity Information Facility (GBIF) and Argo, receive data from all regions.

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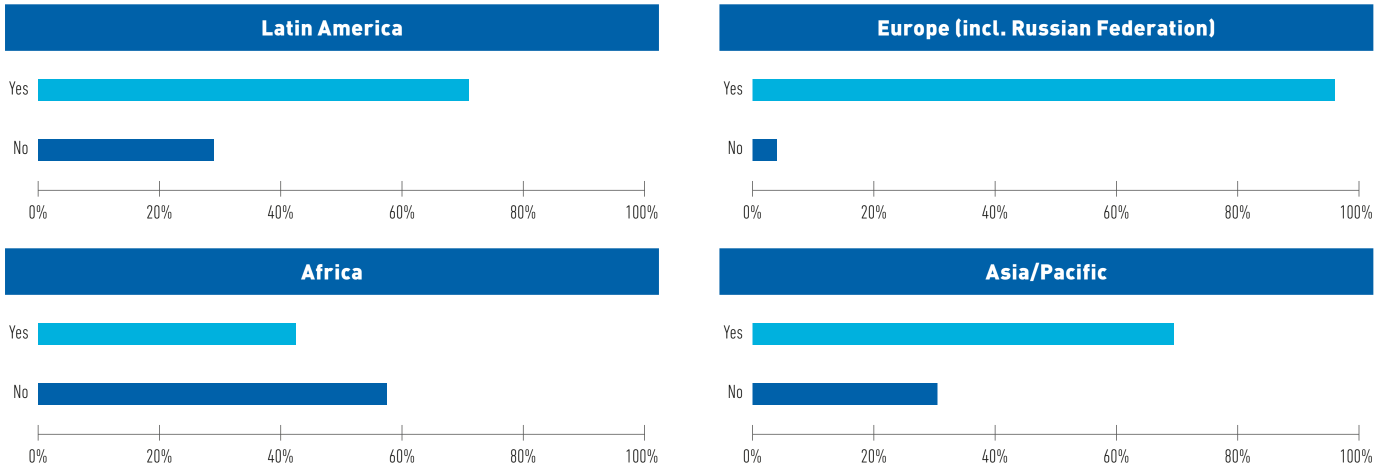

Figure 6.18. Illustration by region of whether data and information from data centres are contributed to international systems or not (i.e. data actively sent or made available to, for example, world data centres, global data assembly centres or other such international systems). *Source*: IODE survey, 2016 (answered by 56 focal points).

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7

International organizations supporting ocean science

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7. International organizations supporting ocean science

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7.1. Introduction

When considering the motivations and benefits of international collaboration in ocean science, the policy and administrative dimensions deserve some reflection. For much of the twentieth century, marine scientific activity and advice was concentrated in a small number of countries. During the last few decades of the twentieth century, science and innovation have become increasingly and genuinely global (Royal Society, 2011). Many of the major global challenges of the twenty-first century have scientific dimensions (Owen *et al.*, 2012) and more science is now being undertaken by more people in more places, forcing managers and decision-makers to expand their views and continuously update their scientific knowledge. This applies for scientists themselves and for those non-scientists who are involved in international scientific or conservationist civil society organizations.

Within science, researchers themselves manage the production of knowledge in many ways. They regulate the production of knowledge, control what counts as knowledge – through peer review and replication – and manage how science is communicated by means, such as conference presentations and professional publications (European Commission, 2009). In addition, scientists heavily influence processes of research funding through peer review and grant panels, and they guide decisions about the hiring and promotion of fellow scientists.

External management seeks to provide, regulate and distribute science by: (i) upstream funding of some types of research over others, thus channelling scientific research in specific directions; (ii) enforcing standards for people and organizations; (iii) attaching certain attributes, such as property rights, to scientific knowledge and the products of innovation; (iv) downstream regulation or restricting what are considered the misapplications and misuses of new science and technology; and (v) educating the public and encouraging debate about the products and processes of science (European Commission, 2009). In addition, science diplomacy[1] facilitates international cooperation and assists in the transfer of knowledge and technology among countries as well as capacity-building to less developed countries.

In brief, ocean science policy concerns the prioritization of scientific research areas, steering the production and application of knowledge for environmental protection, food security, human health and well-being or any other number of sectors, within and across nations. Because ocean management is by tradition sector-oriented (for example: capture fishing and aquaculture, shipping, offshore oil and gas, and offshore renewable energy) and therefore fragmented, ocean matters are debated in a vast array of inter-governmental, non-governmental, and multistakeholder forums and coalitions. These are regulated by a number of bilateral and multilateral binding agreements, and non-binding instruments dealing with various matters of ocean management and relating to a multitude of sectors. As the number of intervening organizations grows, so do risks of duplication, overlapping competencies and lobbyism, potentially constraining political action or justifying inaction. In fact, the divergence between the scientific and political 'tempo' can undermine science policy efforts; the high pace of the scientific and technological innovation poses challenges for governments and the public to adjust quickly to emerging and urgent scientific and environmental issues.

The increasing use of ocean space and resources, and rising interest of civil society in ocean matters, has also led to a sense that existing sector-oriented regional and international policy arrangements are not able to efficiently and effectively address complex ocean issues. These new developments partially explain the emergence of numerous new actors, mostly non-governmental organizations (NGOs), with 'watch-dogging' and rapid response capacity, in the scientific diplomacy landscape.

Many institutions and initiatives dealing with ocean issues exist, at local, national, regional and global levels. They often overlap geographically and/or in their mandates or subject matter agendas, which results in weak coherence. In this regard, the large number of existing organizations involved in ocean management face challenges in relation to their perceived objectivity and dependability.

This chapter aims to provide an overview of existing international legal and institutional frameworks supporting[2] ocean science, management and related issues. It aims to guide the reader through a complex landscape of organizations, international legal instruments and governance processes in a logical and meaningful way, presenting a functional understanding of the organizations, how they are connected and clustered in groups according to their interest, mandate and policy roles, among other criteria. This chapter establishes linkages between institutions that deal directly or indirectly with ocean issues across different spatial scales (regional and global) and frameworks (international, intergovernmental and non-governmental).

1 Science diplomacy is the use of scientific collaborations among nations to address common problems and to build constructive international partnerships.

2 For the purpose of this chapter, the term 'support' includes a wide scope of elements such as: providing scientific guidance, stewardship, interest, advocacy, advice, policy, management, governance, provision of products and/or services, information, lobbing, etc.

It must be noted that it is not the purpose of this chapter to produce any recommendation to reconcile institutional agendas (which are sometimes intersecting) related to management and/or sustainable use of the ocean. However, the information provided here and the conclusions drawn from this information may be useful for strengthening institutional coordination and/or for empowering people to make informed, science-based decisions.

7.2. International organizations and processes relevant to ocean science and management

Effective management of human activities in the ocean requires multilateral and regional management frameworks (Campbell *et al.*, 2016; Thrush *et al.*, 2016; Tjossem, 2016). This section discusses the wide array of organizations, instruments and processes involved in ocean science and management, ranging from short-term operational management to long-term policy development and planning, and from conventional forms of administration to modern forms of participative decision-making (Appendix)[3].

7.2.1. International governmental organizations (IGOs)

An international governmental organization or intergovernmental organization (IGO) is an organization composed primarily of bodies of sovereign States (often referred to as member States) or of other intergovernmental organizations. IGOs are established by a treaty, convention or other agreement that acts as a charter creating the group and, once ratified by the member States, provides the IGO with an international legal personality.[4] IGOs are key contributors to public international law. They are party to numerous agreements and are important facilitators of scientific collaboration.

Intergovernmental organizations differ in function, membership and membership criteria. They have various goals, mandates, scopes and geographical coverage, often outlined in a treaty. Some have a broader scope, e.g. the United Nations (UN), while others may have a subject-specific mandate and/or regional coverage, such as Regional Fisheries Management Organizations (RFMOs) or organizations such as the Mediterranean Science Commission (CIESM, formerly the International Commission for Scientific Exploration of the Mediterranean Sea). The following types of intergovernmental organizations are considered in this chapter:

- Global organizations which comprise – and are open to – nations worldwide, provided certain criteria are met, such as the UN and its specialized agencies;
- Regional international legal instruments under the UN umbrella, including UN subsidiary bodies established to facilitate regional management structures; and
- Regional international organizations, which are open to members from a particular continent or specific region of the world.

7.2.1.1. The UN system for ocean science knowledge and environmental management[5]

Ocean affairs in the UN system are spread by sectors of activity among several UN entities. These sectors include fishing, shipping, mining, pollution, science and many others. Depending on their specific mandate, UN entities provide different services such as technical assistance and capacity-development, research and data management, support of intergovernmental processes, financial assistance, methodologies and outreach (Valdés, 2017). In addition, agencies within the UN system have authority to negotiate treaties and conventions, which are landmarks of international law.

The UN array of agencies and organizations and the international law enshrined in treaties and conventions constitute the foundations for the current UN architecture that deal with ocean science/knowledge and global environmental management. The architecture is completed with two additional pillars: global research programmes, together with other initiatives on good practices for environmental management and governance instigated by the UN system; and science-policy interfaces (Valdés, 2017). These four constituent elements are assembled in a quadruple helix model (Figure 7.1)[6] as proposed by Valdés (2017).

The robustness of the helix models lies in the fact that through the circulation of knowledge, new findings in science, know-how

3 The GOSR questionnaire (2015) included a section on 'Regionally and globally supporting organizations on ocean science'. The responses from the member States were used for the examples and compilation of organizations in this chapter, and a full list of organizations and acronyms is presented in Appendix *to this chapter*.

4 Intergovernmental organizations in a legal sense should be distinguished from groupings or coalitions of states, such as the Group of 7 (G7), which have not been founded by a constituent document and exist as a forum.

5 For additional information on this topic see Valdés, 2017.

6 For more information on helix models see Carayannis and Campbell (2011)

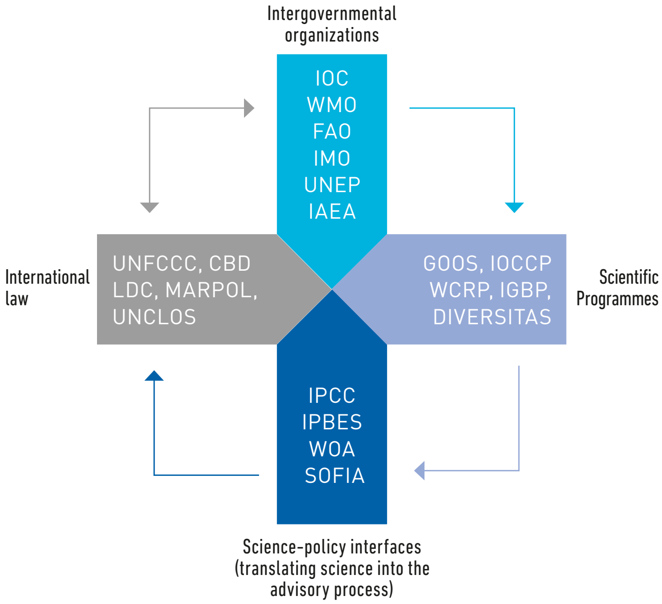

Figure 7.1. Quadruple helix model showing the UN architecture for ocean science knowledge and environmental governance (the list of organizations and entities shown here is not exhaustive). *Source*: redrawn from Valdés (2017).

or decisions made in one helix sub-system become knowledge input to a different helix sub-system (Carayannis and Campbell, 2010). According to Valdés (2017), in order to secure stability in this quadruple helix and to facilitate sustainable development, each of the four described pillars (helices) has a special and necessary role with societal and scientific relevance, as follows:

- **Intergovernmental entities**: UN agencies and organizations are the backbone of the multilateral political system, providing political legitimacy to decisions. These organizations are critical, as they formulate the collective need of nations and provide the 'will to do and to act'. They also assign resources and act as promoters of international law (Valdés, 2017). For the purpose of this study, the following 13 entities have been identified that are directly involved – or have a specific mandate – in ocean matters (in alphabetic order): Food and Agriculture Organization of the United Nations (FAO), International Atomic Energy Agency (IAEA), International Labour Organization (ILO), International Maritime Organization (IMO), Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), International Seabed Authority (ISA), United Nations Department of Economic and Social Affairs (UN-DESA), United Nations Division on Ocean Affairs and the Law of the Sea (UN-DOALOS), United Nations Development Program (UNDP), United Nations Environment Program (UNEP), United Nations Industrial Development Organization (UNIDO), World Bank (WB), and World Meteorological Organization (WMO).

- **International law for the management of the natural environment:** International conventions and treaties are legally binding for countries that have formally ratified them and are crucial enablers for sustainable development and management of the marine environment. They set frameworks and targets (based on scientific knowledge but also on socio-economic scenarios) for international efforts to protect the environment by regulating human activities and impacts. Intergovernmental organizations can contribute to and participate in the negotiation of treaties and conventions. Their secretariats and member States stimulate dialogue among them as well as with social actors in order to adapt legislation to address emerging issues, new scientific knowledge and socio-economic circumstances (Valdés, 2017). Some examples of international marine treaties/conventions[7] are (in alphabetic order): *Convention on Biological Diversity* (CBD), *Convention on the Conservation of Migratory Species of Wild Animals* (CMS), *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (London Convention or LDC), *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (BWM Convention), *International Convention for the Prevention of Pollution from Ships* (MARPOL), *United Nations Convention on the Law of Sea* (UNCLOS) and *United Nations Framework Convention on Climate Change* (UNFCCC) (Appendix).

- **Scientific programmes for sustainability**: These programmes foster scientific knowledge generated by natural, social and human sciences for sustainable development – including the understanding of ecosystem functioning and the connections to human health, well-being and security – to enable political decisions to be made on the basis of solid scientific evidence (Valdés, 2017). Currently, some of the Global Environmental Change (GEC) programmes and projects existing since 1992 are in transition into a new overarching initiative named Future Earth.[8] These GEC programmes were launched and supported by intergovernmental and non-governmental international organizations, such as the International Council for Science (ICSU), WMO, UNESCO, IOC-UNESCO and UNEP.

- **The science-policy interface**: This is a set of processes that enable most of the scientific knowledge produced by scientific programmes for sustainability to be digested and translated into policy-relevant information. Therefore, this helix provides comprehensive information on the issues

7 These conventions were referred to in the responses of IOC member States to the GOSR questionnaire (2015).

8 http://www.futureearth.org/

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demanded by international law and intergovernmental organizations, so that the latest scientific findings are reflected in high-level policy discussions (such as Conference of the Parties, the governing bodies of international conventions and other governance meetings). There are several science-policy interface processes in the UN system. One of the best known, by the general public and policy-makers, is the Intergovernmental Panel on Climate Change (IPCC) which distils and assimilates climate change research and publishes its conclusions in the form of the renowned Assessment Reports.[9] Other relevant science-policy interfaces are the State of World Fisheries and Aquaculture (SOFIA), the World Ocean Assessment (WOA) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (Valdés, 2017).

Many times, and mostly for external observers, it may seem that two or more organizations overlap or duplicate in their mandates and/or activities. Sometimes this is a misperception of the mandate/approach relating to certain activities, which are in most cases complementary, because there is generally a will to cooperate rather than compete (Valdés, 2017). Nevertheless, the UN General Assembly (UNGA), in successive resolutions (such as 56/12, 57/141 and 58/240), requested the UN Secretary-General to ensure an effective, transparent and regular inter-agency coordination mechanism among relevant entities of the UN secretariat as well as related organizations involved in 'oceans and coastal issues' within the UN system (Valdés, 2017). This was the origin of UN-Oceans (Section 7.2).

7.2.1.2. Regional instruments under the UN umbrella

The motto *'think globally, act locally'* is valid for the UN system. Willing to facilitate regional management structures, the UN has promoted or adopted under its umbrella a number of regional subsidiary bodies such as FAO regional fisheries organizations, UNEP regional seas programmes and IOC regional sub-commissions. The information and the analysis provided by these regional actors bring real benefits at the global level when they address the ocean as a whole. Nevertheless, on some occasions, they deserve additional efforts to go beyond regional particularities and tropism.

According to FAO (2012), regional fisheries bodies (RFBs) are mechanisms through which States and organizations work together towards the conservation, management and/or development of fisheries and related issues. Some RFBs have an advisory mandate, and provide advice, decisions or coordinating mechanisms that are not binding for their members. Other RFBs have a management mandate and have binding regulatory powers for the managed area. These Regional Fisheries Management Organizations (RFMOs) and Arrangements (RFMAs) focus on fisheries management at the regional level (Figure 7.2a). Currently, there are more than 50 RFBs worldwide, only about half of which are RFMOs with a management mandate, and only a limited number of RFMOs are able to institute binding measures on members in areas beyond national jurisdiction.

The UNEP Regional Seas Programme, launched in 1974, aims to address the accelerating degradation of the world's ocean and coastal areas through the sustainable management and use of the marine and coastal environment. Today, more than 143 countries participate in 13 Regional Seas programmes established under the auspices of UNEP (Figure 7.2b).

The IOC regional sub-commissions cover: the Caribbean and Adjacent Regions (IOCARIBE), the Western Pacific (WESTPAC), and Africa and the Adjacent Island States (IOCAFRICA). The IOC has also established regional committees: for the Central Indian Ocean (IOCINDIO) and the Black Sea (BSRC). These are intergovernmental subsidiary bodies of the IOC, responsible for the coordination and supervision of scientific and service activities at the regional level.

The promotion and implementation of various regional scientific programmes and projects has been supported by a number of UN organizations and funded by the Word Bank and the Global Environmental Facility (GEF). For example, GEF has been supporting 23 Large Marine Ecosystems (LME) projects since 1998, leading to the establishment of multisectoral LME Commissions in some regions (Chapter 8).

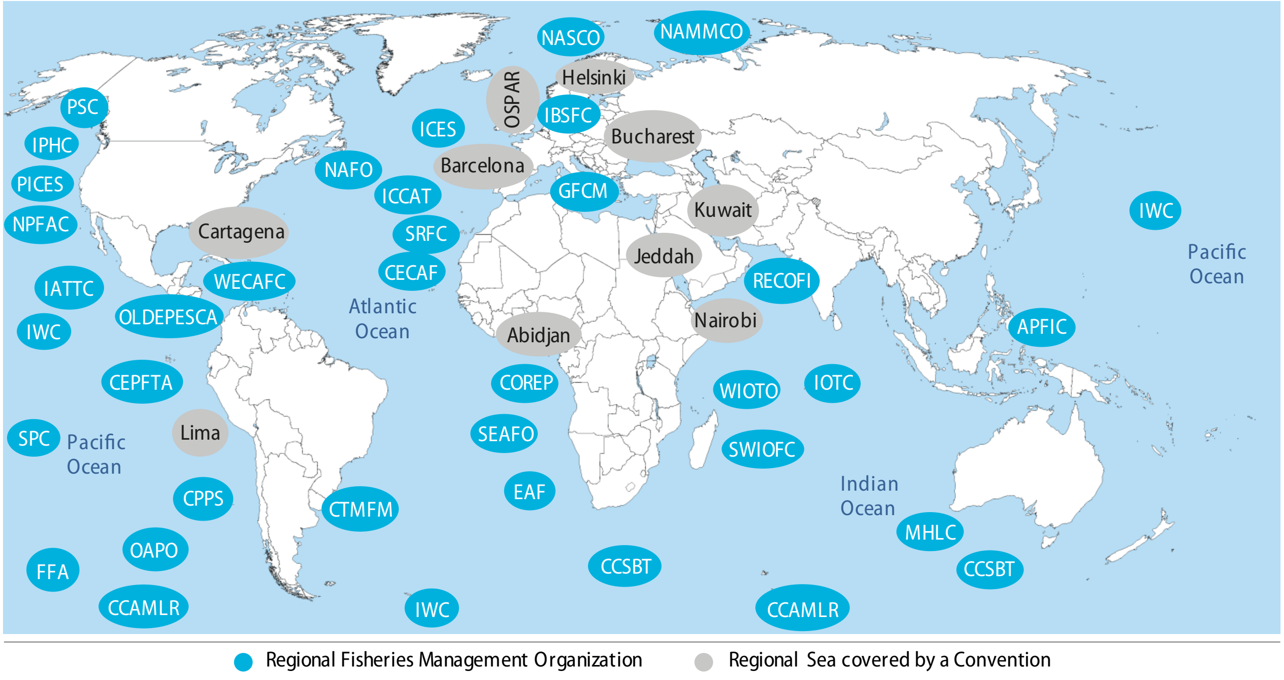
7.2.1.3. Regional international organizations

Regional international organizations are open to members from a particular continent, region or ocean basin in the world. The origin of regional international marine organizations goes back to 1902, when the International Council for the Exploration of the Sea (ICES) charter was officially adopted by 8 countries (growing very rapidly up to the present 20 member States). The founders of ICES envisioned an international scientific collaboration that would achieve the production of knowledge[10] on a scale that would be impossible based on investigations by a single nation (Rozwadowski, 2002). The establishment of ICES predated the establishment of CIESM in 1919 and the International

9 So far, the IPCC has published five Assessment Reports.

10 ICES, together with the International Association for the Physical Sciences of the Oceans (IAPSO), an NGO founded in 1919, was instrumental in the adoption of the *Standard Seawater* used during most of the *twentieth* century (Culkin and Smed, 1979).

a) Main FAO regional fisheries management organizations and regional seas covered by conventions



b) Main UNEP regional seas programmes and initiatives

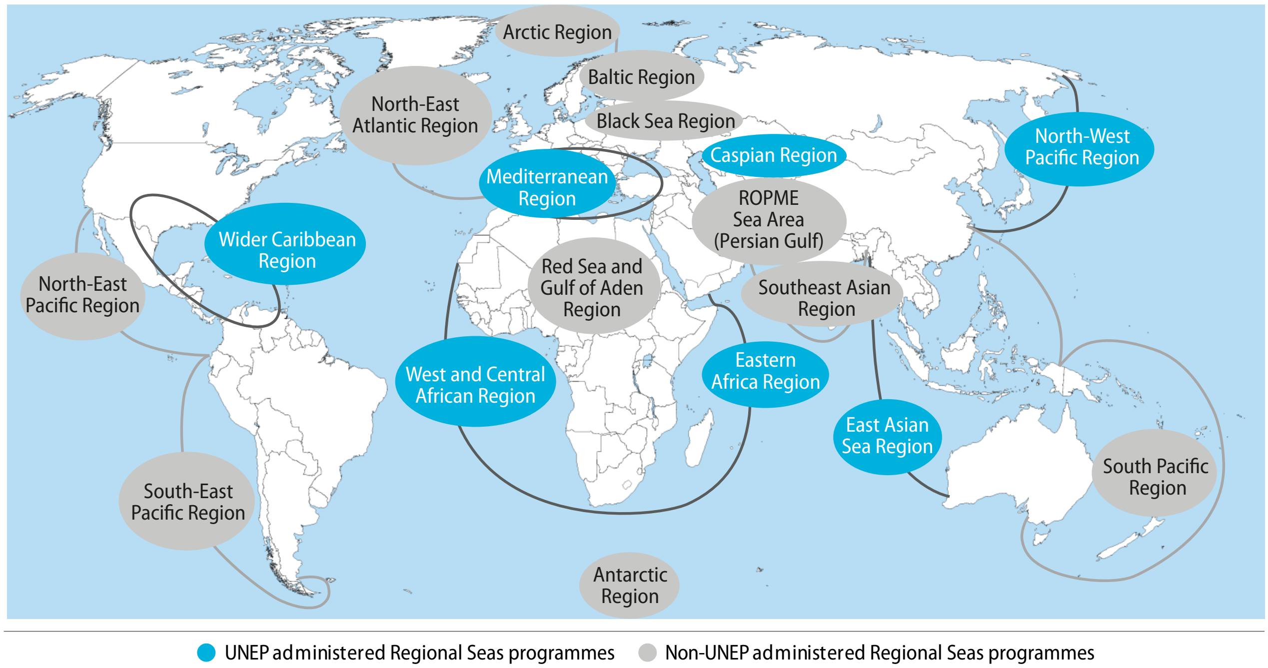


Figure 7.2. Maps showing: **a)** the main FAO Regional Fisheries Management Organizations and regional seas covered by conventions; and **b)** the main UNEP Regional Seas programmes and initiatives. *Sources*: (a) FAO, 2009 and UNEP, 1982 (updated 2010); (b) UNEP, 1982 (updated 2017).

Hydrographic Organization[11] (IHO) in 1921. Their vision quickly won them international recognition that still exists today, even with the later emergence of UN agencies. Their role and achievements in promoting science and management were crucial for understanding the expansion of such typology of international organizations to other ocean basins and regional seas.

Regulation of ocean uses and exploitation of resources in the regional seas and in areas beyond national jurisdiction needs collective action on an international scale. This stewardship is provided by international/intergovernmental organizations and is one of the main drivers for their establishment (Olson, 1965; Ostrom, 1990).

It was after World War II that international science policy organizations became widespread and alliances of governments established international organizations in order to use them as international councils for policy and regulation. Since the 1970s, the world has seen an acceleration in the founding of IGOs (Section 7.4).

Regional institutions are linked to the potential recipients of policies[12] and as a consequence these councils were established worldwide, around the different ocean basins and seas. Most of these councils are multipurpose organizations and some are supported by parallel regional conventions such as the *Convention for the Protection of the Marine Environment of the North-East Atlantic* (OSPAR) and the *Convention on the Protection of the Marine Environment of the Baltic Sea Area* (HELCOM). It is also important to note that although the regional IGO network remains mostly segmented and regionalized, there is evidence of increasing cooperation among different councils and conventions worldwide.

Well-established and renowned marine regional organizations, commissions and consultative parties include the Arctic Council, Antarctic Treaty System, Black Sea Commission, Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), CIESM, Coordinating Body on the Sea of East Asia, ICES, North Pacific Marine Science Organization (PICES), Permanent Commission for the South Pacific (CPPS), Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden, Regional Organization for the Protection of the Marine Environment (ROPME) and the South Pacific Community. Other relevant regional organizations were created with purposes other than marine policy, but have expanded their interest to include ocean affairs, such as the European Commission and the Organisation for Economic Co-operation and Development (OECD).[13]Relevant regional conventions[14] include: *Convention for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of the West*, *Central and Southern Africa Region* (Abidjan Convention), *Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean* (Barcelona Convention), *Convention on the Protection of the Black Sea Against Pollution* (Bucharest Convention), *Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Area* (Cartagena Convention), *Convention on the Protection of the Marine Environment of the Baltic Sea Area* (HELCOM Convention), *Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment* (Jeddah Convention), *Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution* (Kuwait Convention), *Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region* (Nairobi Convention), and *Convention for the Protection of the Marine Environment of the North-East Atlantic* (OSPAR Convention).

7.2.2. Non-governmental organizations (NGOs)

The term 'non-governmental organization' (NGO) was first coined in 1945, when the UN was created. The UN made it possible for certain approved specialized international non-state agencies to be awarded 'observer' status at its assemblies and some of its meetings (Ulleberg, 2009). Formally, a NGO is a not-for-profit organization that is independent from states and international governmental organizations. They are usually funded by donations and some avoid formal funding from governments. NGOs are highly diverse organizations, engaged in a wide range of activities related to ocean science, education, environmental protection, funding and others.

NGO is now widely used as a synonym for advocacy, voluntary or philanthropy organizations that act to protect various public interests in many fields, including science, environmental

11 IHO is an intergovernmental organization with almost global membership; only a few States (all of which are in Africa or the Caribbean) have not signed the charter.

12 For example, the European Union (EU) is the main recipient of new policy ideas developed by ICES and CIESM.

13 The Organisation for Economic Co-operation and Development (OECD) is a global organization, but it has its roots in the Organisation for European Economic Cooperation (OEEC) which was established in 1948 to run the US-financed Marshall Plan. Encouraged by its success and the prospect of carrying its work forward on a global stage, Canada and the US joined OEEC members in signing the new OECD Convention on 14 December 1960. The OECD was officially born on 30 September 1961, when the Convention entered into force. Today, the OECD incorporates 35 member countries worldwide.

14 These regional conventions were referred to in the responses of IOC member States to the GOSR questionnaire (2015).

protection and conservation. They vary in their degree of formality, composition, structure, financing and thematic coverage. Whereas IGOs are hierarchical and organized 'top-down', NGOs tend to be self-organizing network structures, built on bottom-up schemes, bringing together scientists and activists who collaborate not because they are told to, but because they want to (Parmentier, 2012).

Ocean science policy in NGOs is seen in a broader perspective, covering all interactions among players, whether formal or informal, that shape these interactions. Transnational NGOs have become an integral part of the international ocean management architecture and contribute to the implementation of the multilateral environmental agenda. The nature of NGO contributions in marine management, science and conservation is almost as diverse as the nature of NGOs themselves. In fact, it is a nearly impossible task to enumerate the array of NGOs. According to their functions (Parmentier, 2012; Crosman, 2013), five different typologies of NGOs relevant to the marine environment can be identified: (i) science-based, (ii) advocacy/policy development and agenda-setting, (iii) education, environmental awareness/conservation management, (iv) watch-dogging and rapid response and (v) funding and capacity-building. Some NGOs are involved in only one, but most NGOs touch on two or more of these functions.[15]

7.2.2.1. Science-based NGOs

Many relevant NGOs are intrinsically science-based, such as ICSU, International Association for the Physical Sciences of the Oceans (IAPSO), Partnership for Observation of the Global Oceans (POGO), Scientific Committee on Oceanic Research (SCOR), Scientific Committee on Antarctic Research (SCAR) and Conservation International (CI). They benefit from in-house academic and scientific expertise or may even be led by scientists, as are ICSU, the Union of Concerned Scientists (UCS) and the European Marine Board (EMB). These NGOs are important platforms at the crossroads of science and policy, linking scientists with governmental, international agencies and in some cases the private sector. The nature of the scientific work undertaken by these NGOs can be separated into three different roles: (i) the review of scientific knowledge and of assumptions arising from that knowledge; (ii) the development of marine research agendas and the promotion of scientific research programmes; and (iii) laboratory and on-site scientific research. Their work is often showcased through the publication of scientific articles in peer-reviewed scientific journals and in reports/grey literature.

Large science-based NGOs, such as ICSU, have achieved outstanding products, from the creation and promotion of global research programmes that were subsequently adopted by the UN system, such as the World Climate Research Program (WCRP), International Geosphere-Biosphere Program (IGBP), International Human Dimension Programme on Global Environmental Change (IHDP), Diversitas and Future Earth. SCOR, together with the IOC, made the second International Indian Ocean Expedition possible. Also, SCOR and POGO were instrumental in launching the International Quiet Ocean Experiment (IQOE). The EMB Position Papers and related products successfully influence[16] the European Commission's framework programmes and national marine research funding schemes in Europe.

The scientific capacity of some NGOs is more developed than others. For example, for more than 20 years, Greenpeace International has had a Science Unit based at the University of Exeter, UK, where a team of full-time scientists advises the organization's campaigners and undertakes research that helps build the case for their campaigns. Some scientific organizations rely on international scientific collaboration and scientists voluntarily donating time and expertise (e.g. SCOR and SCAR) to overcome capacity constraints.

7.2.2.2. Advocacy/policy development and agenda-setting NGOs

Many NGOs actively contribute to the development and improvement of the policies of public administrations, with the aim of influencing legislation and regulation at local, national, regional and global levels. They do this to improve their performance and effectiveness in order to gain formal endorsement and legitimacy for their demands. These NGOs often organize their own events and processes with the goal of creating opportunities for public administrations to interact with them. They may also participate formally or informally in the processes established by public administrations.

Advocacy organizations, such as Greenpeace, WWF, the Deep Sea Conservation Coalition (DSCC) and Oceana, have been instrumental in the development of many international agreements: the moratorium on commercial whaling (joint

15 A non-exhaustive list of NGOs involved in ocean science and governance can be found at <http://www.un.org/depts/los/Links/NGO-links.htm>.

16 The Marine Board 'Navigating the Future' series provides regular pan-European summaries of the current status of marine research, priority recommendations and future scientific challenges in the context of European societal needs. 'Navigating the Future IV' was designed to inform the Commission calls under the EU Horizon 2020 programme.

'IWC project'), the *1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES) and the ocean dumping ban of wastes (including radioactive wastes) at sea under the London Convention. In addition, these and other NGOs (e.g. Global Forum on Oceans, Global Ocean Commission, World Ocean Council) have identified sustainable development in the ocean (i.e. blue economy) as an area where policy action is possible and required.

7.2.2.3. Education, environmental awareness and conservation campaigns

Many NGOs are active in launching awareness campaigns to raise 'hot' environmental issues. These campaigns can take many different forms, from activism at sea to education campaigns at regional or local scales. They also interact with stakeholders (including government agencies) to promote effective respectful conservation management practices.

As mentioned above, NGOs can play a science advocacy role in the development of international legal instruments. At more local and regional scales – in response to the concerns aired by NGOs over the future of bluefin tuna stocks in the Atlantic and elsewhere – numerous retail chains and restaurants are advertising the fact that they have removed this species from their stalls and menus (this was championed by the Seafood Choices Alliance). The Marine Stewardship Council (MSC) was set up as a fishery certification programme and seafood eco-label to recognize and reward sustainable fishing. Other NGOs (e.g. MedPAN, Coral Reef Alliance, Save Our Seas, Conservation International) were created for conservation management purposes and advocate for the promotion of conservation measures such as marine protected areas, marine reserves, marine parks and no-take zones.

7.2.2.4. 'Watch-dogging' and rapid response

The sea offers innumerable opportunities for NGOs to test and demonstrate the effectiveness of their watchdog function, which constitutes a way for them to scale-up their actions and obtain visibility. 'Watch-dogging' includes monitoring, preventing or stopping certain activities, such as activities that are illegal or incompatible with a conservation agenda.

Various NGOs have been instrumental in watch-dogging illegal, unreported and unregulated fishing in the Southern Ocean. Sea Shepherd Conservation Society takes direct action, while some other NGOs (e.g. the Conservation Law Foundation and the Environmental Investigation Agency, EIA) generate lawsuits designed to force compliance with existing law. EIA has specialized in the investigation of environmental crimes. As part of its 'Species in Peril' programme, EIA documents and seeks to prevent massive kills of dolphins, porpoises and whales.

Very often, these NGOs receive a lot of public support, as they are seen to respond faster than public authorities when environmental disasters affecting the marine environment occur (e.g. after the *Erika* and *Prestige* oil spills, the *Deepwater Horizon* offshore oil platform accident in the Gulf of Mexico, or the Fukushima event).

7.2.2.5. Funding and capacity-building

Activities falling into this category include building capacity, providing opportunities for hands-on involvement in management, and direct provision of funding for NGOs and other organizations involved in marine science. Some NGOs and charitable foundations provide economic expertise and often give access to funding sources for the efforts of other individuals or organizations. Capacity-building includes facilitating stakeholder involvement in decision-making processes, institution building, and facilitating – or acting as a hub for – collaborative management.

Funding provision can be in multiple forms as pure research funding, fellowships or support work that government support alone could not provide, especially in developing countries. Examples include the Coral Reef Alliance, which provides funds to Caribbean and Pacific NGOs to help meet operational needs; the WWF which administers grants from foundations, routing funds to local NGOs as needed; and the Elkhorn Slough Foundation which purchases land and/or rights of use to preserve the environment.

Capacity-development has gradually become the centre of attention in the development discourse over the past few years. NGOs have willingly adopted capacity-development activities as a consequence of this new 'turn' in the development conversation, and the perception that NGOs are reliable actors for rapid interventions in an environmental crisis. In this regard, NGOs provide knowledge, facilitation and guidance that are needed for environmental, socio-economic and ecological monitoring in order to create a local knowledge base and build support for conservation; e.g. the Blue Carbon Initiative is supported by CI, the International Union for Conservation of Nature (IUCN) and IOC.

Charitable foundations—which as 'not-for-profit' organizations can be considered as NGOs—fund marine science projects worldwide (Chapter 4). Examples include: the Pew Charitable Trusts (whose ambitious Global Ocean Legacy Program developed its own 'Seascapes' and also launched the 'Marviva' project, a public-private partnership between the Governments of Ecuador, Colombia, Panama and Costa Rica, plus philanthropic personalities with business and social ties in those countries); the Alfred P. Sloan Foundation (which was the donor for Census of Marine Life); and the Prince Albert II of Monaco Foundation (fully dedicated to oceanography).

7.2.3. Hybrid organizations

Hybrid organizations represent an increasingly common approach designed to enable cooperation between the different social arrangements, networks and institutions that mediate between the institutions of science and politics (Miller, 2001). A hybrid organization mixes elements, value systems of various sectors of society, i.e. the public sector, the private sector and the voluntary sector. These hybrid organizations vary in degree of formality, composition, structure, financing and thematic coverage. Illustrative examples include the Global Partnership for Oceans (GPO) initiated by the World Bank, IUCN and the EU Regional Advisory Councils (RACs) under the EU Common Fisheries Policy.

GPO, launched in 2012 under the auspices of the World Bank, is a growing coalition of more than 100 partners including governments, international organizations, civil society groups and members of the private sector. GPO seeks to draw on the knowledge, expertise and financial support of all its partners to address major threats to ocean and coastal resources, including overfishing and habitat loss in a number of priority regions around the world.

IUCN, created in 1948, is a membership union composed of governments, multilateral agencies, NGOs, companies and corporate foundations. IUCN provides governments and institutions at all levels with the impetus to achieve universal goals, on matters including biodiversity, climate change and sustainable development. One of the most remarkable achievements from IUCN was its contribution to the establishment of the CITES convention.

RACs can be seen as international boundary organizations mixing scientific, socio-economic and political elements and mediating between stakeholders – such as science institutions, fisheries associations, producer organizations, market organizations, environmental NGOs – and politics in order to contribute to the sustainable use of marine resources under the EU Common Fisheries Policy (e.g. Aps *et al.*, 2009). RACs are instruments to facilitate consensus among parties; they rely on science for the credibility of their knowledge and claim to have the approval of political institutions for the legitimacy of their policy orientations. For example, the persisting problem of fleet overcapacity was considered as an important issue for RACs in Europe.

Research and capacity-building programmes are sometimes established by hybrid organizations. Examples include the GEF Areas Beyond National Jurisdiction (ABNJ) Programme led by FAO, and the successful international programme Census of Marine Life (CoML), which was a partnership of intergovernmental/international organizations (e.g. IOC, FAO, UNEP, PICES), international NGOs (e.g. ICSU and SCOR) and private foundations and corporations (e.g. National Geographic Society and Alfred P. Sloan Foundation).

The GEF ABNJ Programme brings together UNEP, UNDP, the World Bank, RFMO/As, the private sector and NGOs, with the FAO serving as the Global Programme Coordination Unit. It has a global Steering Committee and a Technical Advisory Group which work to ensure participation of key partners from the policy, technical and scientific communities, as well as industry. The ABNJ Programme aims to promote efficient and sustainable management of fisheries resources and biodiversity conservation in the ABNJ and to meet related global targets agreed in international fora.

CoML was a ten-year programme that engaged a wide and global network of researchers established in more than 80 nations to assess and explain the diversity, distribution and abundance of life in the ocean. The final report was launched in 2010. In addition to extensive contributions to marine science, CoML has created major legacies including the Ocean Biogeographic Information System (OBIS) database, the world's largest open access, online repository of spatially referenced marine life data that continues under the auspices of the IOC as part of its mandate to facilitate the exchange of oceanographic data and information among participating Member States (Chapter 6).

7.3. UN-Oceans and UN constraints to lead ocean science and policy assessment

Ocean and coastal issues have unfortunately received low visibility and priority within the UN system (Mounir and Inomata, 2012; UK National Commission for UNESCO Secretariat, 2015). Many ocean entities in the UN system are part of higher structures, often sector-oriented (Valdés, 2017). For many of

Table 7.1. Areas of activity declared by the UN-Oceans organizations in 2014 (adapted from Valdés, 2017).

	IOC-UNESCO	WMO	FAO	UNEP-CBD	UNDP	IMO-WMU	IAEA	UNHCR	UNCTAD	DOALOS-ISA	UN DESA
Sustainable development	■	■	■	■	■	■	■	■	■	■	■
Science	■	■	■	■	■	■	■				
Marine environment	■	■	■	■	■	■	■	■			
Marine biodiversity	■		■	■	■	■				■	
Fisheries	■	■	■	■	■		■				
Exploitation non-living resources					■					■	■
Cables & pipelines		■								■	
Marine safety & security	■	■	■	■		■	■	■	■		
People at sea and education	■	■	■			■		■	■		
Underwater cultural heritage	■	■									

these, the oceans were, and remain, a non-central responsibility in their overall remit (Holland and Pugh, 2010).

UN-Oceans was established by the UN High-Level Committee on Programmes in 2003 to *inter alia* establish an effective, transparent and regular inter-agency coordination mechanism on ocean and coastal issues within the UN system, as well as to facilitate, as appropriate, inputs to the annual report on Oceans and the Law of the Sea of the Secretary-General and to the Open-ended Informal Consultative Process on Oceans and the Law of the Sea (ICP). This coordination mechanism was evaluated in 2011–2012 (Mounir and Inomata, 2012), and the new terms of reference were approved by the UN General Assembly in 2013 at its 68th session.

UN-Oceans is currently composed of 16 relevant programmes, entities, organizations and specialized agencies of the UN and the secretariats of relevant UN conventions (e.g. CBD, UNCLOS). It aspires to reinforce assessment on ocean management and enable more coherent and strategic approaches across all UN agencies. Most of the UN-Oceans members responded in 2014 to a questionnaire describing their main areas of work in relation to ocean matters (Table 7.1).

The scatterplot in Figure 7.3 shows the statistical distance (similarities) among the different elements[17] after Table 7.1 was converted in a matrix of zeros and ones. While this highlights the potential overlap between the mandates/focus areas of UN agencies with regards to ocean matters, it also illustrates the opportunities that exist to harness/leverage synergies and complementary activities to better address environmental and socio-economic challenges. A good example is the cooperation established among several specialized agencies to attend the UNFCCC COPs with a common programme of events (Valdés, 2017).

Figure 7.4 is a mapping exercise showing the regional and global governmental and non-governmental organizations involved in the management of ocean environmental issues according to its technical mandate and its regional or global coverage (left panel). For illustration purposes only a few organizations were plotted, but it is obvious that the figure can be populated with many other organizations and tailored *ad hoc* by any interested

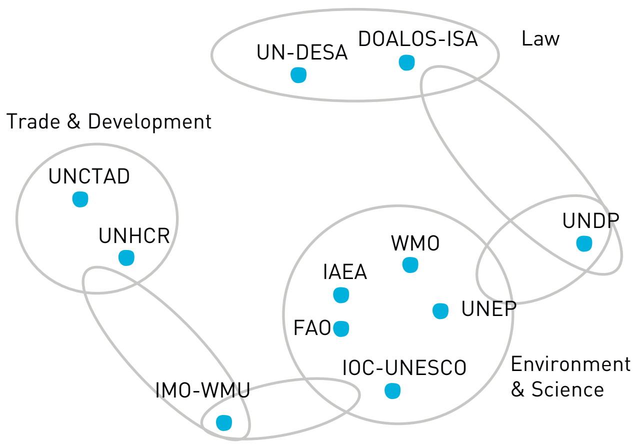


Figure 7.3. UN-Oceans elements represented in a non-multidimensional 2D distance plot (scatterplot 2D distance matrix 1-Pearson r). *Source*: adapted from Valdés (2017).

17 UN-DOALOS and ISA, UNEP and CBD, and IMO and WMU, are presented collectively as they are dependent or directly connected organizations.

person. The final purpose is to show that there is a need for an intergovernmental organization with a global technical mandate and global coverage with the legitimacy and authority to speak with one voice on behalf of the ocean. It seems that this space or niche is appropriate for UN-Oceans (Valdés, 2017).

If the marine NGOs are mapped in a similar exercise (Figure 7.4, right panel) then we see that there are several organizations occupying the space that is not actually occupied by any intergovernmental body (other than UN-Oceans). This is a natural reaction from civil society in response to the need to have voices speaking up to defend the ocean and to demand solutions on emerging issues, something that for an intergovernmental body is an overly long and complicated process (Valdés, 2017).

Ocean and coastal issues nowadays include everything from marine environmental protection (e.g. capture fisheries and aquaculture, marine ecosystem degradation, marine pollution, climate change, ocean carbon), to shipping, protection of workers, tsunamis, nuclear events, piracy and terrorism. These issues are governed/regulated by different UN organizations. The UN system should no longer be seen as a discrete authority on ocean and coastal issues (Mounir and Inomata, 2012). The current fragmentation and the lack of an overarching and operational body with a strong and common voice is a weakness for an architecture that otherwise counts with the necessary elements of the quadruple helix (i.e. authority, law, research and science-policy interface processes; Figure 7.1; Valdés, 2017).

The issue is that the UN preference for a sector-by-sector approach to marine management cannot sustain marine ecosystems as a whole (McGinnis, 2012). This inevitably leads to some confusion over which agency should take the lead on a given issue (UK National Commission for UNESCO Secretariat, 2015). Consideration could be given to expanding UN-Oceans' mandate and scope. It could perhaps be a more product-oriented body, starting by having its own 'stamped' products as UN-Oceans publications (Valdés, 2017). In addition, a dedicated team of staff would be indispensable for a UN-Oceans mechanism to become an operative entity taking an overall coordination role to implement UN priorities on the ocean. Based on the thematic exercise summarized in Figure 7.3, it seems that a UN-Oceans-like organization might try to coordinate an enormous portfolio of topics and activities which can only be addressed by a multilateral legal entity, well-staffed and budgeted (Valdés, 2017).

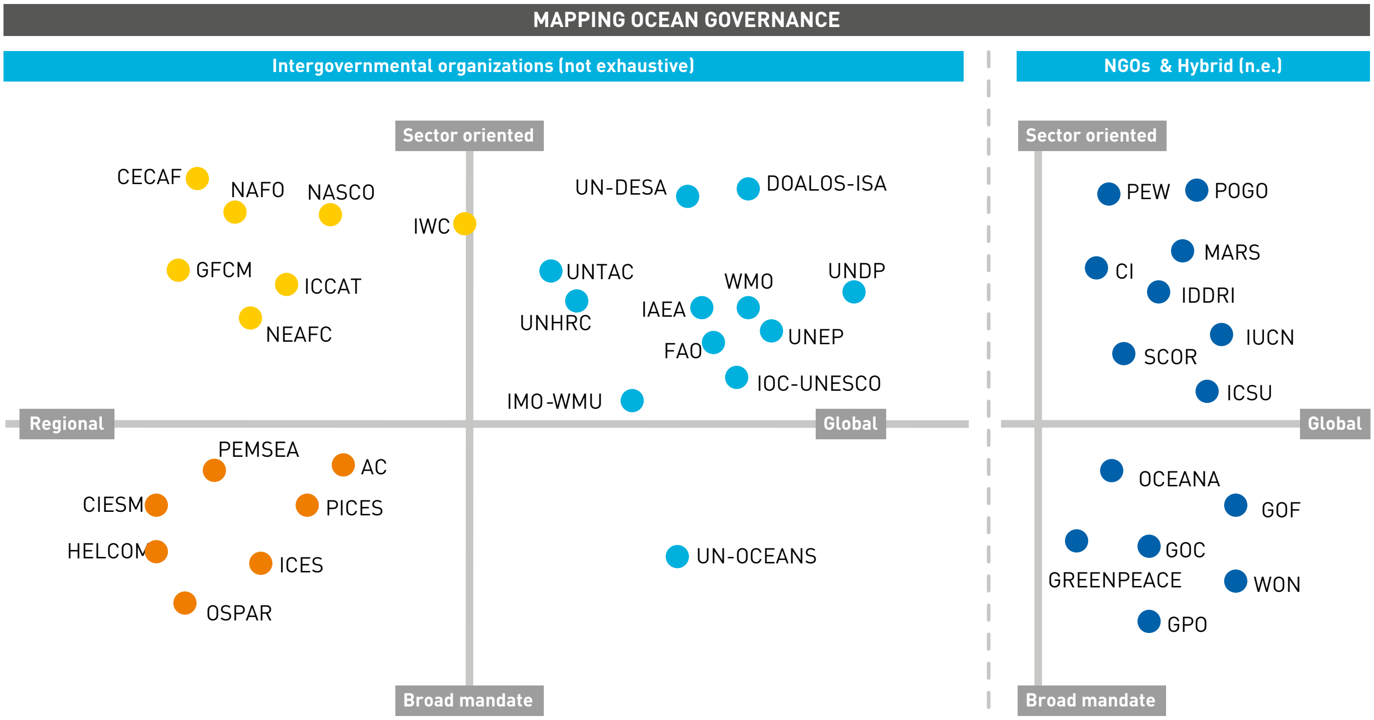


Figure 7.4. Scheme of international governmental and non-governmental lead organizations intervening in ocean management and governance clustered according to their technical mandate and the regional or global coverage (not exhaustive, see the appendix for acronyms). *Source*: adapted from Valdés (2017).

7.4. The importance of NGO action in realizing international goals

NGOs have become service providers where governments are unable to respond to challenges or fulfil their responsibilities (Ulleberg, 2009), working with States and international governmental organizations to implement international ocean environmental protection and conservation. In this regard, international environmental NGOs have become an integral part of the international ocean management architecture and contribute to the implementation of the multilateral environmental agenda (Crosman, 2013).

NGOs gained power, participation and pluralism in social appraisal of environmental science diplomacy. This is called 'Track Two dialogue' or 'Track Two diplomacy' (Montville, 1991; Betsill and Corell, 2008), which means the transnational coordination that involves non-official members of the government. In contrast to government diplomats, track two diplomacy consists of experts, scientists, academicians and other figures that are neither involved in government affairs, nor represent constituencies that are bound by territory, but by common values, knowledge and/or interests related to a specific issue. Therefore, participants in track two diplomacy express views that are independent of any national government and have more freedom to exchange ideas and come up with compromises on their own (Montville, 1991; Betsill and Corell, 2008).

Today's scientific world is characterized by self-organizing networks, bringing together scientists who collaborate not because they are told to but because they want to. These networks, motivated by the bottom-up exchange of scientific insight, knowledge and skills, span the globe and are changing the focus of science from the national to the regional and global level (e.g. Global Ocean Ecosystem Dynamics (GLOBEC), CoML, etc). Policy-makers have not always recognized the importance of these linkages to the quality and direction of science, tending to emphasize research investment to the detriment of developing policies that support and foster such networks (Royal Society, 2011; Parmentier, 2012).

There are examples of NGOs that have had success in achieving their goals or have had a level of influence on international environmental negotiations, for instance the dumping of radioactive waste, the ban on commercial whaling and the Kyoto Protocol negotiations (Ringius, 1997; Corell and Betsill, 2001; Andresen and Skodvin, 2008). Even if they sometimes have little measurable effect on the outcome of the negotiations, NGOs shape the process by working behind the scenes to frame the debate and raise concerns about issues on the negotiation agenda and to influence the positions of key states. Other authors (e.g. Humphreys, 2008) argue that NGOs' most important contributions occurred over time rather than in any specific negotiation; for example, they have succeeded in reframing environmental concern from a romantic issue to one of ecological and human rights.

Despite mounting evidence that NGOs make a difference in global environmental politics, the question of under what conditions NGOs have influence generally remains unanswered. NGO activities, resources and engagement with international negotiations give some indication but this does not provide detailed information on impact and there can be confusion between correlation and causation (Betsill and Corell, 2008). Whereas NGOs may influence many policy actions, international scientific assessments are always conducted by IGO-related scientists in a quality-assured, separate procedure.

In summary, many NGOs complement, and sometimes compete with, governmental agencies in their environmental agendas, but regardless of its advantages, track two diplomacy also has several weaknesses: (i) NGOs often participate in policy and scientific meetings as observers and have no formal voting authority, making it difficult for NGO actors to influence the negotiating process and limiting their ability to influence political power structures; (ii) NGO participants rarely have resources necessary for sustained leverage during negotiations; (iii) track two diplomacy is more effective in democratic societies; (iv) NGOs are in most cases not accountable to the public for poor decisions; and (v) because of their multiplicity, NGOs can lack coordination and common strategies and goals. With a plethora of NGOs playing varying roles in the conduct, promotion, support and application of ocean science, understanding the different roles of these actors is important to streamline ocean science-policy interactions and maximize effectiveness.

7.5. A race for the ocean: The expansion of international organizations

National academies and royal societies of science, many of which gained strong reputations, date back to the seventeenth century. But it was only after the Second World War that international science policy organizations became widespread and alliances of governments established legal and permanent intergovernmental organizations in order to use them as international councils for policy regulation. Since the 1970s, the founding of IGOs as well as NGOs flourished quickly (Figure 7.5a).

After the Industrial Revolution, it was recognized that scientific knowledge could be translated into increased wealth, security and improved standards of living, and that this should be harnessed by States and integrated into large economic establishments. It was in the early 1950s that two international organizations, UNESCO and OECD, began to promote science, policy and innovation among their member States (Finnemore, 1993). Giving science a visible role in these new multilateral organizations was a way of recognizing the importance of science to the world emerging after World War II; the fact that they succeeded in giving a voice to science was due in part to the existing need to strengthen and give coherence to the international science community and in part to their ability to influence world affairs (Royal Society, 2011, Karns *et al.*, 2015).

At that time science was believed to proceed most efficiently and productively when left to scientists. Certainly, this bottom-up approach was the attitude of the scientific societies and it continues to be the attitude of most scientists' professional organizations and of individual scientists active in international research and innovation. UNESCO's early science programmes were designed to serve science and scientists rather than States. In fact, science policy and promoting science capabilities of member States were not even mentioned in the UNESCO charter (Finnemore, 1993). It was later that the situation reverted to a top-down policy approach. Minutes of UNESCO conferences from that time *'describe the decline in participation by scientists, educators and writers and the increased presence of 'government technicians' who viewed themselves as government spokespersons'* (Finnemore, 1993). The move from the bottom-up to top-down policy approach represented a shift in the balance of power between UNESCO's two constituencies. It was said that this shift was *'the price for financial support'* (Finnemore, 1993).

In the last 50 years, science policy-making organizations (UN agencies, international organizations and secretariats to international conventions) have sprung up in virtually all developed countries and in most developing countries. The appearance of these new pieces of state machinery are explained in the literature as demand-driven (Finnemore, 1993; Stirling, 2008), such as when a region perceives that a problem is affecting a group of nations (e.g. marine pollution), those nations find in science policy bureaucracy a route to a common solution (e.g. creating a new international convention). Obviously, this international stewardship favours the creation of regional international institutions linked to the potential recipients of their policies and, as consequently these councils were established worldwide, around different ocean basins and seas.

The number of ocean-related NGOs has likewise exploded over the past century (Turner, 2010) stimulated by the fact that these organizations increasingly participate in international political processes. Since the 1990s, one finds an acceleration of the founding of NGOs (Figure 7.5a): the 1972 United Nations Conference on the Human Environment, Stockholm, was attended by representatives of more than 250 NGOs; at the 1992 United Nations Conference on Environment and Development, Rio de Janeiro, 1,400 NGOs were accredited; and more than 3,200 organizations were accredited to the 2002 World Summit on Sustainable Development, Johannesburg (Betsill and Corell, 2008).

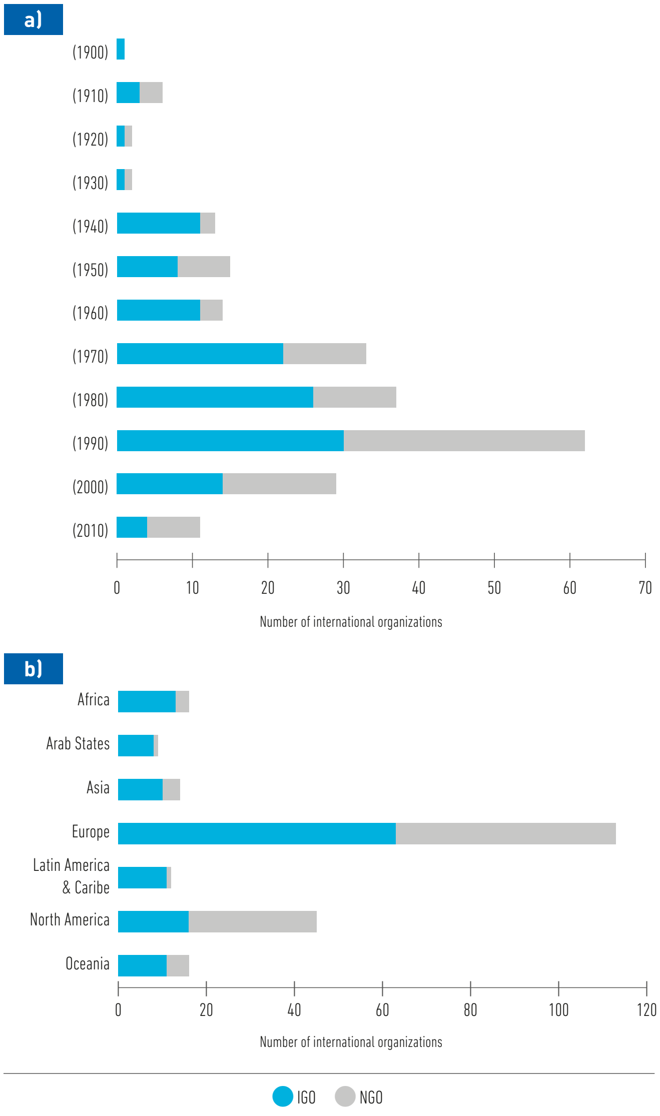


Figure 7.5. a) Number of international organizations (IGOs and NGOs) created by decade since 1900; and **b)** number of international organizations by regions.

The regional distribution of NGOs in Figure 7.5b shows that they have developed mainly in North America and Europe and demonstrates the aspirational vision of most international NGOs to be influential to policy leaders of most developed countries.

7.6. Final remarks

As we consider the importance of pluralism in marine science diplomacy, we also need to bear in mind the power that science can have in and over society and in our lives as many of the major global challenges of the twenty-first century have scientific dimensions. This raises the question of how international institutions balance and assist State representatives to disseminate science policy models (e.g. by financing capacity-building in science and technology and promoting an equitable distribution of policy organizations and implementation agencies worldwide).

The perception that ocean management and governance is key to its sustainability is reflected in recent discussions taking place in UN agencies and international fora dealing with ocean issues and aimed at improving coordination among institutions and stakeholders (e.g. ocean fertilization, biodiversity in areas beyond national jurisdiction, SDG 14 and others; see Chapter 8). Whereas NGOs may have influence on international ocean environmental protection – through advocacy roles, the provision of evidence-based scientific advice, or by facilitating international science collaboration – IGOs may serve similar roles but have an additional function to provide formal science-policy support.

Improved and shared knowledge of the ocean is seen as a prerequisite for an effective system of marine management. Guidance could be developed on how to coordinate, integrate or implement the various international commitments and demands for scientific knowledge of the ocean to support marine management. Given the multitude of challenges facing the global ocean and the plethora of organizations involved in oceans governance, there is a need to enable ocean science-policy interactions through a number of avenues, and this would be better supported by stronger coordination mechanisms and reforms – such as implementation of existing and new international treaties working in the framework of the SDGs – to address new challenges.

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Appendix

Marine science intergovernmental organizations, international instruments and mechanisms, listed alphabetically

Entries are organized alphabetically. Brackets following the entry contain the standard acronym (if any) for the organization, followed by the year of creation and the city and State hosting the Secretariat (if any). Data downloaded from *http://uia.org/ybio?name=* (or from the websites of the organizations).

A

Action Plan for Protection, Development and Management of the Marine Environment of the Northwest Pacific Region (NOWPAP, 1991, Busan/Republic of Korea)

Agreement for Cooperation in Dealing with Pollution of the North Sea by Oil and Other Harmful Substances (1989, Bonn Agreement, London/UK)

Agreement on the Conservation of Albatrosses and Petrels (ACAP, 2001, Hobart/Australia)

Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS, 1991, Bonn/Germany)

Antarctic Treaty System (ATS, 1959, Buenos Aires/Argentina)

Arab Federation of Fish Producers (AFFP, 1976, Tunis/Tunisia)

Arctic Council (AC, 1996, Tromsø/Norway)

Asia-Pacific Fishery Commission (APFIC, 1948, Bangkok/Thailand)

B

Ballast Water Management Convention (BWM, 2017, London/UK)

Baltic Marine Environment Protection Commission (HELCOM, 1974, Helsinki/Finland)

Benguela Current Commission (BCC, 2013, Swakopmund, Namibia)

Bureau International des Expositions (BIE, 1931, Paris/France)

C

Caribbean Environment Programme (CEP, 1981, Kingston/Jamaica)

Caribbean Regional Fisheries Mechanism (CRFM, 2003, Belize/Belize)Caspian Environment Programme (CEP, 1998, Astana/Kazakhstan)

Commission for Inland Fisheries and Aquaculture of Latin America and the Caribbean (COPESCAALC, 1976, Santiago de Chile/Chile)

Commission on the Protection of the Black Sea against Pollution (Black Sea Commission BSC, 1992, Istanbul/Turkey)

Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean Convention (WCPFC, 2004, Kolonia/Federated States of Micronesia)

Convention for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of the West, Central and Southern Africa Region (Abidjan Convention, 1984, Abidjan/Côte d'Ivoire)

Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (Cartagena Convention, 1983, Kingston/Jamaica)

Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region (Nairobi Convention, 1985, Mahé/Seychelles)

Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR, 1998, London/UK)

Convention on Biological Diversity (CBD, 1993, Montreal/Canada)

Convention on the Conservation of Migratory Species of Wild Animals (1979, CMS or Bonn Convention, Bonn/Germany)

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 1973, Geneva/Switzerland)

Convention on Persistent Organic Pollutants (POP Stockholm convention, 2001, Geneva/ Switzerland)

Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (LDC, 1972, London/UK)

Convention on the Protection of the Black Sea against Pollution (Bucharest Convention, 1992, Bucharest/Romania)

Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar convention, 1971, Gland/Switzerland)

Coordinating Body on the Seas of East Asia (COBSEA, 1981, Bangkok/Thailand)

Council of the Eastern Pacific Tuna Fishing Agreement (CEPTFA, not in force)

E

East African Marine Fisheries Research Organization (EAMFRO, 1951, disintegrated in 1977)

European Environment Agency (EEA, 1990, Copenhagen/Denmark)

European Fisheries Control Agency (EFCA, 2006, Vigo/Spain)

European Maritime Safety Agency (EMSA, 2002, Lisbon/Portugal)

European Space Agency (ESA, 1975, Paris/France)

European Union (EU, 1993, Brussels/Belgium)

F

Federation of Arab Scientific Research Councils (FASRC, 1976, Baghdad/Iraq)

Fisheries Advisory Commission for the Southwest Atlantic (CARPAS, 1961, Rome/Italy)

Fishery Committee for the Eastern Central Atlantic (CECAF, 1967, Accra/Ghana)

Food and Agriculture Organization of the United Nations (FAO, 1945, Rome/Italy)

Framework Convention for the Protection of the Marine Environment of the Caspian Sea (2003, Geneva/Switzerland)

G

General Fisheries Commission for the Mediterranean (GFCM, 1952, Rome/Italy)

Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (1995, Nairobi/Kenya)

Group on Earth Observations (GEO, 2005, Geneva/Switzerland)

I

Indian Ocean Commission (IOC, 1982, Ebene/Mauritius)

Indian Ocean Tuna Commission (IOTC, 1993, Victoria/Seychelles)

Inter-American Tropical Tuna Commission (IATTC, 1959, San Diego/USA)

Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO, 1960, Paris/France)

Intergovernmental Panel on Climate Change (IPCC, 1988, Geneva/Switzerland)

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2007, Nairobi/Kenya)

International Atomic Energy Agency (IAEA, 1957, Vienna/Austria)

International Baltic Sea Fishery Commission (IBSFC, 1973, Warsaw/Poland)

International Commission for Scientific Exploration of the Mediterranean Sea, The Mediterranean Science Commission (CIESM, 1910, Monaco/Monaco)

International Commission for the Southeast Atlantic Fisheries (ICSEAF, 1969, replaced by SEAFO)

International Convention for the Prevention of Pollution from Ships (MARPOL, 1973, London/UK)

International Convention on the Control of Harmful Anti-fouling Systems on Ships (IMO AFS, 2001, London/UK)

International Council for the Exploration of the Sea (ICES, 1902, Copenhagen/Denmark)

International Hydrographic Organization (IHO, 1919, Monaco/Monaco)

International Labour Organization (ILO, 1919, Geneva/Switzerland)

International Maritime Organization (IMO, 1948, London/UK)

International North Pacific Fisheries Commission (INPFC, 1993, Vancouver/Canada)

International Pacific Halibut Commission (IPHC, 1923, Seattle/USA)

International Seabed Authority (ISA, 1994, Kingston/Jamaica)

International Whaling Commission (IWC, 1946, Impington/UK)

IOC Regional Committee for the Central Indian Ocean (1988, IOCINDIO, Teheran/Iran)

IOC Sub-Commission for Africa and the Adjacent Island States (IOCAFRICA, 2011, Nairobi/Kenya)

IOC Sub-Commission for the Caribbean and Adjacent Regions (IOCARIBE, 1982, Cartagena de Indias/Colombia)

IOC Sub-Commission for the Western Pacific (WESTPAC, 1979, Bangkok/Thailand)

J

Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP, 1969, London/UK)

K

Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution (Kuwait Convention, 1978, Kuwait City/Kuwait)

L

Latin American Fisheries Development Organization (OLDEPESCA, 1982, Lima/Peru)

London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention, 1972, London/UK)

N

Network of Aquaculture Centres in Asia-Pacific (NACA, 1990, Bangkok/Thailand)

Nordic Council for Scientific Information (NORDINFO, 1976, Copenhagen/Denmark)

North Atlantic Marine Mammal Commission (NAMMCO, 1992, Tromsø /Norway)

North Atlantic Salmon Conservation Organization (NASCO, 1984, Edinburgh/UK)

North-East Asia Subregional Programme for Environmental Cooperation (NEASPEC, 1993, Incheon/Republic of Korea)

North East Atlantic Fisheries Commission (NEAFC, 1980, London/UK)

North Pacific Anadromous Fish Commission (NPAFC, 1992, Vancouver/Canada)

North Pacific Fur Seal Commission (NPFSC, 1958, disbanded in 1988)

North Pacific Marine Science Organization (PICES, 1992, Sidney/Canada)

Northwest Atlantic Fisheries Organization (NAFO, 1979, Dartmouth/Canada)

O

Organisation for Economic Co-operation and Development (OECD, 1961, Paris/France)

P

Pacific Islands Forum Fisheries Agency (FFA, 1977, Honiara/Solomon Islands)

Pacific Salmon Commission (PSC, 1985, Vancouver/Canada)

Partnerships in Environmental Management for the Seas of East Asia (PEMSEA, 1994, Quezon City/Philippines)

Permanent Commission for the South Pacific (CPPS, 1952, Guayaquil/Ecuador)

Protection of the Arctic Marine Environment (PAME, 1993, Akureyri/Iceland)

R

Regional Commission for Fisheries (RECOFI, 1999, Cairo/Egypt)

Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment (Jeddah convention, 1982, Jeddah/Saudi Arabia)

Regional Fisheries Advisory Commission for the Southwest Atlantic (CARPAS, not active since 1974)

Regional Fisheries Committee for the Gulf of Guinea (COREP, 1984, Libreville/Gabon)

Regional Marine Pollution Emergency Information and Training Centre Wider Caribbean (REMPEITC, 1994, Willemstad/Curaçao)

Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC, 1976, Valletta/Malta)

Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA, 1955, Jeddah/Saudi Arabia)

Regional Organization for the Protection of the Marine Environment (ROPME, 1980, Safat/Kuwait)

Regional Programme of Action for the Protection of the Arctic Marine Environment from Land-Based Activities (RPA, 1998, Oslo/Norway)

S

Secretariat of the Pacific Regional Environment Programme (SPREP, 1982, Apia/Samoa)

South Asia Cooperative Environment Programme (SACEP, 1982, Colombo/Sri Lanka)

Southeast Asian Fisheries Development Center (SEAFDEC, 1967, Bangkok/Thailand)

South East Atlantic Fisheries Organization (SEAFO, 2001, Swakopmund/Namibia)

South Pacific Community (SPC, 1947, Nouméa/New Caledonia)

South Pacific Regional Fisheries Management Organization (SPRFMO, 2011, Wellington/New Zealand)

South West Indian Ocean Fisheries Commission (SWIOFC, 2004, Maputo/Mozambique)

Sub-Regional Fisheries Commission (SRFC, 1985, Dakar/Senegal)

U

Union for the Mediterranean (UfM, 1995, Barcelona/Spain)

United Nations (UN, 1945, New York/USA)

United Nations Conference on Trade and Development (UNCTAD, 1964, Geneva/Switzerland)

United Nations Convention on the Law of the Sea (UNCLOS, 1982, New York/USA)

United Nations Development Programme (UNDP, 1965, New York/USA)

United Nations Division of Economic and Social Affairs (UN-DESA, 1948, New York/USA)

United Nations Division of Ocean Affairs and the Law of the Sea (UN-DOALOS, 1982, New York/USA)

United Nations Educational, Scientific and Cultural Organization (UNESCO, 1945, Paris/France)

United Nations Environment Programme (UNEP, 1972, Nairobi/Kenya)

United Nations Framework Convention on Climate Change (UNFCCC, 1992, Bonn/Germany)

United Nations High Commissioner for Refugees (UNHCR, 1951, Geneva/Switzerland)

United Nations Industrial Development Organization (UNIDO, 1967, Vienna/Austria)

United Nations Oceans (UN-Oceans, 2003, New York/USA)

W

Western and Central Pacific Fisheries Commission (WCPFC, 2003, Kolonia/Federated States of Micronesia)

World Bank (WB, 1944, Washington/USA)

World Health Organization (WHO, 1948, Geneva/Switzerland)

World Intellectual Property Organization (WIPO, 1967, Geneva/Switzerland)

World Maritime University (WMU, 1983, Malmö/Sweden)

World Meteorological Organization (WMO, 1947, Geneva/Switzerland)

World Tourism Organization (UNWTO, 1975, Madrid/Spain)

World Trade Organization (WTO, 1995, Geneva/Switzerland)

Transnational Non-Governmental Organizations listed alphabetically

Entries are listed alphabetically by organization name. Brackets following the entry contain the standard acronym (if any) for that organization, followed by the year of creation and the city and State hosting the Secretariat (if any).

A

Advisory Committee on Protection of the Sea (ACOPS, 1952, Cambridge/UK)

Alfred P. Sloan Foundation (1934, New York/USA)

Arab Foundation for Marine Environment (AFME, 1995, Alexandria/Egypt)

Asian Pacific Network for Global Change Research (ARCP, 1996, Kobe/Japan)

Asian Pacific Society of Marine Biotechnology (APSMB, 1995, Taipei/Taiwan, China)

Association of Marine Laboratories of the Caribbean (AMLC, 1957, Kralendijk/Bonaire/ Netherlands)

B

Black Sea Coastal Association (BSCA, 1997, Varna/Bulgaria)

Blue Marine Foundation (2010, London/UK)

C

Centre for Mediterranean Studies (CMS, 1987, Zagreb/Croatia)

Conservation International (CI, 1987, Arlington/USA)

Consortium for Ocean Leadership (2007, Washington/USA)

Coral Reef Alliance (CORAL, 1994, San Francisco/USA)

Cousteau Society (1973, Hampton/USA)

D

Deep Sea Conservation Coalition (DSCC, 2004, Amsterdam/Netherlands)

E

European Bureau for Conservation and Development (EBCD, 1989, Brussels/Belgium)

European Marine Board (EMB, 1999, Ostend/Belgium)

European Society for Marine Biotechnology (ESMB, 1995, Tromsø/Norway)

Environmental Investigation Agency (EIA, 1984, London/UK)

European Network of Marine Research Institutes and Stations (MARS, 1995, Yerseke/Netherlands)

F

Friends of the Earth (1971, Amsterdam/Netherlands)

G

Gaia Foundation (1984, London/UK)

Galapagos Conservancy (GC, 2006, Fairfax/USA)

Global Coral Reef Alliance (GCRA, 1990, Cambridge/USA)

Global Forum on Oceans, Coasts and Islands (GOF, 2002, Newark/USA)

Global Ocean Commission (GOC, 2013, Oxford/UK)

Global Plan of Action for the Conservation, Management and Utilization of Marine Mammals (1977, Nairobi/Kenya)

Green Cross International (CGI, 1993, Geneva/Switzerland)

Greenpeace International (1971, Amsterdam/Netherlands)

I

International Association of Biological Oceanography (IABO, 1966, Auckland/New Zealand)

International Association for the Physical Sciences of the Oceans (IAPSO, 1919, Trieste/Italy)

International Chamber of Shipping (ICS, 1921, London/UK)

International Committee for Marine Conservation (ICMC, 1997, Hochheim/Germany)

International Council for Science (ICSU, 1919, Paris/France)

International Institute for Sustainable Development (IISD, 1990, Winnipeg/Canada)

International Marine Environment Protection Association (INTERMEPA, 2006, Athens/Greece)

International Marine Mammal Association (IMMA, 1974, New Brunswick/Canada)

International Marine Minerals Society (IMMS, 1987, Honolulu/USA)

International Ocean Institute (IOI, 1972, Msida/Malta)

International Ocean Institute-Pacific (IOI-PI, 1993, Suva/Fiji)

International Seafood Sustainability Foundation (ISSF, 2008, McLean/USA)

International Social Sciences Council (ISSC, 1952, Paris/France)

International Union of Geodesy and Geophysics (IUGG, 1919, Postdam/Germany)

L

Living Oceans Society (1998, Sointula/Canada)

M

Marine Conservation Society (MCS, 1977, Ross-on-Wye/UK)

Marine Stewardship Council (MSC, 1997, London/UK)

Marine Reserves Coalition (MRC, 2011, London/UK)

Mediterranean Advisory Council (MEDAC, 2013, Rome/Italy)

Mediterranean Coastal Foundation (MEDCOAST, 1990, Mugla/Turkey)

Mediterranean Wetlands Initiative (MedWet, 1991, Arles/France)

N

Network of Marine Protected Area Managers in the Mediterranean (MedPAN, 1990, Marseille/France)

O

Oceana (1999, Washington DC/USA)

Ocean Alliance (1971, Gloucester/USA)

OceanCare (1989, Wädenswil/Switzerland) Ocean Conservancy (1972, Washington DC/USA)

Ocean Culture and Environment Action Network (2003, OCEAN, Okinawa/Japan)

Ocean Futures Society (1999, Santa Barbara/USA)

Ocean Watch (1989, Pyrmont/Australia)

Office of Economic Cooperation for Mediterranean and Middle East (OCEMO, 2011, Marseille, France)

Organization of Black Sea Economic Cooperation (BSEC, 1992, Istanbul/Turkey)

Organization for the Phyto-Taxonomic Investigation of the Mediterranean Area (OPTIMA, 1974, Chambésy/Switzerland)

P

Pacific Institutes of Marine Science (PIMS, 2002, Hong-Kong/China)

Partnership for Observation of the Global Oceans (POGO, 1999, Plymouth/UK)

Prince Albert II of Monaco Foundation (2006, Monaco/Monaco)

Protection of the Arctic Marine Environment (PAME, 1993, Akureyri/Iceland)

R

Reef Environmental Education Foundation (REEF, 1990, Key Largo/USA)

Reef World Foundation (1999, Anglesey/UK)

S

Save Our Seas Foundation (2003, Geneva/Switzerland)

Scientific Committee on Antarctic Research (SCAR, 1958, Cambridge/UK)

Scientific Committee on Oceanic Research (SCOR, 1957, Newark/USA)

Sea Shepherd Conservation Society (1977, Friday Harbor/USA)

Seal Conservation Society (1996, Crossgar/Ireland)

Seas at Risk (SAR, 1986, Brussels/Belgium)

Seaturtle.org (1996, North Carolina/USA)

Shark Savers (2007, San Francisco/USA)

T

The Nature Conservancy (TNC, 1951, Arlington/USA)

The Ocean Foundation (TOF, 2003, Washington DC/USA)

The Pew Charitable Trusts (Pew, 1948, Philadelphia/USA)

U

Union of Concerned Scientist (UCS, 1969, Cambridge/USA)

W

West African Association for Marine Environment (WAAME, 1995, Dakar/Senegal)

Western Indian Ocean Marine Science Association (WIOMSA) (1993, Zanzibar/Tanzania)

Wetlands International (1995, Wageningen/USA)

Whale and Dolphin Conservation Society (1987, Chippenham/UK)

Wildlife Conservation Society (1985, New York/USA)

World Association of Marine Stations (WAMS, 2011, Fiskebäckskil/Sweden)

World Ocean Council (WOC, 2009, Honolulu/USA)

World Ocean Network (WON, 1999, Boulogne-sur-Mer/France)

World Resources Institute (WRI, 1982, Washington DC/USA)

World Underwater Federation (CMAS, 1959, Rome/Italy)

World Wildlife Fund for Nature (WWF, 1961, Gland/Switzerland)

Hybrid Organizations listed alphabetically

Entries are listed alphabetically by organization name. Brackets following the entry contain the standard acronym (if any) for that organization, followed by the year of creation and the city and State hosting the Secretariat (if any).

Coastal and Marine Union (EUCC, 1991, Leiden/Netherlands)

Global Partnership for Oceans (GPO, 2012, Washington/USA)

Group on Earth Observations (GEO, 2005, Geneva/Switzerland)

Institute for Sustainable Development and International Relations (IDDRI, 2001, Paris/France)

International Coral Reef Initiative (ICRI, 1994, Tokyo/Japan)

International Union for Conservation of Nature (IUCN, 1948, Gland/Switzerland)

Regional Advisory Councils (RACs, several venues in Europe)

8

Contribution of ocean science to the development of ocean and coastal policies and sustainable development

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8. Contribution of ocean science to the development of ocean and coastal policies and sustainable development

Alan Simcock,[1] Lorna Inniss[2] and Henrik Enevoldsen[3]

1 – Joint Coordinator of the United Nations Group of Experts of the Regular Process (World Ocean Assessment) 2009 onwards
2 – UN Environment (UNEP)
3 – Intergovernmental Oceanographic Commission (IOC) of UNESCO

Simcock, A., Innis, L. and Enevoldsen, H. 2017. Contribution of marine science to the development of ocean and coastal policies and sustainable development. In: IOC-UNESCO, *Global Ocean Science Report—The current status of ocean science around the world.* L. Valdés *et al.* (eds). Paris, UNESCO, pp. 170–187.

8.1. Introduction

The best analogy for the development of the relationship between ocean science and ocean policy is that of a rope tied to a great weight. The rope consists of many strands that are twisted together to produce a structure that can bear great weight. The great weight represents the importance for the well-being of both humans and the rest of the living world of getting the right policies on the management of human impacts on the seven-tenths of the planet that is the ocean. Looking at how the different strands developed helps to understand how ocean science influences policy and *vice versa*. This chapter considers the organizational structures in which the science/policy interface is embedded, which affects significantly the ways in which that interface works. The chapter continues with six case studies that illustrate ways in which this interface has promoted conservation of the ocean and supported sustainable management of its resources. It describes how ocean science, based on existing capacity and infrastructure (Chapter 3), investment (Chapter 4), outcomes (Chapter 5) and data management (Chapter 6), influences stakeholders. Finally, in the context of the 2030 Agenda for Sustainable Development, it looks at how further scientific understanding is needed to achieve, and monitor, the ten targets of Sustainable Development Goal 14 (SDG 14 'Conserve and sustainably use the oceans, seas and marine resources').

8.2. The development of the interface between marine science and policy

The three main strands that have underpinned the development of marine science are: the requirements of navies; scientific curiosity; and support for maritime industries (originally fishing and shipping, but now a much wider range including offshore oil and gas exploration and exploitation, seabed mining and renewable energy).

The European wars of the eighteenth century gradually expanded the areas of conflict to cover much of the then known world: the European navies were in action with each other in the Atlantic, the Caribbean and the Indian Ocean. Such action required knowledge of sea conditions—particularly soundings and currents. As early as 1720, the French *Ministère de la Marine* had established an office to centralize French knowledge of marine charts (McClellan and Regourd, 2000). This was followed by the British, Russian and other European oceanographic surveys and hydrological services in the eighteenth and nineteenth century (Blewitt, 1957; Postnikov, 2000; David, 2004). An early example of international cooperation in such efforts was the voyage of the British ship *HMS Chanticleer*, with support from the French and Spanish navies, in the South Atlantic in 1828–1832 (Goodwin, 2004; Webb, 2010).

Scientific curiosity about the ocean is as old as science itself; phenomena such as tides and currents could not but prompt questioning. Scientific pioneers, such as Benjamin Franklin in the USA, started serious investigations. Franklin, for example, investigated the Gulf Stream in 1786 as a result of its impact on the timing of mail packets across the North Atlantic (Deacon, 1997). Pursuit of scientific enquiry in other fields led to major maritime expeditions: a British expedition in 1768–1771 to the South Pacific organized by the British Admiralty and the Royal Society (the British academy of science) to observe the transit of Venus was accompanied by experts who carried out observations of the oceanography and marine biology of that area (David, 2004). The link between the Royal Society and the Admiralty was pursued for many years, culminating in 1873–1876 in the circumnavigation of the globe by *HMS Challenger*, with a team of scientists and specially equipped laboratories, which is generally regarded as the starting point of modern oceanography (Wyville Thomson and Murray, 1880–95; Rice, 1999; Desmond, 2004).

Across Europe, interest in marine science (and in particular the interest in marine biology stemming from the general development of biological sciences) led to setting up marine research institutions, either by governments or by private initiatives: Arcachon (1867), Roscoff (1872) and Banyuls (1881) in France; Naples (1871) in Italy; Sebastopol (1871) in Russia; Plymouth (1884) in England; Santander (1886) in Spain; and Heligoland (1892) in Germany (Desmond, 2004; Borja and Collins, 2004; Egerton, 2014). Similarly, in the USA, independent research institutions were set up at Woods Hole, Massachusetts (1888) and San Diego (1903—now the Scripps Institution of Oceanography) (Ritter, 1912; Lillie, 1944). At more or less the same time, physical and biological oceanography began to be recognized as a specialism in universities; for example, the first professorship of oceanography in the University of Liverpool (England) was established in 1919 (Rudmose Brown and Deacon, 2004).

The purely scientific aspects of marine research became increasingly prominent towards the end of the nineteenth century. In particular, the link between ocean currents and the movements of fish became a subject of scientific interest in Scandinavia. This led to the creation in 1902 of the International Council for the Exploration of the Sea (ICES) – the first intergovernmental environmental body. ICES undertook an initial five-year programme of collaborative research, eventually becoming a permanent and important body for marine science (Smed and Ramster, 2002; Egerton, 2014; Chapter 7). Seventy years later, a similar organization emerged in the North Pacific: in 1990 the North Pacific Marine Science Organization (nicknamed PICES for a 'Pacific ICES') was established (PICES, 2016).

Just over 50 years ago, the necessity for worldwide collaboration in marine research was acknowledged by the setting up of the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO). The IOC has acted since then as a focal point for organizing and supporting collaborative research, providing a central repository for information on both physical and biological oceanography and promoting capacity-building for marine research, especially in the Caribbean and South-East Asia (Scott and Holland, 2010).

Scientific support for maritime industries can be seen as starting with the production of accurate charts and pilotage manuals as a by-product of survey work for national navies; the British Admiralty Charts were issued commercially as early as 1821 (Andrew and David, 2004). However, more specific scientific support started in the mid-nineteenth century. In 1843, Professor van Beneden, Professor of Zoology at the University of Louvain, established a research station at Ostend in Belgium on his family oyster farm. A little later, to improve the aquaculture of oysters in France, the Marine Biological Station was established in 1859 at Concarneau. Concerns about the development of sea-fisheries in the last quarter of the nineteenth century led to pressures to apply science to better understand fish stocks and their distribution and fishing techniques. Many governments of countries around the North Sea established fisheries laboratories and research institutes at that time. As the value of fisheries research was proven, most coastal countries followed suit.

In a little more than 125 years after the first marine research institutions were established, the various strands have become more closely linked, and most marine research institutions now address a wide range of oceanographic questions. The interlinked nature of all marine science, including not only physical and biological oceanography, but also social and environmental aspects, has now been fully recognized by the establishment and organization by the United Nations General Assembly in 2006 of the Regular Process for the Global Reporting and Assessment of the State of the Marine Environment, including Socio-Economic Aspects (United Nations General Assembly resolution 65/37A). This produced the first integrated global assessment of the world's oceans – World Ocean Assessment I – in January 2016. The essential links between ocean and atmosphere have also been recognized in the work of the Intergovernmental Panel on Climate Change and the research that it has prompted – in particular the Special Report on Oceans and Cryosphere in a Changing Climate, which is due to be completed in September 2019.

8.3. Institutional arrangements for marine science

Because the driving forces for the development of marine science have been manifold, the arrangements that have emerged in different countries of the world are equally diverse. One crucial issue that has often emerged is the tension between the parts of government responsible for the development of policy and the research institutions. On the one hand, it is important for the research undertaken to be what is needed to satisfy policy needs. On the other hand, new, innovative developments in science depend on basic, wide-ranging investigation. Experience suggests that such high-quality science is best produced when the research is conducted independently of political pressures, and is subject to peer review with evaluation from a strictly scientific standpoint (Haas, 2004; Ruggiero, 2010). Countries try to achieve these dual goals in the context of their individual organizational history, by applying different models of institutional ocean science organization.

Many countries concentrate much of their marine scientific research (apart from that conducted within universities) in a single institute of marine research, usually dependent on a ministry that takes the lead on maritime and marine issues. Depending on national history, this is often the ministry responsible for the country's naval forces (as in Brazil) or the ministry responsible for agriculture and fisheries (as in Peru). Alternatively, a single marine research institute may be answerable to a range of ministries such as transport, natural resources and agriculture and fisheries (as in Ireland). To safeguard the independence of the research, such an institute is often governed by a separate board appointed by the country's government as a whole for a fixed term.

With a view to safeguarding the independence of scientific research, the majority of research institutes are placed under the supervision of a ministry for science, thus insulating them from the immediate policy pressures of the specialist ministries. This approach was influentially developed in the United Kingdom in 1915, when the Department for Scientific and Industrial Research was created. Similar structures were developed and continue in, for example, Australia (the Commonwealth Scientific and Industrial Research Organization), India (the Department of Scientific and Industrial Research) and Spain (Consejo Superior de Investigaciones Científicas). Such structures do not, however, rule out the existence of other marine research bodies directly controlled by the relevant specialist ministry (e.g. the Instituto Español de Oceanografía in Spain).

One aspect of the relationship between specialist ministries and marine research establishments is the focus of research programmes. Scientists often want to pursue research which will bring them attention, respect and advancement in their chosen discipline. This research may not be as responsive to the needs of policy-makers for research to resolve policy issues. Various means have been tried to resolve this dilemma. Increasingly, marine research institutes are agreeing to a customer/contractor relationship, under which their programmes are focused on the requirements of a funding ministry or agency, which pays for the specified research, without, however, having any management control over the institute.

Such arrangements frequently also ensure that a proportion of the research funding is for 'blue sky' research—research that is not tied to any particular policy goal, but chosen for its intrinsic scientific interest. As part of this 'customer/contractor' approach, some countries (such as New Zealand) are setting their national research bodies up in such a way that they can also compete in the open market for research contracts.

A sound balance between marine scientific research 'customers' and 'contractors' is crucial today and will be even more so in the years ahead. As the use of the ocean becomes more extensive, the need for knowledge is bound to increase and so are the necessary resources to carry out scientific research and related ocean observations. Extensive and constructive dialogues among the science community, marine industries, ocean managers and governments, both nationally and internationally, will be essential to ensure that necessary knowledge, covering the full range of issues required to inform policy-making effectively, is developed without compromising scientific quality. Recognition of the need for greater research coordination and cooperation was one of the reasons why the United Nations General Assembly agreed that part of the task of the Regular Process for the World Ocean Assessment should include the identification of knowledge and capacity-building gaps.

8.4. The science/policy interface in action

An understanding of how marine science can work together with marine policy is essential for both the design of marine scientific research programmes and the development and implementation of marine policy. Case studies of particular issues can promote such an understanding. Six are briefly presented here: fisheries management in the North Sea, harmful algal blooms, the spread of non-native organisms, anti-fouling treatments, the Benguela Current large marine ecosystem, and geoengineering of carbon dioxide absorption.

8.4.1. Fisheries management in the North Sea

In the nineteenth century, concerns for fisheries management in the North Sea focused mainly on defining who should benefit from the fishery, rather than on managing the impact of fishing on the marine environment. This reflected an approach typified in a remark by Thomas Huxley, a prominent supporter of Charles Darwin's theories. Speaking at a London Fisheries Exhibition in 1883, he said *'In relation to our present modes of fishing, a number of the most important sea fisheries…are inexhaustible'*. He added that the natural 'destructive agencies' at work on fish stocks were so great that fisheries could not significantly increase the death rate (Huxley, 1883).

Huxley's qualification about 'the present modes of fishing' was crucial. Over the next few decades, technology converted the fishermen's activities into an even larger 'destructive agency' than natural forces – a process which continued throughout the twentieth century. More reliable means of propulsion, larger fishing vessels (so that more could be caught before a return to port was necessary), refrigeration as a method of preserving fish, new fishing gear, better navigation aids and the use of echo-location of fish – all these have enabled a massive increase in the size of the catch.

By the 1930s, there was sufficient concern about over-fishing for North Sea States to start to take action. Little progress, however, was made on regulation, largely because the scientific knowledge of fish populations was still in its early stages. In the 1930s and 1940s, better understanding of the fish life-cycles was achieved, and after the Second World War, fisheries science continued to improve with major developments in the statistical understanding of how fish populations responded to natural events and the pressures from fisheries (Hardy, 1959).

As the science improved, the need to maintain high levels of fish catch and achieve a fair sharing of the North Sea catch between States led to further efforts at regulation, but it would be nearly 40 years before a system slowly emerged. A new convention was agreed in 1946 – though it did not come into force until 1953. This provided for some conservation measures, but no limits on fishing effort. Provision was made for further conservation measures on the advice of ICES, and ICES began to make recommendations, but none were ever adopted. There was, therefore, no effective set of agreements on fisheries, largely because of the continuing arguments over the extent of national control of the sea.

In 1976, proposals were agreed for a European Community Common Fisheries Policy, implementing a commitment which dated back to 1956 and providing for the introduction – *in the future* – of a system of European Community conservation measures. Thus, although there was by then a good understanding of the science behind the performance of fish populations, legal uncertainty over fisheries jurisdictions and conflicting national interests meant that there was little success in applying this scientific understanding to fisheries management.

Into the middle of all these developments on the legal and management structures came an event in the real world that required urgent action. The collapse of the North Sea herring stock under the pressure of over-fishing created the need for immediate action in the absence of an agreed framework (Bjørndal and Lindroos, 2002). An agreement emerged for bans on herring fishing, resulting in the recuperation of the herring stocks so that catches could resume in the mid-1980s in the North Sea.

This collapse made the States realise the need for an overall framework and, after hectic negotiations over the period to 1983, the North Sea States ended up with a system based on total allowable catches (TACs). These were negotiated annually by fisheries ministers in December, for the following calendar year, on the basis of advice from ICES. Ministers had a difficult political task: on the one hand, they could understand the need to follow scientific advice; on the other, they were under intense domestic political pressure to deliver to their national fishing fleets the potential economic opportunities. Not surprisingly, these conflicting pressures proved irreconcilable. TACs were frequently set higher than the levels recommended by scientists. This pattern continued well into the 2000s. For example, in 2002, ICES recommended a complete moratorium on all catching of North Sea cod. The European Commission proposed an 80% reduction in the cod TAC. The Council of Ministers eventually agreed on only a 45% reduction in TAC, with the result that the actual catches were too large for a sustainable fishery.

The fishers lost confidence in the system and began to evade it. The pressures from the TAC limits led to large amounts of fish being discarded (because they would have been over the quotas) and 'high-grading' (the discarding of economically less worthwhile fish, to stay within the quota). These discards in turn led to a sevenfold increase in scavenging seabirds, fed by the discards. At the same time, the evasion of the controls on landing fish undermined the data on which the scientists based their assessments, so that forecasts became less reliable (Daw and Gray, 2005).

During the 1990s, the thrust of fisheries science slowly broadened: the initial emphasis on single-stock management developed into the ecosystem approach to fisheries management, taking into account the interactions between different fish species, the relationship between fish and other wildlife species and wider environmental issues such as pollution (North Sea Intermediate Ministerial Meeting, 1997). Further, at the end of the 1990s, Aberdeenshire County Council (whose area covers a very large part of the Scottish fishing industry) decided to try to rebuild a climate of trust between fishers, fisheries scientists and fisheries managers. A series of conferences around the North Sea organized by major local authorities invited multiple stakeholders (fishers' organizations, fisheries scientists, fisheries managers, environmental managers and NGOs) to discuss the uncertainties of fisheries science and the problems of fisheries management. This series of conferences led to European Union's Regional Fisheries Advisory Councils (Chapter 7). New approaches were adopted in other fields, so that by 2014 a complete reform of the EU Common Fisheries Policy had been achieved, to come into effect over the following few years. This is intended to incorporate the EU's international commitments to an ecosystem approach and the limitation of fishing effort to the maximum sustainable yield, to ban discards and to adjust fishing capacities to be in balance with fishing opportunities (EU, 2016).

From the point of view of the interface of marine science with marine policy the main messages of this history are: (i) the need for a sound scientific understanding of aspects of the environment that should be regulated; (ii) the need for scientists to present material clearly to policy-makers, so that they understand the uncertainties inherent in the scientific results; (iii) the need to involve all stakeholders so that they understand the scientific messages; and (iv) the need to avoid creating situations in which political pressures are likely to distort the science.

8.4.2. Excessive nutrients and algal blooms

There are many facets to the problems caused by the excessive growth of marine algae – a broad grouping of photosynthesizing organisms found in the parts of the ocean to which light can penetrate. Some of these problems result from toxins produced by the algae. Others result from the sheer quantity of non-toxic algae that can be produced.

Where there are massive blooms of non-toxic algae, one of the frequent outcomes is the *marées vertes* (green tides) that disfigure beaches in many parts of the world. Other outcomes are hypoxic and dead (anoxic) zones, where the action of bacteria in the decay of algae and phytoplankton (microscopic plants) in the bloom causes declining oxygen concentrations or even results in the effective absence of dissolved oxygen. Fish flee from such zones and the immobile sea-bed animals die. These problems are found all around the world. More than 500 sites are currently facing these problems continuously or during parts of the year (Diaz and Rosenberg, 2008), including large parts of the Baltic Sea, the Gulf of Mexico, nearly all the major river estuaries of China and Manila Bay in the Philippines (Sotto *et al.*, 2014; GOERP, 2017).

Ocean science has revealed that the main cause of many of these problems is the input to the sea of excessive amounts of nutrients, in particular nitrogen, which in undisturbed ecosystems regulates and limits primary production (eutrophication). There are four main sources of nitrogen compounds (mainly nitrates) for the ocean: (i) compounds containing nitrogen that are emitted from internal-combustion engines; (ii) sewage (i.e. human faeces and urine) and associated organic material from industrial processes (especially brewing and distilling); (iii) agricultural run-off (including run-off from fertilizers applied in arable agriculture and slurry from livestock rearing); and (iv) emissions to air (mainly methane) from livestock. The effects of these sources can be limited in various ways.

The environmental, social and economic effects of these eutrophication problems are manifold. Tourists avoid affected beaches. Fish and other marine life are killed and ecosystems are disrupted, leading, for example, to the 1991 European Community Nitrates and Urban Waste Water Directives and the Environmental Protection Agency's Chesapeake Bay Program (GOERP, 2017).

A wide range of disciplines needs to collaborate to understand and tackle the problems of excess nutrients resulting in excessive algal growth and a consequent loss of dissolved oxygen in the ocean. Studies have had to, and continue to need to, link at least plankton and algae, the management of sewage, agriculture and traffic, the chemistry of nitrogen compounds, the toxicology of shellfish and hypoxic and anoxic zones, together with regular monitoring of the ocean's physical conditions, state of relevant coastal areas, seawater contents and chlorophyll.

In addition to problems resulting from excessive growth of non-toxic algae, there are also problems with algae species that produce toxins. Some phytoplankton species are toxic; their blooms cause illness and death in humans, fish, seabirds, marine mammals and other oceanic life, often as a result of toxin transfer through the food web. Six human poisoning syndromes are caused by consumption of seafood contaminated by toxins from harmful algal blooms. Other threats to human health are posed by toxic aerosols and water-borne compounds derived from toxic algae that cause respiratory and skin irritation.

The harm from toxic algal blooms arises not only from the illnesses and deaths caused by poisoning but also from the damage to shellfish and other fisheries that have to be closed to protect people from poisoning, and the disruption of ecosystems caused by deaths of fish and other top predators that ingest the algae or the toxins that they produce. Many toxic algal bloom events are reported annually from all parts of the world, and the number is growing. Some of these increased numbers are due to improved observation and recording but there is reliable evidence that there is a real increase in the incidence of this problem, through the interaction of many factors including rising sea temperatures, increased inputs of nutrients to the ocean, transfer of non-native species by shipping and changes in the balance of nutrients in the sea.

Toxic algal blooms are complex phenomena that require the involvement of many disciplines to address the problems that they cause, ranging from molecular and cell biology to large-scale field surveys, numerical modelling and remote sensing. Under the leadership of the IOC, the Scientific Committee on Oceanic Research (SCOR), the United Nations Food and Agriculture Organization (FAO) and regional marine science organizations, major programmes have developed over the last 30 years to bring together all the many strands of science that are needed to understand and manage harmful algal blooms. In the early 1990s, an intergovernmental panel was set up by IOC and in the late 1990s, a coordinated international scientific programme on the ecology and oceanography of harmful algal blooms GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms) was set up under the auspices of IOC and SCOR. GEOHAB has brought about a major increase in understanding of the processes that result in harmful algal blooms, including their relationships to upwelling systems, stratification and eutrophication. It is now becoming possible to forecast when they may occur and better techniques for testing for toxins have improved the protection of human health and markets. At the same time, capacity-building under the programme is helping more States set up monitoring systems to ensure that food from the sea is not contaminated by algal toxins (Anderson *et al.*, 2010).

The successes in this field have shown the importance of collaboration both between States and between scientific disciplines. Much work has been required to establish the cross-disciplinary links and to set up global monitoring and reporting systems. The time span between detecting the issue and policy action, the spatial variability and the different scientific disciplines involved in investigating the problem of harmful algae blooms emphasize the importance of long-term commitments in the field of marine science.

8.4.3. Movement of non-indigenous species

The dispersal of plants and animals over long distances has been part of evolution. Some species (for example, the coconut – *Cocos lucifer*) have probably spread by sea without human intervention of any kind, although the present distribution of coconuts appears to involve deliberate human transfers both in the prehistoric and historic periods (Foale, 2003). Ships have long played a role in transferring species from one part of the world to another. However, recently there has been a massive increase in ship traffic. International trade carried by ships increased by between twofold (oil and gas) to fivefold (coal and ore) between 1970 and 2012 (UNCTAD, 2014). There has therefore been a large increase in the potential for the transfer of marine species between different parts of the world.

One aspect of this is the potential for the carriage of species in ballast water—particularly for tanker ships where ships regularly return in ballast for their next load-bearing voyage. In the late 1980s, Canada and Australia raised the issue in the IMO's Marine Environment Protection Committee (MEPC). In 1991, the MEPC adopted guidelines for preventing the introduction of unwanted organisms and pathogens from ships' ballast water and sediment discharges. In 1993, the IMO Assembly followed this up by asking the MEPC to review the guidelines with a view to develop an international convention. By 1997, the IMO invited States to use the guidelines to address this problem. More than 14 years of negotiations were needed to develop the *2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments* (BWM Convention). Another 13 years have been needed to achieve sufficient ratifications for the convention to enter into force, expected to happen in September 2017 (IMO, 2016b).

Scientific evidence has played an important role in winning the arguments for action in this field, such as widespread surveys of the scale and distribution of the problems of non-indigenous species (Figure 8.1). In 2000, for example, a survey identified 295 non-indigenous species (NIS) in North America and concluded, with some hesitation, that: (i) the rate of reported invasions has increased exponentially over the past 200 years; (ii) most NIS are crustaceans and molluscs, while NIS in taxonomic groups dominated by small organisms are rare; (iii) most invasions have resulted from shipping; (iv) more NIS are present along the Pacific coast than the Atlantic and Gulf coasts; and (v) native and source regions of NIS differ among coasts, corresponding to trade patterns (Ruiz *et al.*, 2000).

The International Union for the Conservation of Nature (IUCN) identified 84 non-indigenous invasive marine species, which have appeared in marine habitats outside their natural distribution (GISD, 2014). Another study in 2008 found 205 species, of these: approximately 39% are thought to – or are likely to – have been transported only by fouling of ships' hulls; 31% in ballast water; and 31% by one or other of these routes (Molnar *et al.*, 2008). Some regional reviews have also identified high numbers of non-indigenous species; for example, 120 in the Baltic Sea and over 300 in the Mediterranean (Zaiko *et al.*, 2011).

These surveys build on an enormous amount of groundwork where individual cases have been examined. The case of the BWM Convention is therefore a good example of the need for worldwide, detailed examination of the marine environment, and effective reporting that provides results that can be accessed and used to produce an integrated global picture, detecting the cause of invasive species and, hopefully in the near future, stagnating or decreasing distribution.

8.4.4. Anti-fouling treatments

From the start of long-sea voyages, the hulls of wooden ships were attacked by the naval shipworm (*Teredo navalis*), which bored into and destroyed the wood. From around 1760, attempts were made to prevent this by covering the hulls with thin sheets

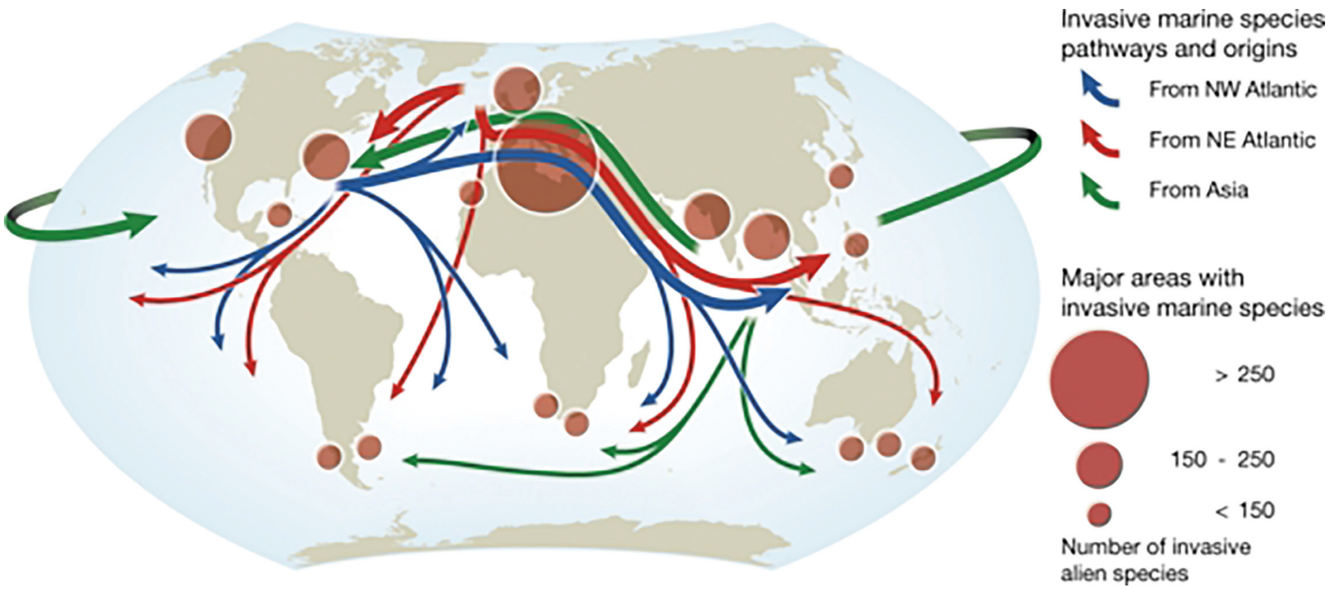

Figure 8.1. Major pathways and origins of invasive species infestations in the marine environment. *Source*: Nelleman *et al.*, 2008 (GRID-Arendal, H. Ahlenius, http://www.grida.no/resources/7191).

of copper. These were also found to help navigation by reducing the accumulation of barnacles, seaweed and other biofouling, which slowed the speed of ships (Rosenberg and Gofas, 2010). Even after steel hulls replaced wooden ones, the impact of accretions of marine life has been important for the operation of shipping. Biofouling reduces ship speed owing to the extra drag, which increases fuel consumption and engine stress. A biofilm 1 mm thick can increase the ship hull friction by 80%, which translates into a 15% loss in speed. Furthermore, a 5% increase in biofouling increases ship fuel consumption by 17% with a 14% increase in greenhouse gas emissions. In 1980, the US Navy estimated that 18% of its fuel consumption was due to biofouling (Bixler and Bhushan, 2012).

Given these substantial economic implications, it is not surprising that a great deal of effort has been applied to finding effective anti-fouling treatments. In the 1960s and 1970s, techniques were developed for embedding compounds of tributyltin (TBT), long known as an effective biocide, into resin bases that would slowly abrade (under the effect of water flowing past) and thus continuously release the TBT. Anti-fouling treatments based on this approach proved highly effective and were quickly and widely adopted (Piver, 1973).

It was not long after that adverse effects from the introduction of TBT anti-fouling treatments started to be detected. As early as 1981, the appearance of male traits in female mud snails was being observed, and it was noted that this could be produced in the laboratory by very low levels (a few parts per billion) of TBT (Smith, 1981). At about the same time, the Pacific oyster (*Crassostrea gigas*) was introduced to aquaculture in Europe, especially in France. Shell malformations appeared in these oysters, and these were found to increase in proportion to the amount of surrounding boating activity. Furthermore, this effect diminished if the affected oysters were re-laid in waters removed from boating activity (Alzieu and Portmann, 1984).

The scientific evidence was sufficiently clear that countries began prohibiting the use of TBT as an anti-fouling treatment on boats of less than 25 m. This caused a major outcry and campaign from the yachting community, who saw large numbers of amateur sailors being disadvantaged for the benefit of a 'few oyster farmers'. Nevertheless, the authorities in many States persisted with this regulation/prohibition (Corrick, 1985).

The scientific evidence of endocrine disruption and other adverse effects, particularly in molluscs, continued to accumulate. In 1990, the IMO recommended that governments should eliminate the use of anti-fouling paints containing TBT. This resolution was intended as a temporary restriction until the IMO could implement a more far-reaching measure. The *2001 International Convention on the Control of Harmful Anti-fouling Systems on Ships*, which entered into force in 2008, prohibits the use of organotin compounds as biocides in anti-fouling paints (IMO, 2016a).

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The case of TBT anti-fouling paints shows the importance of regular monitoring of the ocean. The level of TBT at which harm was caused is so low that, at the time, it could not be detected by chemical analysis; only the observation of reaction of biota to the presence of the chemical enabled it to be detected.

8.4.5. Benguela Current Commission

The world ocean is a single, interlinked system, but in order to understand it and to manage human impacts on it, it is necessary to divide it into more manageable units. As a result of many studies, originally started by the National Oceanic and Atmospheric Agency of the United States, a series of Large Marine Ecosystems (LMEs) has been identified. Sixty-six LMEs are usually recognized, being defined by geomorphic features such as the extent of the continental shelves, oceanographic features such as major ocean currents and ecological factors giving rise to distinct ecosystems.

Off the west coast of Africa, the Benguela Current LME is dominated by the current of that name off the coasts of Angola and Namibia and the western coast of South Africa. In the context of its international waters portfolio, the Global Environmental Facility (GEF) strongly endorses the strategy of country-driven LME management. Through its International Waters focal area, GEF promotes the incorporation of an interdisciplinary approach, along with a development component to improve the management of marine resources (IOC-UNESCO and UNEP, 2016).

GEF places priority on the development of a Strategic Action Programme (SAP) that addresses changing sectoral policies and activities responsible for the root causes of transboundary environmental concerns. The SAP for the Benguela Current LME was implemented between 2002 and 2008. During that time period, 75 projects hosted by a wide variety of marine science bodies and supported by GEF through the United Nations Development Programme were conducted, and a comprehensive picture of the status of the LME was generated. Subjects studied included the cumulative impact of offshore marine diamond mining, the biodiversity of the estuarine, coastal, near-shore and offshore environments of the region and the important fisheries of the area. Extreme environmental events, including the sustained warming of the ocean ('Benguela Niño') and large-scale eruptions of sulphur, were also assessed.

This major improvement in the knowledge of the LME resulted in an acknowledgement by the Governments of Angola, Namibia and South Africa that improved arrangements were needed to coordinate the governance of human activities in the LME. In 2013, the Benguela Current Commission was established, to promote a coordinated regional approach to the long-term conservation, protection, rehabilitation, enhancement and sustainable use of the LME. This is the first inter-governmental commission in the world to be based on the Large Marine Ecosystem concept of ocean governance (BCC, 2017).

The process of establishing the Benguela Current Commission shows how a thorough examination of the science of a marine region can create the knowledge base needed for improved international collaboration and thus strengthen the political will for the necessary agreements.

8.4.6. Geo-engineered sequestration of carbon dioxide

Due to the problems of climate change, much thought has gone into the possibilities of mitigating emissions of greenhouse-gases, especially carbon dioxide. One suggestion involved large-scale ocean fertilization, by adding iron or other nutrients to surface waters. The intention would be to enhance microscopic marine plant growth, on a scale large enough to significantly increase the uptake of atmospheric carbon by the ocean and to remove it from the atmosphere for time periods long enough to provide global climatic benefit. This suggestion grew out of scientific ideas developed in the late 1980s. The suggestion was controversial and in 2008, the ninth meeting of the Conference of the Parties to the *1992 Convention on Biological Diversity* decided that no further ocean fertilization activities – for whatever purpose – should be carried out in non-coastal waters until there was stronger scientific justification, and that it be assessed through a global regulatory mechanism.

At the same time, the **c**ontracting parties to both the *1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (London Convention) and the *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (London Protocol) – the global instruments regulating the dumping of wastes in the sea – adopted a resolution agreeing that the scope of those instruments includes ocean fertilization activities. Under this denomination is any activity undertaken by humans with the principal intention of stimulating primary productivity in the oceans (not including ordinary aquaculture, mariculture or the creation of artificial reefs). They also agreed to consider in more detail what that conclusion implied.

The IOC decided to commission a scientific report on the issue and provide it as input to the debate. The report was prepared with the assistance of the Surface Ocean Lower Atmosphere Study, an international programme that focuses research effort on air-sea interactions and processes, and which is sponsored by the International Geosphere-Biosphere Programme, SCOR, the World Climate Research Programme and the International Commission on Atmospheric Chemistry and Global Pollution.

The report concluded that, while experiments had shown that inputs of iron to high-nutrient regions can greatly increase the biomass of phytoplankton and bacteria, and thus the drawdown of carbon dioxide into surface water, it is not yet known how iron-based ocean fertilization might affect zooplankton, fish and seafloor biota. Furthermore, the report concluded that there is even less information on the effectiveness and effects of fertilizing low-nutrient regions. The report also pointed out that large-scale fertilization could have widespread (and difficult to predict) impacts locally, but also far removed in space and time. It recommended careful study of the issue and monitoring of any experiments (Wallace *et al.*, 2010).

The report was influential in helping the discussions under the London Convention and London Protocol. In 2010, the contracting parties to these instruments adopted the Assessment Framework for Scientific Research Involving Ocean Fertilization and in 2013, the contracting parties of the London Protocol adopted amendments, which incorporated ocean fertilization and other marine geo-engineering activities as well as provisions for regulation of these into the Protocol (GOERP, 2017).

This example shows how a well-organized and well-focused scientific report can help international negotiations to improve the management of human activities and reduce the impacts on the marine environment.

8.5. Looking ahead

An important part of any report looking at ocean science around the world is to identify the gaps in knowledge. Part of the work of the first global integrated assessment of the ocean – World Ocean Assessment I – was to identify the knowledge gaps that hamper the understanding of the ocean and the management of human activities affecting the ocean in order to deliver the services and maintain the ocean resources the world needs (GOERP, 2017). Filling knowledge and associated capacity gaps, investing in ocean science and tracking the impact of marine research, as presented in the Global Ocean Science Report, will be important for sustaining ocean and human health, i.e. achieving SDG 14 and in particular its SDG target 14.a (increase scientific knowledge, develop research capacity and transfer marine technology…).

The information, that the world community needs to understand the ocean, can be divided into four main categories: (i) the physical structure of the ocean; (ii) the composition and movement of the ocean's waters; (iii) the biota of the ocean; and (iv) the ways in which humans interact with the ocean. In general, the North Atlantic and its adjacent seas are probably the most thoroughly studied – though even there, major gaps remain. Parts of the Atlantic Ocean and the Pacific Ocean in the northern hemisphere are better studied than those in the southern hemisphere. Least is known about the Arctic, Southern and the Indian Ocean.

The following examples present a scientific perspective of ocean research topics relevant to SDG 14 targets.

8.5.1. Physical structure of the ocean

Our knowledge of the geomorphic features of the ocean has been greatly enriched over the past 25 years by local and global studies. Although charting the oceans has been in progress for more than seven centuries in coastal waters and for 250 years along the main routes across the open ocean, many features still require more detailed examination. The designation of exclusive economic zones (EEZs) has led many countries to carry out more detailed surveys as a basis for managing their activities in those zones. Ideally, all coastal States would have such detailed surveys as a basis for their EEZ management. Surveys beyond national jurisdiction will sensibly be organized internationally (for example the GEBCO Seabed 2030 project). Such surveys will contribute to SDG target 14.2 (…manage and protect marine and coastal ecosystems…).

It is possible to characterize the physical structure of the ocean in areas beyond national jurisdiction, but the reliability and detail of such characterizations varies considerably among different parts of the ocean. Improvements in information of that kind are highly desirable to understand the interaction between the physical structure and the biota of the ocean, in terms of conserving biodiversity and managing living marine resources. Effective comparison between different parts of the world requires comparable approaches, which are best organized internationally. Such information will contribute towards SDG targets 14.3 (Minimize and address the impacts of ocean acidification…) and 14.7 (…increase economic benefits to small island developing States (SIDS) and least developed countries (LDCs) from sustainable use of marine resources…).

8.5.2. State of the ocean waters

Gaps persist in knowledge of changes in sea temperature (both at the surface and at depth), sea-level rise, salinity distribution, carbon dioxide absorption, and nutrient distribution and cycling. The atmosphere and the ocean form a single linked system. Much of the information needed to understand the ocean is also needed to understand climate change and it is thus important to ensure that oceanic and atmospheric research is coordinated. This information will also be important for SDG 13 (Take urgent action to combat climate change and its impacts) and for the work under the auspices of the *1992 United Nations Framework Convention on Climate Change* and the *2016 Paris Agreement*.

Ocean acidification is a consequence of carbon dioxide absorption, but understanding the implications for the ocean requires more than just a general understanding of how carbon dioxide is being absorbed, as the degree of acidification varies locally. The causes and implications of those variations are important for understanding the impact on marine biota. Such information will further contribute towards SDG target 14.3 (ocean acidification). The Global Ocean Acidification Observing Network is being put in place, involving many national administrations, universities and marine research institutes with the participation of IOC and the International Atomic Energy Agency.

In order to track primary production (on which the overwhelming majority of the ocean food web relies), routine and sustained measurements of dissolved nitrogen and biologically active dissolved phosphorus are highly desirable across all parts of the ocean. Such research involves satellite observation and gliders and floats (for example Argo floats; Chapter 3), and therefore generally requires international cooperation. Such information is crucial not only to achieve SDG target 14.2 (manage and protect management of marine and coastal ecosystems), but also SDG target 14.1 (...prevent and significantly reduce marine pollution of all kinds... especially that related to nutrient inputs).

8.5.3. Biota of the ocean

Plankton are fundamental to life in the ocean. Information on their diversity and abundance is important for many purposes. Such information has been collected for over 70 years in some parts of the ocean (such as the North Atlantic) through continuous plankton recorder surveys and sustained ship based time-series (Chapter 3). Such information is important to complement information on primary production (Section 8.5.2).

Information on biodiversity in the ocean and the number and distribution of the many marine species is also highly useful for understanding the health and reproductive success of individual populations. Many species contain separate populations that have limited interconnections. Since many populations are found in more than one national jurisdiction and some both in areas within and beyond national jurisdiction, effective surveys require international cooperation.

Fish stock assessments are essential to the proper management of fisheries. A good proportion of the fish stocks fished in large-scale fisheries are the object of regular stock assessments. However, many important fish stocks are still not regularly assessed. More significantly, stocks important for small-scale fisheries are often not assessed, which has adverse effects in ensuring the continued availability of fish for such fisheries. This is an important knowledge gap to fill. Likewise, there are gaps in information about the interactions between large-scale and small-scale fisheries for stocks over which their socio-economic interests overlap, and between recreational fishing and other fisheries for some species, such as some trophy fish (marlins, sailfish and others) and other smaller species.

Information on marine species and on fish stocks is important for SDG target 14.4 (...effectively regulate harvesting and end overfishing, and implement science-based management plans...), as well as 14.2 (management and protection of marine and coastal ecosystems), 14.7 (economic benefits for SIDS and LDCs) and 14.B (provide access for small-scale artisanal fishers to marine resources and markets). Better information on fish stocks in areas beyond national jurisdiction is also important for the development of a new international legally-binding instrument for the conservation and sustainable use of biodiversity in areas beyond national jurisdiction, under the *1982 United Nations Convention on the Law of the Sea*–because of the depth of the ocean, ocean areas beyond national jurisdiction represent over 90% of the space occupied by life on earth in all its forms. Further new data will support the implementation of legislation put in place via illegal, unreported and unregulated fishing (IUU) regulations, which combats the depletion of fish stocks, the destruction of marine habitats, distortion of competition, disadvantages for honest fishers, and weakening of coastal communities, particularly in developing countries[1] (FAO, 2001; SDG target 14.6).

1 Regulation (EC) No 1005/2008—EU system to prevent, deter and eliminate illegal, unreported and unregulated fishing.

8.5.4. Ways in which humans interact with the ocean

Some of the issues relating to the ocean and to ocean biota (for example, ocean acidification and fish stock assessments) are linked to the way in which humans affect some aspects of the ocean (for example, through carbon-dioxide emissions or fisheries). However, there are many more areas in which we do not yet know enough about human activities that affect or interact with the ocean to enable us to manage those activities sustainably.

For shipping, much information is available about where ships go, their cargo and the economics of their operations. However, important gaps remain in our knowledge about how their routes and operations affect the marine environment. Those issues include primarily the noise that they make, continued discharges of oil and the extent to which non-native invasive species are being transported. This information is needed for SDG target 14.1 (prevention and reduction of pollution).

Land-based inputs to the ocean have serious implications for both human health and the proper functioning of marine ecosystems. In some parts of the world, those have been studied carefully for over 40 years. In others, little systematic information is found. There are two important gaps in current knowledge. The first is how to link different ways of measuring discharges and emissions. Much information is available from local studies about inputs, but those are frequently measured and analysed in different ways, thereby making comparison difficult or impossible. There are sometimes good reasons for using different techniques, but ways of improving the ability to achieve standardized results and to make comparisons are essential to give a full global view, which will be needed to understand the connectivity of the ocean, affecting local and regional coastal and ocean health. Global understanding is required to effectively design local conservation and protection of marine ecosystems, in order to maintain the provision of marine ecosystem services, for example carbon sequestration and food provision. Secondly, different regions of the world have developed different approaches for assessing the overall quality of their local waters. Good reasons for such differences almost certainly exist, but knowledge of how to compare the different results would be helpful, particularly in assessing priorities among different areas. Again, all this is needed to achieve for SDG target 14.1 (prevention and reduction of pollution).

Another area with many knowledge gaps is the extent to which people (and, consequently, economies) are suffering from diseases that are either the direct result of inputs of waterborne pathogens or toxic substances, or the indirect result of toxins from algal blooms. This information is relevant for targets in SDG 3 (ensure healthy lives and promote wellbeing for all at all ages) as well as for SDG target 14.7 (increase economic benefits for SIDS and LDCs) for example tourism and recreation, as well as manufactured products, for example construction material or charcoal (GOOS, 2003; GOOS, 2005).

The existing offshore mining industries are very diverse and, consequently, their impacts on the marine environment do not have much in common. Where they occur in the coastal zone, it is important that those responsible for integrated coastal zone management have good information on what is happening, particularly in relation to discharges of tailings and other disturbances of the marine environment (Ramirez-Llodra *et al.*, 2015). As offshore mining expands into deeper waters and areas beyond national jurisdiction, it is indispensable to ensure that information about their impacts on the marine environment is collected and published. Such information supports the successful implementation of SDG target 14.2 (management and protection of marine and coastal ecosystems).

Our knowledge of marine debris has many gaps. Unless we understand better the sources, fates, and impacts of marine debris, we shall not be able to tackle the problems that it raises. Although the monitoring of marine debris is currently carried out in several countries around the world, the protocols used are not aligned, preventing comparisons and the harmonization of data. Because marine debris is so mobile, the result is a significant gap in knowledge. More scientific data are needed to evaluate the impacts of marine debris on coastal and marine species, habitats, economic well-being, human health and safety, and social values. Marine food chains are altered by marine debris, potentially impacting human health. More information on the origin, fate and effects of plastic microparticles and nanoparticles is highly desirable. The Joint Group of Experts on the Scientific Aspects of Marine Protection (GESAMP—an advisory body sponsored by nine United Nations agencies and programmes) has carried out a global assessment of microplastics in the marine environment. Likewise, because of their potential biocidal effects on phytoplankton, there is a gap in knowledge about titanium dioxide nanoparticles when subject to ultraviolet light. All this information is necessary for achieving SDG target 14.1 (prevention and reduction of marine pollution, including marine debris).

Many aspects of integrated coastal zone management are still under development. Those responsible for managing coastal areas need information on, at least, coastal erosion, land reclamation from the sea, changes in sedimentation as a result of coastal works and changes in river regimes (such as damming rivers or increased water abstraction), the ways in which the local ports are working and dredging is taking place and the ways in which tourist activity is developing (and is planned to develop), and the impacts that those developments and plans are likely to have on the local marine ecosystem (and, for that matter, the local terrestrial ecosystems). This information is needed for SDG target 14.2 (management of marine and coastal ecosystems). It will also be important for SDG target 14.7 (economic benefits to SIDS and LDCs), since SIDS and coastal LDCs depend largely on effective use of their coastal zones.

Closing those gaps in our knowledge would amount to an ambitious programme of research. Research is already taking place on many more issues on which more information is desirable (for example, on how the genetic resources of the ocean can be used and what the practical possibilities are for seabed mining). Collaboration and sharing will be important for making the best uses of scarce research resources.

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Annexes

Annex A

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A

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Kirsten Isensee has been a project specialist at the Intergovernmental Oceanographic Commission of UNESCO since 2012. Her work focuses on ocean carbon sources and sinks, trying to distinguish the natural and anthropogenic influences on the marine environment. She supports several activities and facilitates collaboration between scientists, policy-makers and stakeholders, including networks such as the Global Ocean Acidification Observing Network, the International Blue Carbon Initiative, the International Group for Marine Ecological Time Series and the Global Ocean Oxygen Network. She received her diploma and her Ph.D. in Marine Biology from the University of Rostock, Germany. During her studies, she specialized in the impact of ocean acidification and climate change on the marine environment.

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Seonghwan Pae holds a Ph.D. in Wildlife Biology from Kyunghee University, Seoul, Republic of Korea. As a Principal Researcher at KIMST (Korea Institute of Marine Science and Technology Promotion), he has been dedicated to the management of diverse areas of R&D projects such as ocean research and observation, construction of an icebreaker (research vessel), planning and construction of a second Antarctic research station, construction of ocean research stations, the Cooperative Project on Korea-China Bilateral Committee on Ocean Science, the Cooperative Project on Marine Science and Technology between Korea and Latin America, the marine bio-resource bank, and a biotechnology programme. From 2014 to 2016 he was an Assistant Programme Specialist at IOC-UNESCO in Paris.

Linda Pikula [2]

Linda Pikula is the NOAA Regional Librarian for the NOAA Central Library in Silver Spring, Maryland. Her duty station is Miami, Florida where she coordinates library services for the Atlantic Oceanographic and Meteorological Laboratory and the National Hurricane Center. She advises the NOAA North-South Consortium of Libraries on collaborative activities. Linda's professional activities currently focus on institutional repositories, data publication and bibliometrics. She is a member of the NOAA Environmental Data Management Dataset Identifier working group, and the NOAA Office of Atmospheric Research (OAR) Public Access to Results of Federally Funded Research (PARR) Group. Linda is the IOC, IODE US NOAA National Coordinator for Marine Information and the Chair of the IOC, IODE Group of Experts in Marine Information Management.

Peter Pissierssens [2]

Peter Pissierssens is the Head of the IOC Project Office for IODE, Ostend, Belgium with nearly 25 years of experience in project management related to ocean data and information exchange. Originating from Belgium, Peter Pissierssens managed IOC programmes and projects related to oceanographic data management, information management, bathymetry and tsunami warning and mitigation. In November 2007, he moved to Ostend, Belgium as the Head of the IOC Project Office for IODE, which is the IODE Secretariat but also the global headquarters of the OceanTeacher Global Academy, a training centre network for ocean data and information management, and secretariat of the Ocean Biogeographic Information System (OBIS). The IODE network federates over 100 oceanographic data centres as well as marine libraries. In 2015, he was also given coordination responsibilities for IOC's capacity development programme.

Lisa Raymond [2]

Lisa Raymond is the Co-Director of the MBLWHOI Library and Director of Library Services at the Woods Hole Oceanographic Institution, responsible for the planning, development and administration of the MBLWHOI Library and for the coordination of the programmes of the science libraries of the Woods Hole Oceanographic Institution. Lisa's research activities focus on data publication and citation. She also works on data curation, accessibility and long-term preservation of legacy data. Lisa is an active member of the International Association of Aquatic and Marine Science Libraries and Information Centers (IAMSLIC) and the American Geophysical Union (AGU). She has been associated with the Library for over 25 years.

Greg Reed [2]

Greg Reed is an internationally recognized expert for oceanographic data management with significant experience in the development, implementation and operation of ocean data and information management infrastructures at national, regional and international scales. He has a strong interest in international cooperation and has served as Co-chair of the Intergovernmental Oceanographic Commission's International Oceanographic Data and Information Exchange (IODE) Committee for two consecutive terms. He is the Chief Editor for OceanTeacher, the IODE capacity development system for oceanographic data and information management. He has taken a lead role in developing a capacity-building framework for oceanographic data and information management for the IODE programme, including participation as course coordinator and lecturer at more than 40 international training courses on aspects of data management and GIS.

Susan Roberts [1]

Susan Roberts is the Director of the Ocean Studies Board at the US National Academies of Sciences, Engineering and Medicine. She began her career as a Programme Officer for the Ocean Studies Board in 1998 and became the Director of the Board in 2004. Dr Roberts specializes in the science and management of living marine resources. She has served as study director for 18 reports produced by the National Academies on topics covering a broad range of ocean science, marine resource management and science policy issues. Her research publications include studies on fish physiology and biochemistry, marine bacterial symbioses, and cell and developmental biology. Dr Roberts received her Ph.D. in Marine Biology from the Scripps Institution of Oceanography. Prior to her position at the Ocean Studies Board, she worked as a postdoctoral researcher at the University of California, Berkeley and as a senior staff fellow at the National Institutes of Health. She is a member of the US National Committee for the Intergovernmental Oceanographic Commission (IOC), American Association for the Advancement of Science, American Geophysical Union, and the Association for the Sciences of Limnology and Oceanography. Dr Roberts is an elected Fellow of the Washington Academy of Sciences.

Martin Schaaper [1], [2]

Martin Schaaper, a Dutch national, is Head of Section, Science, Culture and Communication at the UNESCO Institute for Statistics, based in Montreal, Canada. He is responsible for global data collections, methodological developments, capacity-building and publications in the three areas under his supervision. Before joining UIS in 2009, Martin worked for eight years for the OECD, where he was responsible for the cooperation with non-OECD countries in the fields of STI and ICT statistics, and six years for various small companies, working on a contract basis for Eurostat.

Alan Simcock [2]

Alan Simcock has been Joint Coordinator of the United Nations Group of Experts for the global integrated assessment of the ocean since 2009. He was born in Plymouth, Devon, and educated there and at Oxford University. From 1965, he worked on a variety of issues in the UK Department of the Environment. He also served as Private Secretary to successive UK Prime Ministers from 1969 to 1972. From 1991 to 2001, he was head of the Marine Environment Division of the DoE. In addition, he was Chairman of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic from 1996 to 2000, and Co-Chair of the UN Informal Consultative Process on the Oceans and Law of the Sea (UNICPOLOS) in 2000, 2001 and 2002. From 2001 to 2006, he was Executive Secretary of the OSPAR Commission.

Ariel H. Troisi [2]

Ariel H. Troisi is Head of Oceanography at the Servicio de Hidrografía Naval (SHN), Argentina and Technical Coordinator of the National Commission on the Outer Limit of the Continental Shelf (COPLA). He has been involved for several decades in ocean observations and data collection, becoming the Director of the NODC in 1999, and the IOC/IODE Regional Coordinator for Data Management of the Network for Latin America and the Caribbean in 2009. He co-chaired IOC/IODE from 2011 to 2015. As of June 2015, Ariel has been Vice-chair of the Intergovernmental Oceanographic Commission (IOC-UNESCO). Ariel's professional activities currently focus on science and institutional policy and management, as well as in regional and global coordination.

Luis Valdés [2]

Luis Valdés was the Head of Ocean Sciences at the Intergovernmental Oceanographic Commission of UNESCO from 2009 to 2015, and formerly (2000–2008) he was the Director of the Centro Oceanográfico de Gijón – Instituto Español de Oceanografía (CO Gijón-IEO). With more than 33 years of experience in marine research and field studies related to marine ecology and climate change, he established in 1990 the time series programme, based on ocean sampling sites and marine observatories, which is maintained by Spain in the North Atlantic. He has a long experience in science management and has advised various governmental, intergovernmental and international organizations as well as research funding agencies. He also served as the Spanish Delegate in the IOC-UNESCO and in ICES, where he chaired different Working Groups and Committees, including the Oceanographic Committee.

Annex B

Acronyms and abbreviations

B

A

ADU	Associate Data Unit
AfrOBIS	Ocean Biogeographic Information System for sub-Saharan Africa
AIMS	Australian Institute of Marine Science
AMLC	Association of Marine Laboratories of the Caribbean
AODN	Australian Ocean Data Network
AORA	Atlantic Ocean Research Alliance
ARC	Average of Relative Citation
Argo	Free-drifting profiling floats
ARIF	Average of Relative Impact Factor
ASTII	African Science, Technology and Innovation Indicators
AtlantOS	Atlantic Ocean Observing Systems
AU–NEPAD	African Union–New Partnership for Africa's Development
AUV	Autonomous Underwater Vehicle
AWA	African consortium in West Africa

B

BCC	Benguela Current Commission
Black Sea SCENE	Black Sea Scientific Network
BPR	Bottom Pressure Recorder
BRIC	Grouping acronym: Brazil, Russia, India and China
BSRC	Black Sea Regional Committee
BWM Convention	International Convention for the Control and Management of Ships' Ballast Water and Sediments

C

CAFF	Conservation of Arctic Flora and Fauna
CARICOMP	Caribbean Coastal Marine Productivity Programme
Caspinfo	Caspian environmental and industrial data and information service
CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCLME	Canary Current Large Marine Ecosystem
CCORU	Canadian Consortium of Ocean Research Universities
CDI	Common Data Index
CI	Conservation International
CIESM	Mediterranean Science Commission (Original French : Commission Internationale pour l'Exploration Scientifique de la Méditerranée)
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CL	Circular Letter
CLIVAR	Climate Variability and Predictability (one of the four core projects of the World Climate Research Programme)
CLME	Caribbean Sea Large Marine Ecosystem
CMA	Caribbean Marine Atlas
CMS	Convention on the Conservation of Migratory Species of wild animals
CNRS	National Cent*re* for Scientific Research, France (Original French: Centre National de la Recherche Scientifique)
CoCoNet	Coast to Coast Networks of Marine Protected Areas
CONICET	National Scientific and Technical Research Council, Spain (Original Spanish: Consejo Nacional de Investigaciones Científicas y Técnicas)
COP	Conference of the Parties
Copernicus	European Union Programme aimed at developing European information services based on satellite Earth Observation and *in situ* (non-space) data
CPPS	Permanent Commission for the South Pacific (Original Spanish: Comisión Permanente del Pacífico Sur)
CPR	Continuous Plankton Recorder
CSIC	Spanish National Research Council, Spain (Original Spanish: Consejo Superior de Investigaciones Científicas)

D

DBCP	Data Buoy Cooperation Panel
DEFRA	Department of Environment, Food and Rural Affairs, UK
DFO	Department of Fisheries and Oceans Canada, Canada
DOALOS	Division for Ocean Affairs and Law of the Sea (UN)
DOI	Digital Object Identifier
DSCC	Deep Sea Conservation Coalition

E

E/V	Exploration Vessel
EC	European Commission
ECV	Essential Climate Variable
EEZ	Exclusive Economic Zone
EIA	Environmental Investigation Agency
EMB	European Marine Board
EMBLAS	Environmental Monitoring in the Black Sea
EMBRC	European Marine Biological Resources Centre
EMFF	European Maritime and Fisheries Fund

EMODNET	European Marine Observation and Data Network
EMSO	European Multidisciplinary Seafloor and water column Observatory
EOV	Essential Ocean Variable
ERDF	European Regional Development Funding
EU	European Union
EUDAT	European Data Infrastructure
Eurofleets	Searchable database of the cruise programmes of selected research vessels from European operators

F

FAO	Food and Agriculture Organization of the United Nations
FP	European Union Framework Programme
FPSO	Floating Production Storage and Offloading units
FTE	Full Time Equivalent

G

G7	Group of Seven (Canada, France, Germany, Italy, Japan, UK and USA)
G20	Group of Twenty (Argentina, Australia, Brazil, Canada, China, EU, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russian Federation, Saudi Arabia, South Africa, Turkey, UK and USA)
GBIF	Global Biodiversity Information Facility
GBP	Pound Sterling
GCLME	Guinea Current Large Marine Ecosystem
GCOS	Global Climate Observing System
GDAC	Global Data Assembly Centre
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Oceans
GEC	Global Environmental Change
GEF	Global Environmental Facility
GEOHAB	Global Ecology and Oceanography of Harmful Algal Blooms
GEOTRACES	International Study of Marine Biogeochemical Cycles of Trace Elements and their Isotopes
GERD	Gross Domestic Expenditure on Research and Development
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GIS	Geographic Information System
GISD	Global Invasive Species Database
GLOSS	Global Sea Level Observing System
GODAR	Global Oceanographic Data Archaeology and Rescue
GOERP	Group of Experts of the Regular Process
GOOS	Global Ocean Observing System
GOOS-Africa	Global Ocean Observing System for Africa
GO-SHIP	Global Ocean Ship-based Hydrographic Investigations Programme
GOSR	Global Ocean Science Report (IOC-UNESCO)
GOSUD	Global Ocean Surface Underway Data / Underway Sea Surface Salinity Data Archiving Project
GPO	Global Partnership for Oceans
GTSPP	Global Temperature and Salinity Profile Programme

H

HC	Head Count
HELCOM	Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area
HPC	High Performance Computing

I

IAMSLIC	International Association of Aquatic and Marine Science Libraries and Information Centres
IAEA	International Atomic Energy Agency
IAPSO	International Association for the Physical Sciences of the Oceans
IBI-ROOS	Ireland-Biscay-Iberia Regional Operational Oceanographic System
ICAM	Integrated Coastal Area Management Programme (IOC-UNESCO)
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Seas
ICP	Informal Consultative Process on Oceans and the Law of the Sea
ICSU	International Council for Science
IDS	Institute of Development Studies
IEO	Spanish Institute of Oceanography, Spain (Original Spanish: Instituto Español de Oceanografía)
IF	Impact Factor
IFREMER	French Research Institute for the Exploitation of the Sea (Original French : Institut Français de Recherche pour l'Exploitation de la Mer)
IGBP	International Geosphere-Biosphere Programme
IGMETS	International Group for Marine Ecological Time Series
IGO	International Governmental Organization
IHDP	International Human Dimension Programme on Global Environmental Change
IHO	International Hydrographic Organization
ILO	International Labour Organization
IMO	International Maritime Organization

IOC	Intergovernmental Oceanographic Commission (UNESCO)
IOCAFRICA	IOC Sub-Commission for Africa and the Adjacent Island States
IOCARIBE	IOC Sub-Commission for the Caribbean and Adjacent Regions
IOCCP	International Ocean Carbon Coordination Project
IOCINDIO	IOC Regional Committee for the Central Indian Ocean
IODE	International Oceanographic Data and Information Exchange (IOC-UNESCO)
IQuOD	International Quality Controlled Ocean Database
IOGOOS	Indian Ocean Global Ocean Observing System
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IQOE	International Quiet Ocean Experiment
IQUOD	International Quality Controlled Ocean Database
IR	Institutional Repository
ISA	International Seabed Authority
ISO	International Organization for Standardization
ISSC	International Social Science Council
IT	Information Technology
IUCN	International Union for Conservation of Nature
IUU	Illegal, Unreported and Unregulated

J

JAMBIO	Japanese Association for Marine BiologyJCOMM Joint IOC-WMO Technical Commission for Oceanography and Marine Meteorology
JCOMMOPS	JCOMM in-situ Observing Platform Support cent*re*
JERICO	Joint European Research Infrastructure Network for Coastal Observatories
JNCC	Joint Nature Conservation Committee
J-OBIS	Japan Ocean Biogeographic Information System Centre
JPI	Joint Programming Initiative

L

LDC	London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter
LDCs	Least Developed Countries
LifeWatch	E-Science European Infrastructure for Biodiversity and Ecosystem Research
LME	Large Marine Ecosystem
LTER	Long Term Ecological Research

M

MadBIF	Madagascar Biodiversity Information Facility
MARPOL	International Convention for the Prevention of Pollution from Ships
MARS	Marine Research Institutes and Stations
MCDS	Marine Climate Data System
MedGOOS	Mediterranean Global Ocean Observing System
MEDIN	Marine Environmental Data and Information Network
MedOBIS	Mediterranean node of Ocean Biogeographic Information System
MedPAN	Network of Marine Protected Area managers in the Mediterranean
MEPC	Marine Environment Protection Committee
MESA	Monitoring for Environment and Security in Africa
MIM	Marine Information Managers
MMI	Marine Microbiology Initiative
MOLOA	Mission Observing the West African Coast
MOMSEI	Monsoon Onset Monitoring and its Social *and* Ecosystem Impact
MREKEP	Marine Renewable Energy Knowledge Exchange Programme
MSC	Marine Stewardship Council
MSP	Marine Spatial Planning
MyOcean	Pan-European capacity for ocean monitoring and forecasting

N

N/A	Not Available or No Answer
N/C	Not Calculated
NAML	National Association of Marine Laboratories, USA
NAMMCO	North Atlantic Marine Mammal Commission
NEAR	North-East Asian Regional
NERC	Natural Environment Research Council, USA
NGO	Non-Governmental Organization
NIS	Non-Indigenous Species
NOAA	National Oceanic and Atmospheric Administration, USA
NODC	National Oceanographic Data Centre
NOWPAP	Northwest Pacific Action Plan
NRC	National Research Council, USA
NS	Publications from reference entity N in a given research area
NT	Publications from reference entity N in a reference set of papers

O

OBIS	Ocean Biogeographic Information System
OBIS-USA	US Node of the Ocean Biogeographic Information System
OceanExpert	Directory of Marine and Freshwater Professionals
OCEANIC	Ocean Information Centre
OceanSites	Worldwide system of long-term, deepwater reference stations
ODINAFRICA	Ocean Data and Information Network for Africa
ODINCARSA	Ocean Data and Information Network in the Caribbean and South America
ODINWESTPAC	Ocean Data and Information Network for the WESTPAC region
ODIP	Ocean Data Interoperability Platform
OECD	Organisation for Economic Co-operation and Development
OEEC	Organisation for European Economic Cooperation
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
OTN	Ocean Tracking Network

P

PERSEUS	Policy-oriented marine Environmental Research for the Southern European Seas
PICES	North Pacific Marine Science Organization
PIMS	Perry Institute of Marine Science, USA
PIRATA	Pilot Research moored Array in the Tropical Atlantic
POGO	Partnership for Observation of the Global Oceans
POP	Persistent Organic Pollutant
PROPAO	Regional Programme of Physical Oceanography in Africa (Original French : Programme Régional d'Océanographie Physique en Afrique de l'Ouest)

R

R&D	Research and Development
r^2	Correlation Coefficient
RAC	Regional Advisory Council (EU)
RC	Relative Citation
RDA	Research Data Alliance
RFB	Regional Fisheries Body
RFMA	Regional Fisheries Management Arrangement
RFMO	Regional Fisheries Management Organization
RICYT	Network for Science and Technology Indicators—Ibero-American and Inter-American
RIF	Relative Impact Factor
ROPME	Regional Organization for the Protection of the Marine Environment
ROV	Remotely Operated Vehicle

S

SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SAMOA	SIDS Accelerated Modalities of Action
SAP	Strategic Action Programme
SCAR	Scientific Committee on Antarctic Research
SCOR	Scientific Committee on Oceanic Research
SDG	Sustainable Development Goal (UN)
SeaDataNet	Pan-European infrastructure for ocean *and* marine data management
SEAOBIS	Southeast Asia Regional Node of the Ocean Biogeographic Information System
SI	Specialization Index
SIDS	Small Island Developing States
SOFIA	State of World Fisheries and Aquaculture
SOOS	Southern Ocean Observing System
SPINCAM	Southeast Pacific data and Information Network in support *of i*ntegrated Coastal Area Management
SST	Sea Surface Temperature
SVP	Surface Velocity Programme

T

TAC	Total Allowable Catch
TBT	Tributyltin
TMN	Tasmania Maritime Network

U

UCS	Union of Concerned Scientists
UIS	UNESCO Institute for Statistics
UK	United Kingdom
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNCCD	United Nations Convention to Combat Desertification
UNCLOS	United Nations Convention on the Law of *the* Sea
UNCSD	United Nations Conference on Sustainable Development
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme (now UN Environment)

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
UNIDO	United Nations Industrial Development Organization
UN-Oceans	Interagency collaboration mechanism on ocean and coastal issues within the UN system
UNOLS	University-National Oceanographic Laboratory System
UPMC	Pierre and Marie Curie University, France
USA	United States of America

W

WAMS	World Association of Marine Stations
WB	World Bank
WCRP	World Climate Research Programme
WESTPAC	IOC Sub-Commission for the Western Pacific
WHOI	Woods Hole Oceanographic Institution, USA
WIOMSA	Western Indian Ocean Marine Science Association
WMO	World Meteorological Organization
WOA	World Ocean Assessment (UN)
WOCE	World Ocean Circulation Experiment
WOD	World Ocean Database
WoRMS	World Register of Marine Species
WoS	Web of Science
WWF	World Wildlife Fund

X

XS	Publications from entity X in a given research area
XT	Publications from entity X in a reference set of papers

Annex C

Global Ocean Science Report questionnaire

C

Name

Organization

Country

Postal contact details

Email contact details

Part A Ocean science landscape

I. Please list the key governmental institutes specializing in ocean science[1] in your country.

II. If not, which national organization is 'responsible' for ocean science?

III. Does your country have a National Science and Technology strategy? (Title and/or link to the document)

IV. Does your country have a National Ocean Science strategy? (Title and/or link to the document)

Part B Research investment

Funding for ocean science

The data requested in Tables 1-3 should relate to actual funding for ocean science made by governmental institutions at different levels - regional, national and international. If they are not available, please provide estimated data calculated using budget allocations for ocean science or other methodologies and explain as a note. Ocean science funding should be reported in US Dollars.

1 Ocean science, as used in this report, includes all research disciplines related to the study of the ocean: physical, biological, chemical, geological, hydrographic, health and social sciences, as well as engineering, the humanities and multidisciplinary research on the relationship between humans and the ocean. Definition by *The Expert Panel on Canadian Ocean Science, 2013, Ocean Science in Canada: Meeting the challenge, seizing the opportunity, Council of Canadian Academies.*

1.1. Total governmental funding for ocean science based on received regional, national and international funding in your country.

Year	Total governmental funding for ocean science (A+B+C)	Regional funding for ocean science (A)	National funding for ocean science (B)	International funding for ocean science (C)	Monetary unit (i.e. millions, thousands)
2013					
2012					
2011					
2010					
2009					

Type of period considered

- ❍ Calendar year
- ❍ Fiscal year; starting month:

Notes:

1.2. Total governmental funding for ocean science broken down by sector of performance.

Year	Total (A+B+C+D+E)	Sector of performance			
		Government (A)	Private non-profit (B)	Higher education (C)	Business enterprise (D)
2013					
2012					
2011					
2010					
2009					

Notes:

1.3. Total governmental funding for ocean science broken down by field of science.

Year	Total (A+B+C+)	Field of ocean science			
		Fisheries[2] (A)	Observations[3] (B)	Other ocean science (C)	Business enterprise (D)
2013					
2012					
2011					
2010					
2009					

Notes:

Part C Research capacity and infrastructure

1. Human resources in ocean science

Using the information provided on ocean science funding (given in Part B), all human resources listed in the tables below should be related to governmental funds at either regional, national or international level.

1.1. Ocean Science personnel by occupation

Researchers are professionals engaged in the conception or creation of new knowledge, products processes, methods and systems, and also in the management of the projects concerned.	**Technicians and equivalent staff** are persons with technical knowledge and experience who participate in ocean science by performing scientific and technical tasks involving the application of concepts and operational methods normally under the supervision of researchers.	**Other supporting staff** includes skilled and unskilled craftspeople, secretarial staff participating in ocean science projects or directly associated with such projects, e.g. staff and crew on vessels.

i. Ocean science personnel by occupation – headcounts (HC) (mainly or partially employed).

Year	Total (A+B+C+D)	Occupation			
		Researchers (A)	Technicians and equivalent staff (B)	Other supporting staff (C)	Not specified (D)
2013					
2012					
2011					
2010					
2009					

2 Questions related to fisheries include mariculture and aquaculture.

3 Questions related to observations include: monitoring in general, data repositories, measurements to track harmful algae blooms and pollution, satellite measurements, buoys and moorings.

ii. Ocean science personnel by occupation – full-time equivalents (FTE)

FTE – 1 FTE is equal to 1 person working full time for 1 year. (e.g. 30% of the time dedicated 0.3 FTE, 6 months 0.5 FTE)

Year	Total (A+B+C+D)	Occupation			
		Researchers (A)	Technicians and equivalent staff (B)	Other supporting staff (C)	Not specified (D)
2013					
2012					
2011					
2010					
2009					

Notes:

1.2. Ocean science personnel by gender.

i. Ocean Science personnel by gender – headcounts (HC) (please provide information for 2013 or the latest year you can obtain data).

Year	Total ocean science personnel				Of which researchers			
	Total (A+B+C)	Female (A)	Male (B)	Not specified by gender (C)	Total (D+E+F)	Female (D)	Male (E)	Not specified by gender (F)

ii. Ocean science personnel by gender – full time equivalents (FTE) (please provide information for 2013 or the latest year you can obtain data).

Year	Total ocean science personnel				Of which researchers			
	Total (A+B+C)	Female (A)	Male (B)	Not specified by gender (C)	Total (D+E+F)	Female (D)	Male (E)	Not specified by gender (F)

Notes:

C

1.3. Demographic distribution of researchers, not including undergraduate or graduate students, engaged in ocean science – headcounts (HC) (please provide the information for 2013 or the latest year you can obtain data).

Year	Age class < 30 years	Age class	Technicians and equivalent staff (B)	Other supporting staff (C)	Not specified (D)

1.4. Researches by field of ocean science and sector of employment.

i. Researchers by field of science and sector of employment – headcounts (HC).

Reference year (please provide the information for 2013 or the latest year you can obtain data):

Field of science	Total researchers (A+B+C+D+E)	Sector				
		Government (A)			Government (A)	
Total (i+ii+iii)			Total (i+ii+iii)			Total (i+ii+iii)
i. Fisheries			i. Fisheries			i. Fisheries
ii. Observations			ii. Observations			ii. Observations
iii. Other ocean science			iii. Other ocean science			iii. Other ocean science

ii. Researchers by field of science and sector of employment – full-time equivalents (FTE).

Reference year (please provide the information for 2013 or the latest year you can obtain data):

Field of science	Total researchers (A+B+C+D+E)	Sector				
		Government (A)	Private non-profit (B)	Higher education (C)	Business enterprise (D)	Not specified (E)
Total (i+ii+iii)						
i. Fisheries						
ii. Observations						
iii. Other ocean science						

Notes:

2. Research equipment and facilities for ocean science.

2.1. Please specify the number of laboratories, field stations and other institutions (e.g. dedicated faculties) which concentrate their work on ocean sciences in your country.

Field of science	Number of facilities, e.g. laboratories, field stations and other institutions
Total (i+ii+iii)	
i. Fisheries	
ii. Observations	
iii. Other ocean science	

2.2. Please provide data on major equipment (> 0.5 million USD) associated with ocean science; specify the year of implementation and if possible, give further information about the devices (excluding research vessels and ships).

Equipment (short description)	Number of devices and year of implementation	Occupation			
		2013-2009	2008-2004	2003-1999	Before 1999
1.					
2.					
3.					
4.					
5.					
6.					
7.					

Notes:

2.3. Please provide information about how many research vessels, vessels partly used for ocean science, and ships of opportunity are operated by your nation. Please also specify their size.

Equipment (short description)	Number of equipment and year of implementation	Occupation			
		2013-2009	2008-2004	2003-1999	Before 1999
1.					
2.					
3.					
4.					
5.					
6.					
7.					

C

2.4. Please name research vessels bigger than 55 m.

2.5. Please specify research time (days per year for 2013 or latest year with available data) on those vessels for international and national investigation.

Vessel	Research	
	International cooperation	National investigation
Research vessels		
Vessels partly used for ocean science		
Ships of opportunity		

Notes:

2.6. Please specify whether the data obtained during research cruises are available (open access) or are freely available after a certain period of embargo; please provide the number of years data are under embargo, or state whether access is restricted for international and national investigation. (Percentage for 2013 or latest year with available data).

Vessel	International cooperation			National investigation		
	Open access	Embargo (with following open access)	Restricted access	Open access	Embargo (with following open access)	Restricted access
Research vessels						
Vessels partly used for ocean science						
Ships of opportunity						

Notes:

2.7. Please specify research type (percentage for 2013 or latest year with available data) for the different kind of ships.

Vessel	Type of research per year		
	Fisheries	Observations	Other ocean science
Research vessel			
Vessel partly used for ocean science			
Ships of opportunity			

Part D Oceanographic data and information exchange

I. What are the main ocean science data information and management organizations/institutions in your country?

II. Please give a short description of the marine long-term observation research strategy in your country.

III. Please list and explain currently funded monitoring of the ocean and/or time series stations.

Part E Capacity-building and transfer of technology

I. Please list national efforts and mechanisms to absorb and keep graduates in ocean-related jobs and activities (e.g. Ph.D. programmes, young scientist funding resources, exchange programmes, early career support).

II. Please list the ocean-related training programmes, other than national, that are/were conducted in your country during the past 5 years, including regular and irregular programmes. For international programmes, please specify the cooperating countries.

III. Have there been any country-specific constraints in developing long-term capacity in your country? Please elaborate.

IV. What are the mechanisms that are in place to facilitate the participation of outside national experts in your country's national programmes and policy-making?

- Guest positions
- Exchange programmes
- Board memberships
- Advisory capacity
- Others
- There are none

Notes:

V. Please list the ocean-related technology transfer/innovation activities supported by your country.

VI. Please estimate the percentage of ocean-related technology transfer/innovation in your country in relation to the three main categories.

Fisheries	Observations	Other ocean science

Part F Regionally and globally supporting organizations on ocean science

VII. Where does the primary responsibility for national marine policy-making lie? With the ministry of:

- Science and technology
- Environment
- Fisheries
- Agriculture
- Foreign ministry
- Ministry of marine affairs
- Interministerial body

Notes:

I. What are the sources of information for making decisions on national marine policy? (if possible, estimate the percentage if you choose more than one option)

Sources of information	Yes /No	Percentage
National efforts and sources		
Regional sources		
International sources		
Others		

Notes:

II. Please specify in which ocean-related conventions and treaties your country participates.

	Membership	Participation	Expertise from
UN conventions and treaties			
Regional governmental and non-governmental bodies			
International governmental and non-governmental bodies			
Regional programmes			
International programmes			

Notes:

III. Are there any marine/ocean science-related international project offices, e.g. to run scientific programmes, located in your country? If so, please name them and specify in which city the office is located.

Part G Sustainable development

I. Within the area of your country, are there Marine Protected Areas (MPAs) or marine reserves of the biosphere? Please specify the name, size of the area, date from which it has been protected, and the type of habitat.

Marine Protected Area/ marine reserves of the biosphere	Size of the area (unit)	Protection in force since	Type of habitat

Notes:

II. Please estimate the economic importance of ocean-related tourism for your county. Please try to identify the percentage of the national GDP.

Part H Non-quantitative part

I. Please list the three primary emerging issues/questions for ocean science in your country. In your opinion, which research, technology and/or innovation offers the most potential related to the seas and oceans over the next 20-30 years? (max. 200 words)

II. What are the barriers for a higher involvement of your country in international collaboration? Please explain if these barriers are related to intellectual property rights, legal, administrative, financial issues, technological gaps or lack of knowledge/knowledge transfer. Please indicate if there are any actions (solutions) which you would recommend to overcome those barriers. (max. 200 words)

III. Are there specific research, technology development and/or innovation needs at sea basin level? If so, please explain what those needs are and indicate the corresponding sea basin. (max. 200 words)

IV. From your country's point of view, what needs to be done today to fulfil the work of ocean science? (max. 150 words)

V. Please list three examples of how you think the ocean policy/internationally organized support to ocean science should/could be improved (max. 200 words)

Annex D

GOSR data and information management survey 2016

1. Introduction

The questionnaire seeks to gain information about current ocean science data and information management in your country. Your response will be used for the production of the first IOC Global Ocean Science Report (GOSR); see http://www.unesco.org/new/en/natural-sciences/ioc-oceans/sections-and-programmes/ocean-sciences/global-ocean-science-report/. This questionnaire will supplement the responses previously provided to the survey questionnaire for GOSR included in IOC Circular Letter No. 2560.

Questions marked with * are mandatory.

The information collected through this survey will also be used for an information document for the next IODE Committee Session (March 2017), providing a picture in time of the status of our network of data and information centres.

While the questions are written in English, please feel free to answer (free text fields) in French or Spanish if you are more comfortable with those languages.

2. Current data and information capability

1. Please provide the following information on yourself and your organization.

Name

Institution

City/Town

Country

Email address

2. In what type of centre(s) do you work?

NOTE: IF YOU DO NOT WORK IN ANY OF THE FOUR CENTRE CATEGORIES BELOW THEN PLEASE DO NOT COMPLETE THE SURVEY

❍ IODE National Oceanographic Data Centre (NODC) IODE Associate Data Unit (ADU)

❍ Regional OBIS Node

❍ Marine Library

3. In what capacity are you responding to the survey? (if you have several roles, please complete the survey separately for each one)

❍ IODE national coordinator for data management

❍ IODE national coordinator for marine information (library) management

❍ ADU focal point

Other (please specify):

4. What is the current capacity (staffing) in numbers of full-time staff in your data/information centre?

❍ 1

❍ 2-5

❍ 6-10

❍ more than 10

5. Of your centre's current staff (overall), what percentage of their salary is funded from external (project) sources?

❍ 0%

❍ 1-25%

❍ 26-50%

❍ 51-75%

❍ 76-100%

Comments (difficulties in terms of sustainability...):

6. What is the current capacity (infrastructure) in your data or information centre (number of computers, servers...) and what problems are you facing related to infrastructure? (See also question 18)

7. Is your centre involved in any of the following types of collaboration? (tick one or more):

❍ National (between your centre and other national institutions)

❍ Regional (e.g. Europe, Africa, South-East Asia)

❍ International (in addition to IODE)

Please provide more information on the collaborations (project names…):

8. Is your centre collaborating with other IOC programmes, projects (in addition to IODE)?

❍ Ocean science (harmful algal blooms, ocean CO2…)

❍ Ocean observation and services (GOOS)

❍ Marine policy (including marine spatial planning, large marine ecosystems, integrated coastal area management)

❍ I do not know

Specify projects/activities you are involved in:

9. What observational data types are regularly collected and managed by your data centre?:

❍ Biological data (incl. plankton, benthos, pigments, animals, plants, bacteria…)

❍ Physical data (waves, currents, hydrography, sea level, temperature, salinity, optics, acoustics)

❍ Geological and geophysical (sediments, bathymetry…)

❍ Chemical (nutrients, pH, CO2, dissolved gases, …)

❍ Pollutant (monitoring)

❍ Fisheries data

Other (please specify):

10. What data/information products does your centre provide to your clients:

❍ Online access to metadata

❍ Online access to data

❍ Online access to library catalogue

❍ Online access to e-documents and e-publications

❍ Published ocean data (e.g. 'snapshots' of datasets as used for publications)

- ❍ GIS products (maps, atlases)
- ❍ Portals
- ❍ Numerical model data
- ❍ CD-ROM products

Other (please specify):

11. What services does your centre provide to your clients?

- ❍ Data archival
- ❍ Personal data repository
- ❍ Cloud computing space
- ❍ Virtual research laboratory
- ❍ Web services (see http://www.webopedia.com/TERM/W/Web_Services.html)
- ❍ Provision of DOI for data set
- ❍ Data analysis tools
- ❍ Data visualization tools
- ❍ Data quality control tools
- ❍ Communication tools (hosting of web sites, mailing lists, group discussion support, project management tools...)
- ❍ Special tools (vocabularies, format descriptions, gazetteers...)
- ❍ Access to documented methods, standards and guidelines

Other (please specify):

12. What are the URLs of the section of your centre's data/information centre web site that deals with your online products and services? (enter up to 5):

- URL1
- URL2
- URL3
- URL4
- URL5

13. Do you have a national data (sharing) policy on the management and sharing of data?

❍ Yes

❍ No

Provide details of the policy, URL where it can be accessed and contact email to find out more.

14. Does your data centre restrict access to data?

❍ We do not restrict at all

❍ We restrict access to certain data types

❍ We restrict access to data collected in certain geographic areas

❍ We restrict access during a certain period of time (embargo)

Any other restrictions:

15. Does your centre apply the IOC Oceanographic Data Exchange Policy adopted as Resolution IOC- XXII-6? (see http://www.iode.org/policy)

❍ Yes

❍ No

❍ I don't know

16. Who are the clients and end users of the data, products or services provided by your centre?

❍ Only users in my own institution

❍ National researchers in my own country

❍ Researchers in any country

❍ Policy-makers of my own ministry

❍ Policy-makers in other ministries of my country

❍ Policy-makers in any country (e.g. through UN commitments)

❍ Military

❍ Civil protection

❍ Private sector (e.g. fisheries, hotels, industry...)

❍ School children

❍ General public

Other (please specify):

17. Are data and information from your centre contributed to international systems (meaning that you actively send data, or make data available, to e.g. world data centres, GDACs or other such international systems)?

❍ Yes

❍ No

Provide details:

18. Does your centre have specific capacity (development) needs? If so, what are these needs?

❍ We need basic training in data/information management

❍ We need advanced training in certain topics

❍ We need internships in other data/information centres

❍ We need equipment

❍ We need better internet connectivity

❍ We need opportunities to share our experience at conferences

❍ We need better networking (community building) with colleagues

❍ We need more funding

Other (please specify):

19. Is your centre involved in IODE, but you would like IODE to focus more on certain aspects? (be as specific as possible):

20. List any data or information you would like to access from other data centres/systems but to which you currently do not have access, and also list the reasons you cannot access these data.

Thank you for your collaboration

Annex E

International scientific conferences

Table Annex E. List of international conferences, divided by major focus, illustrating the percentage of male and female participants, the number of participants and countries represented.

Year	Hosting country	Conference name	Male [%]	Female [%]	Number of participants	Number of countries
Environmental science conferences						
2012	UK	Planet under Pressure	59	40	2 999	104
Ocean science						
2013	USA	Aquatic Sciences Meeting	55	45	1 879	44
2014	Spain	2nd IORC	56	44	555	70
2015	Spain	Aquatic Sciences Meeting	52	48	2 468	62
Ocean observation and marine data						
2009	Italy	OceanObs'09	79	21	637	36
Marine ecosystems functions and processes						
2009	Canada	3rd GLOBEC OSM	72	28	311	34
2010	Argentina	3rd Jellyfish Blooms Symposium	52	48	95	27
2011	Chile	5th Zooplankton Symposium	49	51	297	36
2013	Japan	4th Jellyfish Bloom Symposium	69	31	136	29
2014	Norway	IMBER - Future Ocean	61	39	465	45
Ocean and climate						
2012	Korea (Rep.)	2nd Effects of CC on the World's Ocean	75	25	362	39
2012	USA	3rd OHCO2W	51	49	538	36
2015	Brazil	3rd Effects of CC on the World's Ocean	53	47	274	37
Human health and well-being						
2013	France	GEOHAB	55	45	51	21
2014	New Zealand	16th IC Harmful Algae	53	47	394	35
2014	USA	Oceans and Human Health	43	57	87	11
Ocean technology and engineering						
2011	Spain	Oceans'11	82	18	403	31
2012	Spain	IC Coastal Engineering	80	20	795	45
Mediterranean Sea						
2010	Italy	CIESM Congress	50	50	1 000	N/A
2013	France	CIESM Congress	49	51	1 000	N/A
North Atlantic Ocean						
2012	Norway	ICES Annual Science Conference	67	33	647	31
2013	Iceland	ICES Annual Science Conference	65	35	688	36
2014	Spain	ICES Annual Science Conference	58	42	569	34
Pacific Ocean						
2012	Japan	PICES Annual Meeting	80	20	466	22
2013	Canada	PICES Annual Meeting	67	33	365	11
2014	Korea	PICES Annual Meeting	72	28	365	18

Annex F
Bibliometric indicators (2010–2014)

Table Annex F.1. Bibliometric indicators by country in ocean science (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**372 852**	**2 206 429**	**1.00**	**1.00**	**1.20**	**1.00**
South America		22 258	98 007	0.80	0.87	1.24	1.57
	Brazil	13 211	51 042	0.75	0.83	1.29	1.39
	Argentina	3 780	18 740	0.88	0.97	1.20	1.86
	Chile	3 577	20 541	0.95	0.94	1.20	2.32
	Colombia	998	4 619	0.72	0.78	1.14	1.17
	Venezuela	553	2 459	0.54	0.73	0.80	2.05
	Uruguay	442	3 613	1.22	1.04	1.15	2.29
	Peru	407	3 352	1.52	1.11	1.36	2.10
	Ecuador	280	1 584	0.83	1.12	1.85	2.71
	Bolivia	116	755	0.94	1.03	1.49	2.31
	Nicaragua	37	284	N/C	0.94	0.67	2.19
	El Salvador	23	135	N/C	N/C	2.75	2.16
	Guyana	18	36	N/C	N/C	7.00	3.22
	Paraguay	13	33	N/C	N/C	1.20	0.77
	Suriname	11	41	N/C	N/C	0.50	3.30
Oceania		25 072	205 383	1.35	1.20	1.24	1.76
	Australia	20 937	174 009	1.38	1.21	1.28	1.69
	New Zealand	4 818	40 114	1.29	1.18	1.07	2.30
	Fiji	155	846	0.96	1.24	1.59	5.62
	Papua New Guinea	68	724	1.58	1.12	1.50	2.51
	Solomon Islands	28	236	N/C	N/C	0.92	7.57
	Palau	26	130	N/C	N/C	2.67	15.20
	Vanuatu	24	162	N/C	N/C	1.30	5.04
	Cook Islands	20	147	N/C	N/C	3.00	19.66
	Fed. States of Micronesia	20	65	N/C	N/C	3.00	9.01
	Tonga	5	68	N/C	N/C	1.50	4.51
	Marshall Islands	5	35	N/C	N/C	N/C	6.76
	Tuvalu	4	7	N/C	N/C	N/C	17.30
	Kiribati	4	9	N/C	N/C	N/C	7.87
	Samoa	3	4	N/C	N/C	N/C	6.49
	Niue	2	6	N/C	N/C	N/C	14.42
	Nauru	1	4	N/C	N/C	N/C	7.21

Table Annex F.1. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
North America		**116 708**	**925 691**	**1.22**	**1.17**	**1.13**	**1.06**
	USA	96 088	801 788	1.27	1.20	1.12	1.01
	Canada	21 073	175 076	1.27	1.19	1.13	1.35
	Mexico	5 278	21 445	0.73	0.82	1.29	1.78
	Cuba	345	1 607	0.62	0.79	0.90	1.62
	Panama	341	2 938	1.28	1.11	1.22	4.21
	Costa Rica	304	1 675	0.93	0.94	1.16	2.72
	Trinidad and Tobago	138	661	0.64	0.96	1.06	2.89
	Jamaica	81	471	0.86	0.99	1.31	1.70
	Bahamas	67	420	1.04	1.08	1.48	11.32
	Barbados	54	348	N/C	1.02	1.93	3.07
	Grenada	45	178	N/C	1.07	1.31	1.56
	Belize	27	220	N/C	N/C	1.86	6.95
	Guatemala	27	188	N/C	N/C	1.00	0.91
	Dominican Republic	21	51	N/C	N/C	7.00	1.54
	Honduras	20	112	N/C	N/C	1.17	1.63
	Saint Kitts and Nevis	18	51	N/C	N/C	11.00	4.10
	Haiti	17	110	N/C	N/C	1.17	1.40
	Dominica	9	134	N/C	N/C	0.33	2.67
	Saint Vincent and the Grenadines	5	21	N/C	N/C	0.67	7.72
	Antigua and Barbuda	3	19	N/C	N/C	2.00	4.33
Europe		**149 642**	**1 033 199**	**1.14**	**1.09**	**1.19**	**1.06**
	UK	29 472	271 018	1.45	1.27	1.19	1.13
	Germany	24 227	218 285	1.39	1.22	1.26	0.94
	France	22 078	196 093	1.36	1.22	1.17	1.23
	Spain	17 826	134 189	1.22	1.14	1.21	1.31
	Italy	15 083	106 016	1.18	1.09	1.26	0.98
	Norway	9 888	75 613	1.32	1.16	1.20	3.45
	Russian Federation	8 816	31 458	0.58	0.58	1.16	1.18
	Netherlands	8 780	82 639	1.54	1.28	1.24	0.99
	Portugal	6 606	43 963	1.18	1.07	1.34	2.00
	Sweden	6 377	59 111	1.39	1.25	1.25	1.10
	Denmark	5 794	55 114	1.56	1.25	1.32	1.59
	Switzerland	5 299	62 385	1.71	1.34	1.34	0.81

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Table Annex F.1. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Poland	5 041	21 650	0.79	0.76	1.35	0.84
	Belgium	5 011	42 834	1.33	1.19	1.19	1.00
	Greece	3 531	22 121	1.09	0.99	1.19	1.23
	Finland	3 114	26 942	1.39	1.19	1.32	1.06
	Austria	2 779	26 564	1.52	1.16	1.29	0.80
	Czechia	2 720	17 410	1.07	0.95	1.26	0.81
	Ireland	2 272	18 243	1.31	1.22	1.23	1.18
	Croatia	1 654	6 626	0.67	0.79	1.00	1.73
	Romania	1 652	5 191	0.66	0.67	1.08	0.61
	Hungary	1 045	6 007	1.01	0.95	1.34	0.65
	Estonia	904	5 771	1.07	0.93	1.31	2.04
	Slovenia	858	5 235	1.09	0.97	1.24	0.89
	Iceland	788	6 444	1.43	1.17	1.26	3.44
	Ukraine	715	2 939	0.95	0.67	1.34	0.55
	Serbia	686	2 608	0.71	0.79	1.62	0.55
	Bulgaria	677	2 586	0.63	0.67	0.97	1.08
	Slovakia	595	2 832	0.91	0.84	1.36	0.58
	Lithuania	551	2 077	0.78	0.82	1.36	0.86
	Latvia	211	555	0.76	0.94	1.66	0.77
	Luxembourg	205	1 375	1.06	1.06	2.00	0.95
	Monaco	193	2 192	1.65	1.30	0.87	10.16
	Malta	130	684	1.08	0.99	1.26	2.36
	Montenegro	130	636	1.88	0.60	1.50	2.72
	Albania	109	272	0.43	0.46	0.73	2.55
	Former Yugoslav Rep. of Macedonia	85	265	0.57	0.80	1.40	0.86
	Belarus	83	246	0.54	0.59	1.13	0.30
	Bosnia and Herzegovina	61	200	0.60	0.72	0.88	0.50
	Rep. of Moldova	23	62	N/C	N/C	1.14	0.34
	Liechtenstein	7	19	N/C	N/C	1.50	0.44
	Andorra	5	43	N/C	N/C	1.50	3.18
	San Marino	2	3	N/C	N/C	N/C	1.08
Asia		**123 769**	**597 174**	**0.85**	**0.87**	**1.38**	**0.88**
	China	57 848	283 431	0.90	0.85	1.54	0.85
	Japan	20 516	117 333	0.86	0.99	1.11	0.98
	India	12 631	54 753	0.75	0.80	1.36	0.92

Table Annex F.1. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Rep. of Korea	10 688	53 480	0.88	0.90	1.46	0.86
	Turkey	6 153	24 358	0.71	0.75	0.97	0.96
	Iran	4 437	16 148	0.72	0.75	1.39	0.73
	Malaysia	3 315	13 640	0.82	0.83	1.84	1.09
	Israel	2 397	17 881	1.09	1.22	1.16	0.74
	Thailand	2 323	11 904	0.85	0.89	1.06	1.32
	Singapore	2 307	16 935	1.35	1.14	1.44	0.80
	Saudi Arabia	1 831	11 084	1.08	0.93	2.25	0.96
	Indonesia	1 116	5 725	1.02	0.99	1.96	2.27
	Pakistan	1 113	3 956	0.62	0.63	1.39	0.72
	Viet Nam	946	3 715	0.74	0.95	1.55	1.93
	Philippines	730	4 240	0.99	0.99	1.25	2.79
	Bangladesh	632	2 749	0.85	0.87	1.43	1.65
	United Arab Emirates	453	2 499	0.93	1.05	1.36	1.15
	Oman	323	1 648	0.91	0.92	1.15	2.39
	Sri Lanka	276	1 685	1.06	0.85	1.04	1.88
	Cyprus	243	2 079	1.36	0.98	1.30	0.90
	Kuwait	227	733	0.45	0.75	0.81	1.33
	Jordan	221	821	0.71	0.86	1.76	0.72
	Iraq	199	642	0.59	0.70	2.53	1.29
	Lebanon	164	837	0.86	0.96	2.24	0.64
	Qatar	163	726	0.97	0.99	3.06	0.80
	Nepal	106	871	1.55	1.05	2.03	1.00
	Azerbaijan	86	213	0.45	0.56	1.16	0.70
	Georgia	86	296	0.51	0.77	0.89	0.63
	Mongolia	81	548	1.13	1.12	1.82	1.73
	Yemen	79	508	1.29	0.96	1.50	1.88
	Syria	78	361	0.82	0.84	0.94	1.02
	Lao People's Dem. Rep.	73	285	0.69	1.04	1.45	2.28
	Kazakhstan	72	252	N/C	0.77	2.25	0.50
	Armenia	70	305	0.52	0.78	0.93	0.38
	Brunei Darussalam	66	365	0.98	0.96	1.32	3.02
	Uzbekistan	60	248	0.76	1.04	0.89	0.72
	Cambodia	59	348	N/C	1.03	1.67	1.34
	Bahrain	43	207	N/C	0.71	0.83	1.01

Table Annex F.1. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Myanmar	31	142	N/C	0.99	0.92	2.00
	Maldives	27	139	N/C	N/C	3.20	12.98
	Kyrgyzstan	26	210	N/C	N/C	1.33	1.31
	Tajikistan	18	39	N/C	N/C	1.50	1.19
	Turkmenistan	7	30	N/C	N/C	1.50	1.66
	Dem. People's Rep. of Korea	7	49	N/C	N/C	0.67	1.05
	Afghanistan	5	22	N/C	N/C	4.00	0.45
	Bhutan	4	34	N/C	N/C	1.00	0.50
Africa		**11 472**	**60 648**	**0.92**	**0.92**	**1.32**	**1.35**
	South Africa	3 979	26 526	1.17	1.00	1.34	1.56
	Egypt	2 063	8 234	0.73	0.81	1.56	1.11
	Tunisia	1 355	6 207	0.73	0.84	1.19	1.62
	Nigeria	604	1 670	0.42	0.62	0.86	1.07
	Morocco	545	3 151	1.05	1.00	1.25	1.29
	Kenya	542	3 920	1.16	1.12	1.29	1.66
	Algeria	493	1 775	0.67	0.78	1.53	0.81
	United Rep. of Tanzania	300	1 878	1.07	1.02	1.24	1.76
	Ghana	218	1 031	0.75	0.89	0.89	1.49
	Ethiopia	203	1 199	1.03	1.20	1.32	1.08
	Senegal	185	1 129	0.98	0.99	0.94	2.13
	Cameroon	167	723	0.74	1.01	1.29	1.06
	Uganda	154	915	1.05	1.00	1.43	0.82
	Madagascar	138	1 044	1.12	1.05	1.44	2.91
	Mauritius	100	655	1.03	0.96	1.73	3.58
	Zimbabwe	94	388	0.49	0.73	1.68	1.31
	Seychelles	88	609	1.26	1.10	1.88	11.75
	Benin	87	265	0.64	N/C	2.65	1.47
	Côte d'Ivoire	86	270	0.60	0.77	1.24	1.60
	Mozambique	82	751	1.42	0.98	1.03	2.20
	Libya	82	303	0.61	0.77	1.58	1.63
	Namibia	80	590	1.06	1.09	1.96	2.74
	Botswana	61	174	N/C	0.78	2.27	1.14
	Sudan	53	274	N/C	0.97	1.00	0.66
	Malawi	51	220	0.61	0.91	0.74	0.65
	Zambia	51	272	N/C	1.07	1.11	0.88
	Burkina Faso	50	328	N/C	0.93	1.85	0.74

Table Annex F.1. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Cabo Verde	41	386	N/C	1.16	2.36	10.56
	Gabon	37	292	N/C	1.03	1.38	1.36
	Angola	33	133	N/C	0.95	1.14	3.50
	Congo	32	210	N/C	1.03	1.70	1.32
	Mauritania	31	177	N/C	1.14	2.11	5.54
	Niger	30	240	N/C	N/C	1.10	1.33
	Dem. Rep. of the Congo	29	260	N/C	N/C	1.25	0.97
	Mali	27	273	N/C	N/C	0.55	0.74
	Guinea	19	163	N/C	N/C	1.00	2.28
	Burundi	17	35	N/C	N/C	1.00	3.20
	Eritrea	16	161	N/C	N/C	1.29	4.49
	Rwanda	16	67	N/C	N/C	0.50	0.55
	Togo	15	48	N/C	N/C	1.00	1.04
	Swaziland	13	79	N/C	N/C	0.25	1.26
	Sierra Leone	10	95	N/C	N/C	2.00	1.20
	Chad	9	49	N/C	N/C	1.33	2.19
	Comoros	9	56	N/C	N/C	0.20	12.98
	Gambia	7	72	N/C	N/C	2.00	0.28
	Guinea-Bissau	7	49	N/C	N/C	3.00	0.99
	Central African Republic	5	31	N/C	N/C	N/C	0.76
	Djibouti	4	45	N/C	N/C	1.00	1.97
	Liberia	3	8	N/C	N/C	N/C	0.93
	Lesotho	3	13	N/C	N/C	1.00	0.50
	São Tomé-et-Príncipe	1	6	N/C	N/C	N/C	1.97

Note: ARC and ARIF are not computed (N/C) for countries with *fewer* than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1% and HCP 10% (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

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Table Annex F.2. Bibliometric indicators by country in the Marine Ecosystems Functions and Processes category (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**60 625**	**423 145**	**1,00**	**1,00**	**1,21**	**1,00**
South America		4 715	22 376	0,77	0,82	1,30	2,05
	Brazil	2 478	10 246	0,76	0,78	1,41	1,61
	Argentina	927	4 920	0,81	0,89	1,19	2,80
	Chile	913	5 297	0,82	0,90	1,27	3,64
	Colombia	203	1 327	0,73	0,71	1,01	1,46
	Uruguay	126	1 074	1,00	0,90	0,96	4,01
	Venezuela	124	803	0,49	0,68	0,87	2,82
	Peru	119	1 110	2,13	0,98	1,45	3,78
	Ecuador	80	697	0,78	1,19	1,68	4,76
	Bolivia	24	253	N/C	N/C	1,86	2,94
	Nicaragua	12	64	N/C	N/C	0,50	4,36
	Guyana	4	8	N/C	N/C	N/C	4,40
	Suriname	4	11	N/C	N/C	N/C	7,39
	El Salvador	2	17	N/C	N/C	N/C	1,16
	Paraguay	1	0	N/C	N/C	N/C	0,36
Oceania		5 901	56 258	1,31	1,14	1,27	2,55
	Australia	4 920	48 504	1,37	1,16	1,31	2,44
	New Zealand	1 191	10 988	1,30	1,08	1,14	3,49
	Fiji	33	201	N/C	0,95	1,42	7,35
	Papua New Guinea	16	222	N/C	N/C	1,33	3,64
	Palau	13	60	N/C	N/C	3,00	46,74
	Solomon Islands	8	60	N/C	N/C	0,50	13,30
	Fed. States of Micronesia	6	15	N/C	N/C	3,00	16,63
	Vanuatu	5	32	N/C	N/C	4,00	6,46
	Cook Islands	4	5	N/C	N/C	N/C	24,19
	Tuvalu	1	0	N/C	N/C	N/C	26,61
	Marshall Islands	1	6	N/C	N/C	N/C	8,31
	Samoa	1	1	N/C	N/C	N/C	13,30
North America		22 948	202 160	1,20	1,12	1,21	1,28
	United States	18 613	172 432	1,26	1,16	1,21	1,20
	Canada	4 738	46 575	1,31	1,14	1,17	1,87
	Mexico	1 161	6 116	0,82	0,73	1,31	2,41
	Panama	117	1 181	1,35	1,07	1,41	8,89

Table Annex F.2. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Costa Rica	97	581	0,84	0,79	1,29	5,34
	Cuba	71	383	0,60	0,66	1,30	2,05
	Trinidad and Tobago	33	222	N/C	0,94	1,64	4,25
	Bahamas	29	186	N/C	N/C	1,75	30,14
	Barbados	11	41	N/C	N/C	1,67	3,85
	Belize	8	89	N/C	N/C	1,50	12,67
	Jamaica	7	109	N/C	N/C	1,50	0,90
	Guatemala	4	87	N/C	N/C	N/C	0,83
	Grenada	4	18	N/C	N/C	N/C	0,85
	Dominican Republic	3	8	N/C	N/C	N/C	1,35
	Honduras	2	12	N/C	N/C	N/C	1,00
	Haiti	2	45	N/C	N/C	N/C	1,02
	Dominica	2	2	N/C	N/C	N/C	3,64
Europe		**26 496**	**215 345**	**1,15**	**1,07**	**1,21**	**1,15**
	United Kingdom	5 562	60 695	1,45	1,23	1,24	1,31
	Germany	4 680	48 116	1,42	1,18	1,30	1,12
	France	4 633	46 509	1,35	1,16	1,24	1,58
	Spain	3 646	31 285	1,26	1,10	1,31	1,65
	Italy	2 432	19 939	1,24	1,03	1,28	0,97
	Norway	1 837	17 898	1,42	1,15	1,21	3,94
	Netherlands	1 745	18 675	1,45	1,24	1,10	1,20
	Portugal	1 425	10 929	1,13	1,03	1,24	2,66
	Sweden	1 375	14 961	1,39	1,20	1,19	1,45
	Denmark	1 295	14 522	1,60	1,21	1,24	2,18
	Russian Federation	1 145	5 256	0,79	0,62	1,25	0,94
	Belgium	1 005	10 063	1,45	1,12	1,19	1,23
	Switzerland	919	10 965	1,60	1,29	1,65	0,87
	Poland	902	4 960	0,98	0,78	1,25	0,93
	Finland	653	5 710	1,38	1,08	1,24	1,37
	Greece	573	5 008	1,25	0,95	1,03	1,22
	Austria	509	5 345	1,52	1,14	1,16	0,90
	Ireland	456	4 500	1,35	1,15	1,19	1,45
	Czech Republic	438	3 460	1,06	0,94	1,29	0,80
	Croatia	285	1 229	0,60	0,77	0,83	1,84
	Estonia	202	1 484	1,04	N/C	1,63	2,81

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Table Annex F.2. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Iceland	169	1 959	2,30	1,15	1,46	4,54
	Romania	168	842	0,64	0,70	1,09	0,38
	Hungary	153	1 155	1,70	0,92	1,20	0,58
	Slovenia	131	937	1,10	0,95	1,49	0,84
	Ukraine	104	805	2,17	0,67	1,33	0,49
	Lithuania	87	449	0,99	0,82	1,27	0,84
	Bulgaria	83	388	0,63	0,67	1,03	0,81
	Slovakia	78	464	0,93	0,83	1,27	0,46
	Monaco	60	778	1,62	1,15	1,50	19,42
	Serbia	56	339	N/C	0,72	2,19	0,27
	Latvia	38	233	N/C	0,87	1,58	0,85
	Malta	33	239	N/C	1,01	0,86	3,69
	Montenegro	27	345	N/C	N/C	1,63	3,47
	Albania	21	38	N/C	N/C	0,12	3,02
	Luxembourg	18	95	N/C	N/C	2,00	0,51
	Former Yugoslav Rep. of Macedonia	14	34	N/C	N/C	1,00	0,87
	Belarus	12	40	N/C	N/C	1,00	0,27
	Bosnia and Herzegovina	3	0	N/C	N/C	2,00	0,15
	Rep. of Moldova	1	4	N/C	N/C	N/C	0,09
	Liechtenstein	1	1	N/C	N/C	N/C	0,39
Asia		**13 558**	**75 470**	**0,81**	**0,86**	**1,36**	**0,60**
	China	5 474	32 191	0,92	0,86	1,60	0,50
	Japan	2 988	18 764	0,80	0,98	1,03	0,88
	India	1 633	7 000	0,64	0,71	1,41	0,74
	Rep. of Korea	991	5 804	0,86	0,88	1,56	0,49
	Turkey	599	2 810	0,69	0,67	0,90	0,57
	Israel	432	4 175	1,12	1,18	1,42	0,82
	Iran	396	1 555	0,62	0,63	1,20	0,40
	Malaysia	355	1 695	0,69	0,79	1,37	0,72
	Saudi Arabia	245	1 512	0,82	0,89	2,59	0,79
	Thailand	239	1 068	0,68	0,82	1,06	0,84
	Singapore	220	1 503	1,00	1,05	2,22	0,47
	Indonesia	167	1 398	1,14	1,10	2,10	2,09
	Philippines	154	1 390	0,98	0,91	1,52	3,62
	Viet Nam	144	692	0,71	0,93	1,46	1,81

Table Annex F.2. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Pakistan	113	287	0,41	0,49	1,12	0,45
	Bangladesh	82	395	0,84	0,72	1,79	1,32
	United Arab Emirates	56	585	1,06	1,00	0,92	0,87
	Oman	54	349	0,88	0,85	0,86	2,45
	Sri Lanka	46	426	N/C	N/C	0,64	1,93
	Cyprus	29	132	N/C	N/C	2,43	0,66
	Kuwait	28	152	N/C	N/C	0,71	1,01
	Jordan	27	204	N/C	N/C	1,33	0,54
	Syria	19	151	N/C	N/C	0,44	1,53
	Qatar	18	171	N/C	N/C	2,75	0,54
	Lebanon	16	138	N/C	N/C	N/C	0,39
	Lao People's Dem. Rep.	15	46	N/C	N/C	1,17	2,88
	Brunei Darussalam	14	69	N/C	N/C	1,00	3,95
	Cambodia	14	106	N/C	N/C	1,00	1,95
	Uzbekistan	12	37	N/C	N/C	1,75	0,89
	Mongolia	11	72	N/C	N/C	1,50	1,44
	Azerbaijan	11	6	N/C	N/C	3,50	0,55
	Georgia	11	57	N/C	N/C	1,67	0,50
	Kazakhstan	10	25	N/C	N/C	1,67	0,43
	Yemen	9	40	N/C	N/C	1,33	1,31
	Nepal	9	65	N/C	N/C	1,33	0,52
	Iraq	8	21	N/C	N/C	1,00	0,32
	Bahrain	6	97	N/C	N/C	1,00	0,86
	Myanmar	5	15	N/C	N/C	1,50	1,98
	Armenia	3	87	N/C	N/C	2,00	0,10
	Maldives	3	5	N/C	N/C	N/C	8,87
	Kyrgyzstan	2	1	N/C	N/C	1,00	0,62
	Tajikistan	1	0	N/C	N/C	N/C	0,41
Africa		**2 274**	**14 577**	**0,95**	**0,90**	**1,28**	**1,65**
	South Africa	1 065	8 114	1,14	0,97	1,27	2,57
	Tunisia	263	1 352	0,62	0,69	1,43	1,93
	Egypt	202	1 014	0,79	0,73	1,26	0,67
	Kenya	124	768	0,81	1,01	1,18	2,33
	Morocco	105	709	N/C	1,01	1,78	1,52
	Algeria	81	356	0,71	0,62	0,74	0,81

Table Annex F.2. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	United Rep. of Tanzania	69	401	1,02	1,01	1,04	2,50
	Nigeria	65	117	0,20	0,56	1,00	0,71
	Senegal	39	196	N/C	0,96	1,46	2,76
	Namibia	33	422	N/C	1,25	1,50	6,95
	Ethiopia	32	184	N/C	0,99	2,00	1,05
	Madagascar	30	243	N/C	N/C	1,88	3,90
	Seychelles	28	299	N/C	N/C	2,67	22,99
	Uganda	28	177	N/C	N/C	0,79	0,92
	Benin	25	66	N/C	N/C	2,83	2,59
	Ghana	25	135	N/C	N/C	1,11	1,05
	Côte d'Ivoire	22	57	N/C	N/C	1,11	2,51
	Zimbabwe	22	141	N/C	N/C	3,25	1,88
	Mauritius	22	197	N/C	N/C	0,55	4,85
	Cameroon	22	129	N/C	N/C	2,00	0,86
	Mozambique	18	295	N/C	N/C	0,70	2,97
	Mauritania	14	26	N/C	N/C	11,00	15,39
	Burkina Faso	12	97	N/C	N/C	0,75	1,10
	Libya	12	61	N/C	N/C	1,75	1,47
	Angola	11	39	N/C	N/C	1,75	7,17
	Botswana	11	56	N/C	N/C	0,75	1,27
	Zambia	10	95	N/C	N/C	1,00	1,06
	Cabo Verde	10	140	N/C	N/C	1,50	15,84
	Congo	9	116	N/C	N/C	0,60	2,28
	Sudan	8	51	N/C	N/C	3,00	0,61
	Gabon	7	54	N/C	N/C	2,50	1,58
	Malawi	7	22	N/C	N/C	N/C	0,55
	Dem. Rep. of the Congo	6	26	N/C	N/C	1,00	1,24
	Burundi	6	19	N/C	N/C	0,25	6,94
	Eritrea	4	15	N/C	N/C	3,00	6,91
	Guinea-Bissau	3	41	N/C	N/C	1,00	2,61
	Mali	2	39	N/C	N/C	N/C	0,34
	Sierra Leone	2	6	N/C	N/C	N/C	1,47
	Djibouti	1	1	N/C	N/C	N/C	3,02
	Rwanda	1	0	N/C	N/C	N/C	0,21
	Liberia	1	2	N/C	N/C	N/C	1,90

Table Annex F.2. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Swaziland	1	2	N/C	N/C	N/C	0,59
	Niger	1	0	N/C	N/C	N/C	0,27
	Togo	1	5	N/C	N/C	N/C	0,43
	Guinea	1	8	N/C	N/C	N/C	0,74
	Central African Republic	1	7	N/C	N/C	N/C	0,94

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1 % and HCP 10 % (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

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Table Annex F.3. Bibliometric indicators by country in the Ocean and Climate category (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**45 311**	**370 321**	**1,00**	**1,00**	**1,32**	**1,00**
South America		1 543	9 807	0,85	0,95	1,53	0,90
	Brazil	769	3 450	0,64	0,83	1,64	0,67
	Argentina	316	2 077	0,96	1,00	1,55	1,28
	Chile	308	3 318	1,26	1,16	1,33	1,64
	Colombia	85	585	0,67	1,03	1,30	0,82
	Peru	73	653	1,07	1,14	1,82	3,10
	Venezuela	37	417	N/C	1,13	0,88	1,13
	Uruguay	35	195	N/C	1,02	1,55	1,49
	Ecuador	23	198	N/C	N/C	2,14	1,83
	Bolivia	16	122	N/C	N/C	2,25	2,62
	Paraguay	5	8	N/C	N/C	3,00	2,42
	Guyana	2	4	N/C	N/C	N/C	2,94
	Suriname	2	13	N/C	N/C	N/C	4,94
	Nicaragua	1	1	N/C	N/C	N/C	0,49
Oceania		3 569	38 062	1,30	1,19	1,54	2,06
	Australia	3 090	33 220	1,33	1,19	1,63	2,05
	New Zealand	588	6 592	1,20	1,21	1,20	2,31
	Fiji	17	108	N/C	N/C	2,50	5,07
	Solomon Islands	6	53	N/C	N/C	2,00	13,35
	Papua New Guinea	5	22	N/C	N/C	N/C	1,52
	Palau	5	28	N/C	N/C	N/C	24,05
	Vanuatu	5	30	N/C	N/C	1,50	8,64
	Cook Islands	4	54	N/C	N/C	N/C	32,36
	Fed. States of Micronesia	4	16	N/C	N/C	N/C	14,83
	Marshall Islands	4	29	N/C	N/C	N/C	44,50
	Tuvalu	2	6	N/C	N/C	N/C	71,19
	Tonga	2	6	N/C	N/C	N/C	14,83
	Niue	2	6	N/C	N/C	N/C	118,66
	Kiribati	2	6	N/C	N/C	N/C	32,36
	Nauru	1	4	N/C	N/C	N/C	59,33

Table Annex F.3. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
North America		**19 070**	**201 996**	**1,20**	**1,11**	**1,31**	**1,42**
	United States	16 831	186 469	1,25	1,12	1,30	1,46
	Canada	2 899	31 315	1,17	1,10	1,28	1,53
	Mexico	359	2 032	0,76	0,89	1,61	1,00
	Costa Rica	23	128	N/C	N/C	1,83	1,69
	Trinidad and Tobago	20	122	N/C	N/C	2,60	3,45
	Cuba	18	126	N/C	N/C	1,33	0,70
	Panama	18	189	N/C	N/C	2,67	1,83
	Barbados	14	165	N/C	N/C	2,67	6,56
	Jamaica	12	46	N/C	N/C	5,00	2,07
	Honduras	4	9	N/C	N/C	2,00	2,68
	Bahamas	4	18	N/C	N/C	N/C	5,56
	Grenada	3	8	N/C	N/C	0,50	0,85
	Dominica	2	83	N/C	N/C	1,00	4,88
	Dominican Republic	2	10	N/C	N/C	N/C	1,21
	Belize	1	4	N/C	N/C	N/C	2,12
	Antigua and Barbuda	1	4	N/C	N/C	N/C	11,87
	Guatemala	1	1	N/C	N/C	N/C	0,28
	Saint Kitts and Nevis	1	4	N/C	N/C	N/C	1,87
	Saint Vincent and the Grenadines	1	4	N/C	N/C	N/C	12,71
Europe		**19 969**	**190 159**	**1,15**	**1,09**	**1,28**	**1,16**
	United Kingdom	5 376	69 381	1,46	1,26	1,37	1,69
	Germany	4 556	52 530	1,35	1,17	1,36	1,46
	France	3 783	43 937	1,33	1,17	1,26	1,73
	Spain	1 989	19 161	1,22	1,16	1,44	1,21
	Italy	1 931	20 182	1,29	1,05	1,26	1,03
	Netherlands	1 557	21 458	1,64	1,28	1,37	1,44
	Norway	1 349	16 334	1,38	1,17	1,48	3,87
	Russian Federation	1 114	5 950	0,61	0,60	1,11	1,23
	Switzerland	1 061	15 810	1,67	1,29	1,35	1,34
	Sweden	1 059	13 283	1,42	1,15	1,47	1,50
	Denmark	840	10 732	1,54	1,20	1,39	1,89

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Table Annex F.3. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Belgium	667	8 269	1,34	1,19	1,38	1,09
	Finland	556	7 213	1,43	1,07	1,41	1,56
	Portugal	544	6 089	1,51	1,00	1,34	1,36
	Greece	481	3 960	1,01	0,89	1,19	1,37
	Austria	321	5 073	1,96	1,23	1,80	0,76
	Poland	317	2 086	0,83	0,86	1,01	0,44
	Ireland	269	2 871	1,27	1,05	1,14	1,15
	Estonia	152	1 062	0,79	0,79	1,25	2,83
	Czech Republic	148	1 001	0,82	0,93	1,33	0,36
	Croatia	141	811	0,59	0,84	0,81	1,22
	Romania	135	735	0,69	0,80	1,33	0,41
	Iceland	102	1 007	1,20	1,19	1,52	3,66
	Ukraine	95	456	0,56	0,44	1,12	0,60
	Hungary	93	763	1,09	0,84	1,06	0,48
	Lithuania	73	335	0,74	0,75	1,90	0,94
	Bulgaria	60	294	0,54	0,76	1,35	0,79
	Slovenia	47	374	0,93	1,01	0,85	0,40
	Serbia	47	424	N/C	0,99	1,18	0,31
	Monaco	40	721	N/C	0,93	1,29	17,32
	Slovakia	35	169	N/C	0,79	1,80	0,28
	Luxembourg	19	96	N/C	N/C	15,00	0,72
	Latvia	19	92	N/C	N/C	2,00	0,57
	Malta	13	120	N/C	N/C	0,83	1,94
	Albania	10	32	N/C	N/C	0,13	1,92
	Belarus	10	76	N/C	N/C	1,00	0,30
	Former Yugoslav Rep. of Macedonia	6	24	N/C	N/C	1,50	0,50
	Bosnia and Herzegovina	4	25	N/C	N/C	2,00	0,27
	Montenegro	4	5	N/C	N/C	2,00	0,69
	Andorra	4	43	N/C	N/C	1,00	20,94
Asia		**13 254**	**80 258**	**0,77**	**0,87**	**1,52**	**0,78**
	China	6 400	38 956	0,78	0,84	1,65	0,78
	Japan	2 728	20 984	0,87	0,99	1,22	1,07
	India	1 578	8 268	0,64	0,84	1,51	0,95
	Rep. of Korea	1 245	6 839	0,66	0,89	1,62	0,82

Table Annex F.3. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Turkey	333	1 618	0,69	0,84	1,71	0,43
	Israel	324	3 021	1,03	1,17	1,06	0,83
	Iran	242	860	0,65	0,78	2,41	0,33
	Malaysia	208	1 081	0,80	0,76	2,35	0,56
	Saudi Arabia	178	1 178	1,10	0,89	4,96	0,77
	Singapore	152	1 137	0,83	1,05	1,88	0,43
	Indonesia	129	862	0,86	0,96	1,89	2,16
	Thailand	123	843	0,89	0,88	1,10	0,58
	Viet Nam	95	617	1,04	1,02	1,66	1,60
	Pakistan	79	338	0,58	0,76	2,25	0,42
	Bangladesh	78	348	0,78	0,85	1,91	1,67
	United Arab Emirates	62	406	0,68	0,90	1,22	1,29
	Philippines	60	413	0,97	1,02	1,23	1,89
	Cyprus	49	599	N/C	0,78	1,10	1,49
	Oman	33	188	N/C	0,80	0,87	2,01
	Jordan	31	127	N/C	0,81	3,00	0,84
	Sri Lanka	29	215	N/C	N/C	1,00	1,63
	Nepal	19	237	N/C	N/C	2,60	1,48
	Kuwait	16	86	N/C	N/C	1,20	0,77
	Lebanon	16	117	N/C	N/C	1,60	0,52
	Iraq	11	19	N/C	N/C	9,00	0,59
	Syria	10	17	N/C	N/C	0,80	1,08
	Mongolia	10	78	N/C	N/C	2,00	1,75
	Yemen	10	89	N/C	N/C	1,00	1,95
	Qatar	10	81	N/C	N/C	2,50	0,40
	Georgia	10	9	N/C	N/C	0,67	0,60
	Cambodia	8	63	N/C	N/C	1,50	1,49
	Brunei Darussalam	7	40	N/C	N/C	1,00	2,64
	Kazakhstan	7	28	N/C	N/C	5,00	0,40
	Uzbekistan	6	12	N/C	N/C	5,00	0,59
	Maldives	6	58	N/C	N/C	1,50	23,73
	Bahrain	5	18	N/C	N/C	1,50	0,96
	Armenia	5	49	N/C	N/C	1,00	0,22
	Kyrgyzstan	4	56	N/C	N/C	3,00	1,66

Table Annex F.3. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Lao People's Dem. Rep.	4	47	N/C	N/C	N/C	1,03
	Tajikistan	4	31	N/C	N/C	0,50	2,18
	Turkmenistan	3	13	N/C	N/C	2,00	5,87
	Azerbaijan	3	10	N/C	N/C	2,00	0,20
	Myanmar	2	29	N/C	N/C	N/C	1,06
	Bhutan	1	7	N/C	N/C	N/C	1,02
Africa		1 127	8 204	0,94	0,93	1,64	1,09
	South Africa	442	4 597	1,15	0,99	1,62	1,43
	Egypt	148	715	0,82	0,79	1,76	0,65
	Tunisia	85	367	0,56	0,85	2,50	0,83
	Morocco	78	478	N/C	0,99	2,83	1,51
	Kenya	61	381	N/C	1,04	2,64	1,54
	Nigeria	57	159	N/C	0,76	1,89	0,83
	Algeria	41	220	N/C	0,63	1,91	0,55
	United Rep. of Tanzania	37	227	N/C	1,06	1,90	1,79
	Ethiopia	33	231	N/C	1,09	0,92	1,45
	Senegal	27	264	N/C	N/C	0,77	2,56
	Cameroon	26	102	N/C	N/C	1,86	1,36
	Ghana	21	71	N/C	N/C	0,80	1,18
	Zimbabwe	18	78	N/C	N/C	1,17	2,06
	Uganda	18	134	N/C	N/C	1,33	0,79
	Benin	18	86	N/C	N/C	2,00	2,50
	Namibia	14	138	N/C	N/C	2,50	3,94
	Cabo Verde	12	137	N/C	N/C	1,50	25,43
	Sudan	11	112	N/C	N/C	0,80	1,13
	Mauritius	10	87	N/C	N/C	0,80	2,95
	Niger	10	149	N/C	N/C	1,00	3,64
	Côte d'Ivoire	9	42	N/C	N/C	0,20	1,38
	Madagascar	9	114	N/C	N/C	1,67	1,56
	Malawi	8	30	N/C	N/C	0,75	0,84
	Mozambique	8	40	N/C	N/C	0,50	1,77
	Botswana	6	18	N/C	N/C	0,67	0,93
	Burkina Faso	6	38	N/C	N/C	4,00	0,73
	Angola	5	40	N/C	N/C	3,00	4,36

Table Annex F.3. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Congo	5	26	N/C	N/C	3,00	1,70
	Libya	4	20	N/C	N/C	1,00	0,66
	Mauritania	4	21	N/C	N/C	N/C	5,88
	Seychelles	4	36	N/C	N/C	0,50	4,39
	Togo	3	31	N/C	N/C	N/C	1,71
	Mali	3	48	N/C	N/C	1,00	0,68
	Zambia	3	13	N/C	N/C	2,00	0,43
	Dem. Rep. of the Congo	2	30	N/C	N/C	N/C	0,55
	Rwanda	2	7	N/C	N/C	N/C	0,57
	Gabon	2	14	N/C	N/C	1,00	0,61
	Eritrea	1	0	N/C	N/C	N/C	2,31
	Guinea	1	0	N/C	N/C	N/C	0,99
	Djibouti	1	9	N/C	N/C	N/C	4,05
	Comoros	1	27	N/C	N/C	N/C	11,87
	Chad	1	5	N/C	N/C	N/C	2,00
	Gambia	1	13	N/C	N/C	N/C	0,33
	Lesotho	1	7	N/C	N/C	N/C	1,36

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1 % and HCP 10 % (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

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Table Annex F.4. Bibliometric indicators by country in the Ocean Health category (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**79 973**	**549 353**	**1,00**	**1,00**	**1,24**	**1,00**
South America		5 013	25 519	0,77	0,88	1,34	1,65
	Brazil	3 192	15 024	0,74	0,85	1,36	1,57
	Argentina	770	4 398	0,92	1,00	1,53	1,77
	Chile	671	4 138	0,82	0,96	1,26	2,03
	Colombia	210	1 202	0,66	0,73	1,18	1,15
	Venezuela	123	662	0,36	0,61	0,87	2,12
	Uruguay	108	1 274	1,37	1,05	1,77	2,61
	Ecuador	79	647	1,10	1,16	1,68	3,57
	Peru	78	668	0,98	1,11	1,06	1,88
	Bolivia	30	288	N/C	N/C	1,20	2,78
	Nicaragua	13	149	N/C	N/C	0,40	3,58
	Guyana	5	17	N/C	N/C	N/C	4,17
	El Salvador	4	36	N/C	N/C	1,00	1,75
	Suriname	2	6	N/C	N/C	N/C	2,80
	Paraguay	1	4	N/C	N/C	N/C	0,27
Oceania		5 566	50 805	1,36	1,22	1,29	1,82
	Australia	4 616	42 608	1,39	1,24	1,35	1,73
	New Zealand	1 079	9 635	1,24	1,17	1,07	2,40
	Fiji	44	305	N/C	1,16	1,77	7,43
	Papua New Guinea	12	260	N/C	N/C	3,00	2,07
	Palau	10	49	N/C	N/C	3,50	27,26
	Solomon Islands	9	70	N/C	N/C	1,00	11,34
	Vanuatu	9	34	N/C	N/C	1,67	8,81
	Fed. States of Micronesia	6	26	N/C	N/C	2,00	12,61
	Cook Islands	3	6	N/C	N/C	N/C	13,75
	Marshall Islands	2	23	N/C	N/C	N/C	12,61
	Kiribati	2	3	N/C	N/C	N/C	18,34
North America		24 798	219 823	1,20	1,16	1,19	1,05
	United States	19 781	185 027	1,25	1,18	1,20	0,97
	Canada	5 189	49 403	1,28	1,20	1,16	1,55
	Mexico	1 245	6 401	0,73	0,81	1,29	1,96
	Cuba	86	466	0,65	0,77	0,86	1,89

Table Annex F.4. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Costa Rica	69	455	0,92	0,96	1,42	2,88
	Panama	66	628	1,27	1,28	1,17	3,80
	Trinidad and Tobago	34	131	N/C	1,02	1,55	3,32
	Jamaica	23	201	N/C	N/C	2,60	2,25
	Bahamas	16	89	N/C	N/C	2,50	12,61
	Barbados	14	32	N/C	N/C	2,67	3,72
	Guatemala	12	128	N/C	N/C	0,67	1,89
	Belize	12	120	N/C	N/C	3,00	14,41
	Grenada	6	19	N/C	N/C	N/C	0,97
	Haiti	4	8	N/C	N/C	N/C	1,54
	Dominican Republic	2	0	N/C	N/C	N/C	0,68
	Dominica	1	3	N/C	N/C	N/C	1,38
Europe		**31 353**	**247 846**	**1,12**	**1,08**	**1,21**	**1,04**
	United Kingdom	5 530	59 517	1,45	1,26	1,29	0,99
	Spain	4 537	39 920	1,21	1,16	1,20	1,56
	France	4 350	40 271	1,27	1,18	1,27	1,13
	Germany	4 077	41 867	1,38	1,20	1,27	0,74
	Italy	3 550	29 686	1,20	1,06	1,27	1,07
	Portugal	1 933	15 807	1,21	1,08	1,39	2,73
	Netherlands	1 733	18 215	1,47	1,26	1,37	0,91
	Norway	1 678	16 291	1,32	1,19	1,18	2,73
	Sweden	1 485	17 031	1,46	1,23	1,21	1,19
	Poland	1 312	6 058	0,71	0,73	1,38	1,02
	Belgium	1 160	10 935	1,29	1,16	1,31	1,08
	Denmark	1 149	12 253	1,55	1,24	1,30	1,47
	Switzerland	1 123	15 379	1,67	1,33	1,43	0,80
	Greece	1 026	8 384	1,19	0,95	1,27	1,66
	Russian Federation	1 018	4 002	0,53	0,58	1,02	0,64
	Finland	733	6 529	1,15	1,13	1,27	1,17
	Czech Republic	664	4 861	1,04	0,95	1,27	0,92
	Ireland	584	5 290	1,33	1,15	1,30	1,41
	Romania	520	1 871	0,60	0,52	1,13	0,90
	Austria	480	5 521	1,47	1,21	1,33	0,64
	Croatia	450	2 246	0,70	0,84	1,02	2,20

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Table Annex F.4. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Slovenia	269	2 202	1,17	0,99	1,36	1,30
	Hungary	237	1 437	0,89	0,92	1,44	0,69
	Serbia	215	957	0,70	0,74	2,09	0,80
	Estonia	204	1 911	1,21	0,98	1,44	2,15
	Lithuania	199	1 207	1,04	0,92	1,35	1,46
	Bulgaria	186	748	0,64	0,66	1,23	1,38
	Slovakia	176	1 003	0,97	0,80	1,13	0,79
	Ukraine	157	918	0,99	0,71	1,18	0,56
	Iceland	121	1 027	1,34	1,31	1,55	2,46
	Monaco	74	676	1,00	1,16	0,64	18,16
	Latvia	56	267	N/C	N/C	1,88	0,95
	Luxembourg	56	323	N/C	1,11	2,00	1,21
	Albania	51	110	N/C	0,33	0,56	5,55
	Malta	40	411	N/C	1,00	0,82	3,39
	Montenegro	34	137	N/C	0,54	1,70	3,31
	Former Yugoslav Rep. of Macedonia	21	57	N/C	N/C	1,00	0,99
	Belarus	19	71	N/C	N/C	0,50	0,32
	Bosnia and Herzegovina	14	111	N/C	N/C	0,57	0,54
	Rep. of Moldova	8	24	N/C	N/C	3,00	0,54
	Liechtenstein	1	1	N/C	N/C	N/C	0,29
Asia		**25 361**	**145 282**	**0,86**	**0,86**	**1,43**	**0,85**
	China	12 152	73 260	0,95	0,89	1,57	0,83
	India	3 070	16 059	0,75	0,78	1,36	1,05
	Japan	2 745	18 015	0,87	0,98	1,19	0,61
	Rep. of Korea	1 904	12 139	0,94	0,95	1,48	0,71
	Turkey	1 595	7 655	0,71	0,71	0,92	1,16
	Iran	1 049	4 805	0,72	0,70	1,48	0,81
	Malaysia	939	5 014	0,85	N/C	1,78	1,44
	Saudi Arabia	492	3 377	1,08	0,91	2,11	1,20
	Israel	416	3 487	1,07	1,18	1,15	0,60
	Thailand	415	1 737	0,66	0,84	1,32	1,10
	Pakistan	385	1 684	0,68	0,59	1,35	1,17
	Singapore	381	4 246	1,56	1,18	1,61	0,61
	Indonesia	238	1 507	1,00	0,95	2,16	2,26
	Philippines	217	1 889	1,05	1,02	1,36	3,87

Table Annex F.4. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Viet Nam	203	933	0,66	0,88	1,55	1,93
	Bangladesh	186	1 166	0,92	0,81	1,07	2,26
	United Arab Emirates	114	723	0,92	1,06	1,94	1,35
	Cyprus	97	1 270	1,70	0,98	1,24	1,68
	Kuwait	86	320	0,50	0,73	0,97	2,34
	Oman	73	296	0,71	0,76	1,38	2,51
	Sri Lanka	68	509	0,93	0,74	0,96	2,16
	Jordan	66	195	0,50	0,77	1,83	1,01
	Lebanon	57	389	N/C	0,92	3,50	1,04
	Iraq	45	245	N/C	0,67	2,15	1,36
	Qatar	37	329	N/C	0,91	3,67	0,85
	Syria	25	161	N/C	N/C	1,22	1,53
	Nepal	24	224	N/C	N/C	0,67	1,06
	Georgia	22	35	N/C	N/C	0,54	0,75
	Bahrain	22	139	N/C	N/C	0,80	2,40
	Kazakhstan	21	63	N/C	N/C	1,83	0,68
	Azerbaijan	18	37	N/C	N/C	1,00	0,68
	Cambodia	16	76	N/C	N/C	0,88	1,69
	Armenia	14	96	N/C	N/C	0,50	0,35
	Mongolia	11	37	N/C	N/C	2,50	1,09
	Yemen	11	25	N/C	N/C	2,33	1,22
	Lao People's Dem. Rep.	9	43	N/C	N/C	1,00	1,31
	Brunei Darussalam	8	29	N/C	N/C	4,00	1,71
	Uzbekistan	8	50	N/C	N/C	0,75	0,45
	Maldives	7	34	N/C	N/C	2,00	15,69
	Kyrgyzstan	5	7	N/C	N/C	1,00	1,18
	Dem. People's Rep. of Korea	4	19	N/C	N/C	2,00	2,80
	Myanmar	3	7	N/C	N/C	1,00	0,90
	Tajikistan	2	3	N/C	N/C	N/C	0,62
	Bhutan	1	2	N/C	N/C	N/C	0,58
Africa		3 329	18 602	0,80	0,86	1,28	1,83
	South Africa	1 031	7 152	0,89	0,94	1,30	1,89
	Egypt	558	2 513	0,73	0,76	1,47	1,40
	Tunisia	469	2 717	0,77	0,85	1,25	2,61
	Nigeria	268	712	0,31	0,56	0,89	2,22

Table Annex F.4. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Kenya	166	1 208	1,07	1,04	1,08	2,37
	Algeria	159	695	0,82	0,73	1,25	1,21
	Morocco	148	1 104	1,10	0,93	1,16	1,63
	Ghana	89	366	0,58	0,81	0,74	2,84
	United Rep. of Tanzania	89	585	0,93	0,90	0,81	2,44
	Uganda	50	432	N/C	1,12	1,35	1,25
	Senegal	44	187	N/C	0,89	1,40	2,36
	Ethiopia	44	211	N/C	1,05	1,53	1,10
	Cameroon	43	152	N/C	0,83	1,47	1,27
	Madagascar	36	429	N/C	1,04	1,27	3,55
	Zimbabwe	36	204	N/C	0,67	2,09	2,33
	Seychelles	35	352	N/C	1,18	2,22	21,79
	Mauritius	35	362	N/C	0,99	0,59	5,84
	Mozambique	27	412	N/C	N/C	0,77	3,38
	Benin	25	69	N/C	N/C	9,00	1,97
	Côte d'Ivoire	24	54	N/C	N/C	6,00	2,08
	Botswana	17	62	N/C	N/C	1,50	1,49
	Namibia	17	192	N/C	N/C	1,00	2,71
	Zambia	17	68	N/C	N/C	2,00	1,37
	Libya	15	56	N/C	N/C	1,60	1,39
	Malawi	15	42	N/C	N/C	0,86	0,89
	Burkina Faso	14	70	N/C	N/C	1,75	0,97
	Cabo Verde	12	141	N/C	N/C	2,67	14,41
	Congo	11	93	N/C	N/C	1,00	2,11
	Gabon	10	75	N/C	N/C	2,50	1,72
	Sudan	9	27	N/C	N/C	0,75	0,52
	Togo	8	33	N/C	N/C	0,60	2,58
	Dem. Rep. of the Congo	8	49	N/C	N/C	3,00	1,25
	Mali	7	56	N/C	N/C	1,00	0,90
	Angola	7	22	N/C	N/C	0,75	3,46
	Burundi	7	12	N/C	N/C	2,50	6,14
	Mauritania	7	10	N/C	N/C	6,00	5,83
	Rwanda	7	37	N/C	N/C	0,33	1,12
	Swaziland	5	14	N/C	N/C	0,33	2,25
	Sierra Leone	5	55	N/C	N/C	4,00	2,79

Table Annex F.4. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Niger	4	11	N/C	N/C	3,00	0,82
	Guinea	4	26	N/C	N/C	2,00	2,24
	Liberia	3	8	N/C	N/C	N/C	4,32
	Guinea-Bissau	3	38	N/C	N/C	1,00	1,98
	Eritrea	2	7	N/C	N/C	1,00	2,62
	Chad	2	3	N/C	N/C	N/C	2,27
	Comoros	2	7	N/C	N/C	N/C	13,45
	Djibouti	1	1	N/C	N/C	N/C	2,29
	Central African Republic	1	0	N/C	N/C	N/C	0,71
	Lesotho	1	0	N/C	N/C	N/C	0,77

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1 % and HCP 10 % (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

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Table Annex F.5. Bibliometric indicators by country in the Human Health and Wellbeing category (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**22 259**	**154 236**	**1,00**	**1,00**	**1,28**	**1,00**
South America		**1 288**	**6 767**	**0,78**	**0,87**	**1,47**	**1,53**
	Brazil	759	3 223	0,64	0,80	1,51	1,34
	Chile	224	1 526	1,03	0,99	1,31	2,43
	Argentina	164	1 007	1,18	1,02	1,88	1,35
	Colombia	72	376	0,75	0,83	1,44	1,41
	Venezuela	39	222	N/C	0,54	0,88	2,42
	Peru	38	318	N/C	0,99	1,07	3,29
	Ecuador	35	293	N/C	1,15	2,50	5,68
	Uruguay	22	558	N/C	N/C	1,86	1,91
	Bolivia	8	31	N/C	N/C	1,50	2,67
	Nicaragua	7	99	N/C	N/C	0,67	6,93
	El Salvador	2	28	N/C	N/C	1,00	3,15
	Guyana	1	0	N/C	N/C	N/C	2,99
	Suriname	1	5	N/C	N/C	N/C	5,03
Oceania		**1 649**	**15 622**	**1,34**	**1,21**	**1,25**	**1,94**
	Australia	1 364	13 267	1,39	1,23	1,28	1,84
	New Zealand	323	2 660	1,11	1,08	1,08	2,58
	Fiji	19	104	N/C	N/C	1,50	11,53
	Solomon Islands	11	85	N/C	N/C	0,83	49,82
	Papua New Guinea	8	104	N/C	N/C	0,40	4,95
	Cook Islands	3	10	N/C	N/C	N/C	49,41
	Vanuatu	2	32	N/C	N/C	N/C	7,04
	Tonga	1	11	N/C	N/C	N/C	15,10
	Fed. States of Micronesia	1	13	N/C	N/C	N/C	7,55
	Kiribati	1	3	N/C	N/C	N/C	32,94
North America		**7 110**	**64 222**	**1,22**	**1,19**	**1,24**	**1,08**
	United States	5 877	55 840	1,26	1,21	1,25	1,03
	Canada	1 259	12 724	1,34	1,27	1,15	1,35
	Mexico	338	2 126	0,84	0,87	1,45	1,91
	Costa Rica	25	63	N/C	N/C	1,25	3,75
	Cuba	20	151	N/C	N/C	0,89	1,58
	Panama	16	137	N/C	N/C	11,00	3,31

Table Annex F.5. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Trinidad and Tobago	9	30	N/C	N/C	0,80	3,16
	Barbados	7	14	N/C	N/C	5,00	6,67
	Jamaica	7	27	N/C	N/C	2,50	2,46
	Grenada	6	19	N/C	N/C	1,50	3,48
	Belize	4	32	N/C	N/C	0,50	17,25
	Haiti	3	5	N/C	N/C	2,00	4,15
	Guatemala	3	16	N/C	N/C	1,00	1,70
	Saint Kitts and Nevis	2	0	N/C	N/C	N/C	7,63
	Dominican Republic	2	6	N/C	N/C	N/C	2,46
	Honduras	2	4	N/C	N/C	N/C	2,72
Europe		**8 536**	**70 483**	**1,17**	**1,08**	**1,25**	**1,01**
	United Kingdom	1 822	19 552	1,47	1,27	1,32	1,17
	Spain	1 223	10 587	1,21	1,11	1,25	1,51
	France	1 190	11 294	1,28	1,16	1,33	1,11
	Germany	1 077	10 737	1,34	1,14	1,28	0,70
	Italy	943	8 194	1,27	1,07	1,39	1,03
	Netherlands	611	6 863	1,46	1,23	1,43	1,15
	Norway	541	5 810	1,49	1,19	1,20	3,16
	Portugal	452	5 071	1,62	1,08	1,41	2,30
	Sweden	431	5 466	1,44	1,22	1,24	1,24
	Denmark	349	3 930	1,51	1,18	1,18	1,60
	Switzerland	292	4 329	1,55	1,29	1,31	0,75
	Belgium	288	2 228	1,17	1,18	1,83	0,96
	Poland	270	1 546	0,82	0,72	1,71	0,76
	Greece	249	1 973	1,12	0,93	1,09	1,45
	Ireland	218	2 261	1,44	1,31	0,91	1,89
	Finland	183	2 114	1,27	1,20	1,33	1,05
	Russian Federation	139	992	0,98	0,70	1,11	0,31
	Austria	123	1 554	1,51	1,23	1,36	0,59
	Czech Republic	108	1 217	1,46	1,04	1,60	0,54
	Croatia	105	528	0,71	0,80	0,93	1,84
	Romania	93	219	N/C	0,45	1,16	0,58
	Slovenia	64	650	1,40	0,99	1,32	1,12
	Serbia	49	154	N/C	0,69	2,55	0,65

Table Annex F.5. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Iceland	47	188	N/C	1,08	2,67	3,44
	Hungary	43	189	N/C	1,16	3,83	0,45
	Bulgaria	38	127	N/C	0,84	2,09	1,02
	Estonia	37	260	N/C	0,88	1,14	1,40
	Lithuania	31	404	N/C	N/C	1,09	0,81
	Luxembourg	26	142	N/C	N/C	4,50	2,02
	Ukraine	24	59	N/C	N/C	1,11	0,31
	Slovakia	22	99	N/C	N/C	0,67	0,36
	Latvia	14	145	N/C	N/C	0,63	0,86
	Monaco	14	138	N/C	N/C	2,00	12,34
	Malta	12	187	N/C	N/C	1,25	3,65
	Bosnia and Herzegovina	9	49	N/C	N/C	0,33	1,24
	Montenegro	7	14	N/C	N/C	1,50	2,45
	Albania	6	12	N/C	N/C	N/C	2,35
	Former Yugoslav Rep. of Macedonia	5	39	N/C	N/C	1,00	0,84
	Belarus	2	45	N/C	N/C	N/C	0,12
	Rep. of Moldova	1	1	N/C	N/C	N/C	0,24
Asia		**7 229**	**39 758**	**0,83**	**0,85**	**1,42**	**0,87**
	China	3 039	16 855	0,88	0,88	1,62	0,75
	Japan	934	5 561	0,77	0,95	1,21	0,75
	India	764	3 709	0,73	0,74	1,29	0,94
	Rep. of Korea	711	4 249	0,88	0,85	1,38	0,96
	Turkey	361	1 594	0,59	0,62	0,79	0,94
	Malaysia	294	2 047	1,16	0,92	1,80	1,61
	Iran	275	1 206	0,67	0,66	1,25	0,76
	Thailand	214	1 245	0,89	0,88	1,29	2,04
	Israel	159	1 295	0,99	0,99	1,44	0,83
	Saudi Arabia	157	920	0,97	0,78	2,71	1,38
	Singapore	134	1 371	1,26	1,18	1,55	0,78
	Viet Nam	109	516	0,73	0,99	1,93	3,73
	Philippines	92	595	0,87	1,10	1,14	5,90
	Bangladesh	87	568	0,88	0,93	1,30	3,80
	Indonesia	76	762	1,51	0,97	1,86	2,59
	Pakistan	71	272	0,68	0,62	1,95	0,77

Table Annex F.5. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	United Arab Emirates	46	236	N/C	0,86	2,55	1,95
	Sri Lanka	36	382	N/C	1,04	0,79	4,12
	Kuwait	33	85	N/C	0,60	0,64	3,23
	Oman	29	126	N/C	N/C	1,00	3,59
	Cyprus	24	111	N/C	N/C	1,00	1,49
	Jordan	23	54	N/C	N/C	2,83	1,26
	Qatar	21	117	N/C	N/C	7,00	1,73
	Lebanon	17	49	N/C	N/C	10,00	1,12
	Cambodia	16	144	N/C	N/C	2,25	6,08
	Nepal	13	76	N/C	N/C	1,50	2,06
	Georgia	12	20	N/C	N/C	9,00	1,47
	Lao People's Dem. Rep.	12	95	N/C	N/C	1,00	6,26
	Brunei Darussalam	10	63	N/C	N/C	0,40	7,68
	Iraq	10	58	N/C	N/C	2,00	1,09
	Yemen	8	77	N/C	N/C	0,25	3,18
	Bahrain	8	26	N/C	N/C	2,50	3,13
	Uzbekistan	6	22	N/C	N/C	2,00	1,21
	Syria	6	114	N/C	N/C	0,25	1,32
	Kyrgyzstan	3	19	N/C	N/C	0,50	2,53
	Afghanistan	3	16	N/C	N/C	N/C	4,51
	Azerbaijan	3	10	N/C	N/C	1,00	0,41
	Armenia	3	1	N/C	N/C	1,00	0,27
	Mongolia	2	4	N/C	N/C	N/C	0,71
	Maldives	2	2	N/C	N/C	1,00	16,10
	Myanmar	1	2	N/C	N/C	N/C	1,08
	Kazakhstan	1	2	N/C	N/C	N/C	0,12
Africa		**1 250**	**8 207**	**0,92**	**0,95**	**1,58**	**2,46**
	South Africa	322	3 448	1,33	1,08	1,58	2,12
	Egypt	196	813	0,70	0,75	1,79	1,76
	Kenya	141	1 415	1,52	1,28	1,59	7,23
	Tunisia	136	480	0,46	0,78	1,83	2,72
	Nigeria	63	179	0,29	0,65	0,66	1,87
	United Rep. of Tanzania	62	438	1,12	1,10	1,65	6,11
	Algeria	55	224	N/C	0,53	1,82	1,51

Table Annex F.5. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Ghana	42	277	N/C	0,96	0,72	4,81
	Ethiopia	35	121	N/C	0,95	1,46	3,13
	Morocco	32	138	N/C	N/C	1,80	1,26
	Uganda	31	151	N/C	0,98	1,50	2,78
	Cameroon	30	153	N/C	N/C	2,29	3,19
	Senegal	25	102	N/C	N/C	1,71	4,82
	Madagascar	19	139	N/C	N/C	1,83	6,72
	Burkina Faso	16	142	N/C	N/C	3,00	3,99
	Benin	14	80	N/C	N/C	5,00	3,96
	Zambia	11	70	N/C	N/C	1,25	3,19
	Côte d'Ivoire	11	87	N/C	N/C	1,25	3,42
	Malawi	11	30	N/C	N/C	1,25	2,35
	Seychelles	10	59	N/C	N/C	2,50	22,37
	Mauritius	10	59	N/C	N/C	3,00	6,00
	Mozambique	10	176	N/C	N/C	0,75	4,50
	Mali	8	60	N/C	N/C	2,00	3,70
	Zimbabwe	7	32	N/C	N/C	0,40	1,63
	Libya	7	15	N/C	N/C	1,33	2,34
	Namibia	6	5	N/C	N/C	1,50	3,44
	Gabon	5	77	N/C	N/C	0,33	3,08
	Togo	4	27	N/C	N/C	0,33	4,63
	Gambia	4	24	N/C	N/C	1,00	2,71
	Mauritania	4	31	N/C	N/C	3,00	11,98
	Swaziland	3	19	N/C	N/C	N/C	4,85
	Dem. Rep. of the Congo	3	12	N/C	N/C	N/C	1,69
	Botswana	3	15	N/C	N/C	2,00	0,94
	Guinea	3	12	N/C	N/C	N/C	6,04
	Sudan	3	5	N/C	N/C	2,00	0,63
	Congo	3	12	N/C	N/C	N/C	2,07
	Rwanda	3	14	N/C	N/C	1,00	1,73
	Angola	2	10	N/C	N/C	1,00	3,55
	Burundi	2	1	N/C	N/C	N/C	6,30
	Comoros	2	8	N/C	N/C	N/C	48,31
	Guinea-Bissau	2	3	N/C	N/C	N/C	4,74

Table Annex F.5. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Niger	1	8	N/C	N/C	N/C	0,74
	Eritrea	1	4	N/C	N/C	N/C	4,71
	Central African Republic	1	0	N/C	N/C	N/C	2,55
	Chad	1	1	N/C	N/C	N/C	4,07

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1 % and HCP 10 % (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

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Table Annex F.6. Bibliometric indicators by country in the Blue Growth category (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**79 256**	**457 338**	**1,00**	**1,00**	**1,31**	**1,00**
South America		4 980	21 961	0,80	0,88	1,34	1,66
	Brazil	3 010	11 061	0,70	0,83	1,43	1,49
	Chile	912	5 139	1,02	0,96	1,21	2,78
	Argentina	615	3 565	0,94	1,02	1,23	1,42
	Colombia	245	1 102	0,81	0,81	1,60	1,35
	Peru	122	943	1,07	1,07	1,17	2,97
	Venezuela	108	590	N/C	0,65	0,80	1,88
	Uruguay	91	1 030	1,44	1,04	1,73	2,22
	Ecuador	76	645	1,04	1,23	1,50	3,46
	Bolivia	25	199	N/C	N/C	1,50	2,34
	Nicaragua	14	64	N/C	N/C	0,33	3,89
	El Salvador	9	27	N/C	N/C	4,00	3,98
	Guyana	5	8	N/C	N/C	N/C	4,20
	Suriname	4	11	N/C	N/C	N/C	5,65
	Paraguay	3	4	N/C	N/C	2,00	0,83
Oceania		5 916	48 835	1,33	1,20	1,30	1,96
	Australia	4 979	40 828	1,35	1,22	1,35	1,89
	New Zealand	1 040	9 612	1,31	1,17	1,06	2,33
	Fiji	94	540	0,91	1,26	1,74	16,02
	Papua New Guinea	21	349	N/C	N/C	1,43	3,65
	Solomon Islands	18	160	N/C	N/C	1,14	22,90
	Palau	11	44	N/C	N/C	9,00	30,25
	Vanuatu	8	30	N/C	N/C	2,50	7,90
	Fed. States of Micronesia	7	32	N/C	N/C	2,00	14,84
	Cook Islands	5	12	N/C	N/C	N/C	23,13
	Kiribati	2	3	N/C	N/C	N/C	18,50
	Tuvalu	1	0	N/C	N/C	N/C	20,35
	Tonga	1	11	N/C	N/C	N/C	4,24
	Marshall Islands	1	6	N/C	N/C	N/C	6,36

Table Annex F.6. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
North America		**23 369**	**175 476**	**1,20**	**1,15**	**1,20**	**1,00**
	United States	18 655	146 975	1,24	1,17	1,21	0,92
	Canada	4 566	37 923	1,32	1,23	1,18	1,38
	Mexico	1 359	6 102	0,73	0,84	1,22	2,16
	Costa Rica	87	528	0,94	1,04	1,03	3,66
	Cuba	86	561	0,78	0,84	0,70	1,90
	Panama	60	476	1,19	1,25	1,81	3,49
	Trinidad and Tobago	39	114	N/C	0,89	1,33	3,84
	Jamaica	25	216	N/C	N/C	3,75	2,47
	Bahamas	24	150	N/C	N/C	2,00	19,08
	Barbados	22	77	N/C	N/C	2,40	5,89
	Belize	19	162	N/C	N/C	1,60	23,02
	Grenada	17	69	N/C	N/C	1,00	2,77
	Guatemala	13	141	N/C	N/C	1,20	2,07
	Dominican Republic	8	22	N/C	N/C	4,00	2,76
	Honduras	7	10	N/C	N/C	4,00	2,68
	Saint Kitts and Nevis	4	12	N/C	N/C	N/C	4,28
	Saint Vincent and the Grenadines	2	14	N/C	N/C	1,00	14,54
	Dominica	2	3	N/C	N/C	N/C	2,79
	Haiti	1	3	N/C	N/C	N/C	0,39
Europe		**30 912**	**210 441**	**1,18**	**1,10**	**1,31**	**1,03**
	United Kingdom	6 458	57 524	1,44	1,24	1,28	1,16
	Spain	4 496	35 149	1,28	1,15	1,30	1,56
	Germany	3 782	33 131	1,39	1,18	1,38	0,69
	France	3 733	32 901	1,39	1,19	1,38	0,98
	Norway	3 112	21 826	1,33	1,13	1,30	5,11
	Italy	3 085	22 054	1,18	1,08	1,45	0,94
	Netherlands	1 799	15 848	1,51	1,25	1,43	0,95
	Portugal	1 689	12 587	1,32	1,11	1,53	2,41
	Denmark	1 445	12 403	1,55	1,19	1,52	1,86
	Sweden	1 281	11 494	1,41	1,29	1,40	1,04

Table Annex F.6. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Greece	1 059	7 297	1,16	0,98	1,29	1,73
	Belgium	944	6 525	1,11	1,18	1,36	0,88
	Russian Federation	833	3 989	0,76	0,72	1,30	0,53
	Ireland	748	5 849	1,39	1,22	1,27	1,82
	Switzerland	737	10 094	1,86	1,37	1,52	0,53
	Poland	717	3 981	1,08	0,87	1,63	0,56
	Finland	619	4 821	1,25	1,23	1,34	0,99
	Romania	412	1 067	0,44	0,53	0,98	0,72
	Austria	398	3 284	1,27	1,16	1,33	0,54
	Croatia	396	1 524	0,66	0,80	1,01	1,95
	Czech Republic	380	3 218	1,25	1,05	1,06	0,53
	Iceland	240	1 484	0,99	1,18	1,17	4,93
	Hungary	182	919	0,93	1,00	1,82	0,53
	Slovenia	163	1 282	1,29	1,04	1,54	0,80
	Serbia	146	535	0,58	0,91	1,83	0,55
	Bulgaria	137	473	0,54	0,69	0,93	1,03
	Estonia	132	928	1,03	1,06	1,97	1,40
	Lithuania	131	804	1,17	1,00	1,79	0,97
	Ukraine	93	325	0,74	0,74	1,29	0,34
	Latvia	68	284	N/C	0,96	1,29	1,17
	Slovakia	59	276	N/C	0,83	1,25	0,27
	Malta	46	328	N/C	1,02	1,47	3,93
	Luxembourg	45	321	N/C	1,24	2,08	0,98
	Montenegro	26	63	N/C	N/C	2,13	2,56
	Albania	24	49	N/C	N/C	0,67	2,64
	Monaco	24	175	N/C	N/C	1,22	5,94
	Bosnia and Herzegovina	18	26	N/C	N/C	0,78	0,70
	Former Yugoslav Rep. of Macedonia	18	39	N/C	N/C	1,14	0,85
	Belarus	8	40	N/C	N/C	1,50	0,14
	Rep. of Moldova	6	12	N/C	N/C	1,50	0,41
	Liechtenstein	4	7	N/C	N/C	1,00	1,18
	Andorra	1	0	N/C	N/C	N/C	2,99

Table Annex F.6. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
Asia		**26 051**	**125 347**	**0,85**	**0,86**	**1,48**	**0,88**
	China	10 952	53 194	0,88	0,86	1,66	0,76
	Japan	3 477	17 080	0,77	0,94	1,16	0,78
	India	3 261	14 876	0,79	0,74	1,42	1,12
	Rep. of Korea	2 310	12 094	0,91	0,91	1,75	0,87
	Turkey	1 300	5 867	0,77	0,78	0,97	0,95
	Iran	1 089	3 413	0,57	0,66	1,45	0,84
	Malaysia	1 051	5 293	0,97	0,95	1,92	1,62
	Thailand	616	2 895	0,82	0,90	1,09	1,65
	Saudi Arabia	483	3 675	1,35	1,04	2,67	1,19
	Singapore	483	4 599	1,73	1,24	1,58	0,79
	Israel	452	3 822	1,17	1,10	1,20	0,66
	Viet Nam	362	1 468	0,73	0,98	1,53	3,48
	Indonesia	324	1 875	1,03	1,07	2,38	3,11
	Philippines	298	1 962	0,93	1,05	1,10	5,36
	Pakistan	271	1 008	0,66	0,67	1,48	0,83
	Bangladesh	251	964	0,82	0,88	1,59	3,08
	United Arab Emirates	137	808	1,07	1,05	1,46	1,63
	Oman	117	634	0,95	0,93	1,11	4,06
	Sri Lanka	92	858	1,71	0,91	1,24	2,95
	Cyprus	77	604	1,50	1,00	1,44	1,34
	Kuwait	70	203	0,50	0,59	0,63	1,93
	Qatar	66	339	N/C	0,97	3,00	1,52
	Jordan	57	217	N/C	0,85	1,76	0,88
	Lebanon	50	343	N/C	1,03	1,73	0,92
	Iraq	46	172	N/C	0,76	2,45	1,41
	Lao People's Dem. Rep.	29	106	N/C	N/C	1,33	4,25
	Cambodia	27	150	N/C	N/C	1,56	2,88
	Nepal	25	106	N/C	N/C	1,44	1,11
	Yemen	22	137	N/C	N/C	1,43	2,46
	Georgia	21	41	N/C	N/C	7,00	0,72
	Brunei Darussalam	21	128	N/C	N/C	0,50	4,53

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Table Annex F.6. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Bahrain	18	131	N/C	N/C	1,17	1,98
	Syria	17	159	N/C	N/C	0,86	1,05
	Kazakhstan	16	53	N/C	N/C	5,00	0,53
	Uzbekistan	15	53	N/C	N/C	1,00	0,85
	Mongolia	14	55	N/C	N/C	10,00	1,40
	Azerbaijan	13	17	N/C	N/C	0,57	0,49
	Maldives	9	27	N/C	N/C	3,00	20,35
	Armenia	8	99	N/C	N/C	1,33	0,20
	Kyrgyzstan	4	6	N/C	N/C	1,00	0,95
	Turkmenistan	4	5	N/C	N/C	0,50	4,47
	Myanmar	3	17	N/C	N/C	N/C	0,91
	Tajikistan	2	0	N/C	N/C	N/C	0,62
	Afghanistan	2	2	N/C	N/C	N/C	0,84
	Bhutan	1	2	N/C	N/C	N/C	0,58
Africa		**3 091**	**16 516**	**0,89**	**0,93**	**1,41**	**1,71**
	South Africa	965	6 618	1,10	1,02	1,45	1,78
	Egypt	577	2 455	0,70	0,86	1,52	1,46
	Tunisia	331	1 577	0,66	0,82	1,40	1,86
	Kenya	194	1 210	1,05	1,14	1,32	2,79
	Nigeria	173	455	0,47	0,64	0,80	1,45
	Algeria	130	530	0,85	0,78	1,86	1,00
	United Rep. of Tanzania	117	759	1,17	1,00	1,23	3,24
	Morocco	115	803	1,13	0,92	1,17	1,28
	Uganda	68	356	1,10	0,95	2,11	1,71
	Ghana	67	159	0,39	0,87	1,50	2,16
	Ethiopia	57	206	0,64	N/C	1,05	1,43
	Senegal	56	308	1,15	0,99	1,25	3,03
	Seychelles	43	306	N/C	1,24	2,78	27,01
	Mauritius	40	338	N/C	0,96	1,62	6,74
	Cameroon	40	140	N/C	0,96	0,64	1,20
	Mozambique	38	364	N/C	1,07	1,00	4,80
	Madagascar	38	311	N/C	1,01	2,00	3,78
	Benin	31	29	N/C	N/C	3,50	2,46
	Côte d'Ivoire	29	102	N/C	N/C	1,30	2,53

Table Annex F.6. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Libya	26	119	N/C	N/C	1,22	2,44
	Malawi	24	87	N/C	N/C	1,25	1,44
	Namibia	24	207	N/C	N/C	1,83	3,86
	Zimbabwe	16	142	N/C	N/C	1,14	1,05
	Mauritania	15	123	N/C	N/C	2,00	12,61
	Angola	14	43	N/C	N/C	1,33	6,98
	Zambia	14	106	N/C	N/C	3,50	1,14
	Botswana	14	33	N/C	N/C	0,33	1,24
	Congo	12	46	N/C	N/C	1,50	2,33
	Gabon	11	78	N/C	N/C	2,33	1,90
	Burkina Faso	10	133	N/C	N/C	0,33	0,70
	Sudan	9	31	N/C	N/C	1,00	0,53
	Cabo Verde	9	189	N/C	N/C	0,80	10,90
	Guinea	8	127	N/C	N/C	0,20	4,52
	Burundi	8	8	N/C	N/C	1,67	7,08
	Mali	6	37	N/C	N/C	1,00	0,78
	Rwanda	5	13	N/C	N/C	1,00	0,81
	Niger	5	3	N/C	N/C	3,00	1,04
	Guinea-Bissau	4	44	N/C	N/C	1,00	2,66
	Eritrea	3	14	N/C	N/C	0,50	3,96
	Dem. Rep. of the Congo	3	105	N/C	N/C	N/C	0,47
	Sierra Leone	3	51	N/C	N/C	2,00	1,69
	Swaziland	3	33	N/C	N/C	0,50	1,36
	Comoros	2	7	N/C	N/C	N/C	13,57
	Chad	2	5	N/C	N/C	N/C	2,29
	Togo	2	2	N/C	N/C	N/C	0,65
	Gambia	1	6	N/C	N/C	N/C	0,19
	Lesotho	1	6	N/C	N/C	N/C	0,78
	Liberia	1	3	N/C	N/C	N/C	1,45

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1 % and HCP 10 % (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

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Table Annex F.7. Bibliometric indicators by country in the Ocean Crust and Marine Geohazards category (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**54 493**	**348 599**	**1,00**	**1,00**	**1,23**	**1,00**
South America		2 492	12 166	0,82	0,92	1,34	1,21
	Brazil	1 236	5 312	0,76	0,87	1,40	0,89
	Argentina	530	2 662	0,84	0,91	1,31	1,78
	Chile	507	3 098	0,95	1,03	1,24	2,25
	Colombia	134	751	0,92	0,85	1,26	1,07
	Venezuela	66	207	0,43	0,97	1,13	1,67
	Peru	63	457	1,06	1,20	1,45	2,23
	Uruguay	58	294	0,82	1,05	1,29	2,06
	Ecuador	43	213	N/C	1,25	2,17	2,85
	Bolivia	18	155	N/C	N/C	1,00	2,45
	El Salvador	6	24	N/C	N/C	4,00	3,86
	Paraguay	3	12	N/C	N/C	1,00	1,21
	Nicaragua	3	14	N/C	N/C	N/C	1,21
	Guyana	1	0	N/C	N/C	N/C	1,22
	Suriname	1	0	N/C	N/C	N/C	2,06
Oceania		4 455	39 681	1,34	1,19	1,16	2,14
	Australia	3 593	33 323	1,40	1,20	1,22	1,98
	New Zealand	1 039	7 952	1,12	1,18	0,97	3,39
	Fiji	19	73	N/C	N/C	1,11	4,71
	Papua New Guinea	14	113	N/C	N/C	2,67	3,54
	Vanuatu	11	80	N/C	N/C	1,20	15,81
	Solomon Islands	4	22	N/C	N/C	1,00	7,40
	Cook Islands	4	65	N/C	N/C	2,00	26,91
	Fed. States of Micronesia	4	11	N/C	N/C	N/C	12,33
	Palau	4	11	N/C	N/C	N/C	16,00
	Marshall Islands	2	10	N/C	N/C	N/C	18,50
	Tonga	2	52	N/C	N/C	1,00	12,33
	Kiribati	2	4	N/C	N/C	N/C	26,91
	Tuvalu	1	4	N/C	N/C	N/C	29,60
	Niue	1	4	N/C	N/C	N/C	49,33
	Nauru	1	4	N/C	N/C	N/C	49,33
North America		17 694	150 830	1,23	1,19	1,17	1,10
	United States	14 929	135 142	1,30	1,23	1,17	1,07
	Canada	2 956	23 532	1,13	1,16	1,19	1,30

Table Annex F.7. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Mexico	754	3 375	0,69	0,81	1,34	1,74
	Panama	55	574	1,54	1,18	1,11	4,65
	Costa Rica	45	318	N/C	1,14	1,47	2,75
	Cuba	42	119	N/C	0,75	1,06	1,35
	Trinidad and Tobago	37	107	N/C	0,99	1,15	5,30
	Jamaica	22	124	N/C	N/C	2,50	3,16
	Barbados	14	135	N/C	N/C	1,60	5,45
	Haiti	8	91	N/C	N/C	0,75	4,52
	Grenada	6	16	N/C	N/C	0,20	1,42
	Bahamas	5	14	N/C	N/C	2,00	5,78
	Belize	3	28	N/C	N/C	N/C	5,29
	Honduras	3	9	N/C	N/C	0,50	1,67
	Guatemala	3	16	N/C	N/C	N/C	0,69
	Dominica	2	6	N/C	N/C	N/C	4,05
	Saint Kitts and Nevis	2	8	N/C	N/C	N/C	3,12
	Antigua and Barbuda	1	3	N/C	N/C	N/C	9,87
	Saint Vincent and the Grenadines	1	3	N/C	N/C	N/C	10,57
Europe		24 523	176 615	1,10	1,08	1,17	1,19
	United Kingdom	5 659	53 270	1,39	1,27	1,20	1,48
	Germany	4 754	42 309	1,30	1,22	1,23	1,27
	France	4 477	39 410	1,30	1,21	1,16	1,70
	Italy	2 968	21 703	1,12	1,08	1,16	1,32
	Spain	2 457	17 079	1,12	1,13	1,32	1,24
	Russian Federation	1 941	8 377	0,61	0,58	1,07	1,78
	Norway	1 585	12 494	1,19	1,14	1,09	3,79
	Netherlands	1 541	14 954	1,49	1,27	1,15	1,18
	Switzerland	1 070	11 998	1,72	1,37	1,39	1,12
	Portugal	960	6 334	1,07	1,02	1,22	1,99
	Denmark	845	7 525	1,29	1,25	1,16	1,58
	Sweden	761	6 111	1,27	1,19	1,45	0,90
	Poland	699	3 311	0,81	0,74	1,38	0,80
	Belgium	653	5 507	1,20	1,10	0,97	0,89
	Greece	615	3 471	0,97	0,92	1,33	1,46
	Austria	448	4 054	1,39	1,11	1,46	0,88
	Ireland	312	2 403	1,10	1,14	0,97	1,11

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Table Annex F.7. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Czech Republic	252	1 385	0,82	0,91	1,34	0,51
	Romania	239	1 115	0,87	0,90	1,28	0,60
	Finland	223	1 885	1,49	1,13	1,29	0,52
	Croatia	174	719	0,64	0,77	1,09	1,25
	Estonia	134	937	0,89	0,73	1,34	2,07
	Iceland	121	1 163	1,50	1,29	1,21	3,61
	Hungary	121	710	0,81	1,04	1,17	0,51
	Bulgaria	115	570	0,72	0,77	0,93	1,26
	Slovakia	89	358	0,70	0,78	1,39	0,59
	Ukraine	79	414	0,95	0,62	1,25	0,41
	Slovenia	76	327	0,85	0,92	1,38	0,54
	Serbia	64	417	1,00	N/C	1,47	0,35
	Lithuania	59	128	N/C	0,70	1,32	0,63
	Malta	27	107	N/C	N/C	2,00	3,36
	Luxembourg	24	129	N/C	N/C	3,75	0,76
	Monaco	20	242	N/C	N/C	0,67	7,20
	Latvia	19	15	N/C	N/C	2,75	0,47
	Albania	19	72	N/C	N/C	0,67	3,04
	Former Yugoslav Rep. of Macedonia	9	43	N/C	N/C	2,50	0,62
	Montenegro	7	2	N/C	N/C	N/C	1,00
	Belarus	4	5	N/C	N/C	1,00	0,10
	Bosnia and Herzegovina	3	4	N/C	N/C	N/C	0,17
	San Marino	2	3	N/C	N/C	N/C	7,40
	Andorra	2	35	N/C	N/C	1,00	8,71
	Rep. of Moldova	1	4	N/C	N/C	N/C	0,10
Asia		**19 050**	**106 260**	**0,92**	**0,87**	**1,47**	**0,93**
	China	8 884	56 334	1,06	0,84	1,55	0,90
	Japan	3 827	25 770	1,04	1,04	1,41	1,25
	India	2 596	10 923	0,62	0,79	1,37	1,30
	Rep. of Korea	1 134	5 185	0,76	0,90	1,56	0,62
	Turkey	825	4 267	0,85	0,85	1,20	0,88
	Iran	537	2 284	0,73	0,78	1,45	0,60
	Malaysia	375	1 145	0,67	0,76	2,38	0,84
	Israel	349	2 165	0,95	1,20	1,18	0,74

Table Annex F.7. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Indonesia	271	1 396	0,86	0,97	1,39	3,78
	Singapore	256	1 376	1,20	1,02	1,83	0,61
	Saudi Arabia	237	1 194	0,95	0,88	2,94	0,85
	Thailand	205	1 104	0,82	0,98	1,00	0,80
	Viet Nam	154	652	0,79	0,98	1,98	2,15
	Pakistan	106	469	0,70	0,80	1,31	0,47
	Philippines	100	451	0,79	1,06	1,24	2,62
	Bangladesh	94	379	0,79	0,90	2,26	1,68
	United Arab Emirates	76	469	0,85	0,90	0,78	1,32
	Oman	69	484	1,01	0,98	0,97	3,49
	Sri Lanka	65	230	0,56	0,80	1,00	3,04
	Jordan	57	270	N/C	0,80	1,65	1,28
	Iraq	48	146	N/C	0,73	2,07	2,13
	Yemen	41	331	N/C	0,88	1,67	6,66
	Mongolia	36	347	N/C	1,14	2,11	5,25
	Cyprus	36	319	N/C	0,77	2,56	0,91
	Kuwait	24	159	N/C	N/C	0,60	0,96
	Azerbaijan	24	109	N/C	N/C	1,29	1,33
	Qatar	21	178	N/C	N/C	1,25	0,70
	Armenia	20	105	N/C	N/C	1,29	0,74
	Syria	19	139	N/C	N/C	0,63	1,70
	Lebanon	17	54	N/C	N/C	1,33	0,46
	Georgia	16	71	N/C	N/C	0,44	0,80
	Bahrain	14	131	N/C	N/C	0,60	2,24
	Nepal	13	216	N/C	N/C	2,67	0,84
	Kyrgyzstan	12	119	N/C	N/C	3,00	4,14
	Kazakhstan	12	35	N/C	N/C	1,40	0,57
	Myanmar	11	61	N/C	N/C	1,33	4,85
	Brunei Darussalam	11	28	N/C	N/C	8,00	3,45
	Uzbekistan	8	87	N/C	N/C	1,67	0,66
	Lao People's Dem. Rep.	7	51	N/C	N/C	0,50	1,49
	Cambodia	5	17	N/C	N/C	3,00	0,78
	Tajikistan	5	16	N/C	N/C	1,00	2,27
	Maldives	5	33	N/C	N/C	0,33	16,44

Table Annex F.7. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Turkmenistan	3	13	N/C	N/C	2,00	4,88
	Bhutan	2	32	N/C	N/C	1,00	1,70
	Dem. People's Rep. of Korea	1	2	N/C	N/C	N/C	1,03
	Afghanistan	1	5	N/C	N/C	N/C	0,61
Africa		**1 756**	**10 005**	**0,93**	**0,95**	**1,42**	**1,41**
	South Africa	575	4 369	1,15	1,09	1,31	1,54
	Egypt	399	1 332	0,64	0,76	1,74	1,47
	Morocco	160	1 030	0,97	1,04	1,26	2,58
	Tunisia	144	627	0,65	0,78	1,51	1,18
	Nigeria	69	123	N/C	0,74	1,86	0,84
	Algeria	63	268	N/C	0,95	1,52	0,70
	Ethiopia	48	508	N/C	1,58	1,24	1,75
	Kenya	45	291	N/C	1,14	1,17	0,94
	Ghana	43	233	N/C	0,88	1,43	2,01
	Cameroon	39	136	N/C	1,00	2,44	1,70
	Senegal	30	274	N/C	1,04	0,69	2,36
	United Rep. of Tanzania	29	263	N/C	N/C	1,17	1,17
	Libya	21	79	N/C	N/C	2,40	2,86
	Mauritius	21	180	N/C	N/C	2,00	5,15
	Madagascar	20	213	N/C	N/C	1,13	2,89
	Botswana	17	43	N/C	N/C	1,80	2,18
	Namibia	14	68	N/C	N/C	3,33	3,28
	Uganda	13	101	N/C	N/C	1,20	0,48
	Benin	12	49	N/C	N/C	2,33	1,39
	Mozambique	11	36	N/C	N/C	4,00	2,02
	Sudan	10	108	N/C	N/C	0,67	0,85
	Eritrea	10	141	N/C	N/C	1,00	19,22
	Niger	10	144	N/C	N/C	0,75	3,03
	Angola	9	52	N/C	N/C	1,33	6,53
	Côte d'Ivoire	8	79	N/C	N/C	0,67	1,02
	Seychelles	6	100	N/C	N/C	3,00	5,48
	Gabon	6	33	N/C	N/C	2,00	1,51
	Cabo Verde	5	86	N/C	N/C	1,50	8,81

Table Annex F.7. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Burkina Faso	5	38	N/C	N/C	2,00	0,51
	Zimbabwe	5	31	N/C	N/C	0,33	0,48
	Congo	4	12	N/C	N/C	3,00	1,13
	Mauritania	4	8	N/C	N/C	1,00	4,89
	Mali	4	52	N/C	N/C	N/C	0,76
	Dem. Rep. of the Congo	3	37	N/C	N/C	0,50	0,69
	Togo	3	10	N/C	N/C	0,50	1,42
	Guinea-Bissau	2	8	N/C	N/C	N/C	1,93
	Comoros	2	8	N/C	N/C	1,00	19,73
	Zambia	2	20	N/C	N/C	1,00	0,24
	Malawi	2	3	N/C	N/C	N/C	0,17
	Djibouti	1	20	N/C	N/C	N/C	3,36
	Gambia	1	13	N/C	N/C	N/C	0,28
	Chad	1	0	N/C	N/C	N/C	1,66

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1 % and HCP 10 % (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

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Table Annex F.8. Bibliometric indicators by country in the Ocean Technology and Engineering category (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**36 091**	**145 924**	**1,00**	**1,00**	**1,37**	**1,00**
South America		**943**	**3 659**	**0,93**	**1,06**	**1,39**	**0,69**
	Brazil	621	1 900	0,75	1,02	1,47	0,68
	Argentina	115	578	1,20	1,14	1,37	0,58
	Chile	113	821	1,59	1,20	1,18	0,76
	Colombia	74	272	1,06	0,93	1,42	0,90
	Venezuela	14	40	N/C	N/C	0,83	0,54
	Uruguay	10	46	N/C	N/C	2,00	0,53
	Peru	10	50	N/C	N/C	6,00	0,53
	Ecuador	7	22	N/C	N/C	1,33	0,70
	El Salvador	2	8	N/C	N/C	N/C	1,94
	Nicaragua	1	30	N/C	N/C	N/C	0,61
	Guyana	1	0	N/C	N/C	N/C	1,85
	Paraguay	1	0	N/C	N/C	N/C	0,61
	Bolivia	1	1	N/C	N/C	N/C	0,21
Oceania		**1 561**	**10 099**	**1,62**	**1,30**	**1,67**	**1,13**
	Australia	1 362	8 749	1,61	1,30	1,78	1,13
	New Zealand	202	1 438	1,72	1,28	1,04	0,99
	Fiji	24	94	N/C	N/C	3,00	8,98
	Fed. States of Micronesia	1	8	N/C	N/C	N/C	4,66
North America		**9 331**	**54 107**	**1,30**	**1,21**	**1,16**	**0,88**
	United States	8 070	48 437	1,34	1,21	1,17	0,88
	Canada	1 268	7 191	1,20	1,24	1,05	0,84
	Mexico	237	564	0,59	1,03	1,75	0,83
	Cuba	17	111	N/C	N/C	2,00	0,83
	Trinidad and Tobago	7	3	N/C	N/C	5,00	1,51
	Panama	6	69	N/C	N/C	0,25	0,77
	Barbados	3	2	N/C	N/C	N/C	1,76
	Jamaica	2	0	N/C	N/C	N/C	0,43
	Costa Rica	1	0	N/C	N/C	N/C	0,09
	Honduras	1	3	N/C	N/C	N/C	0,84
	Guatemala	1	1	N/C	N/C	N/C	0,35

Table Annex F.8. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
Europe		12 610	63 267	1,22	1,12	1,35	0,92
	United Kingdom	2 549	14 223	1,35	1,29	1,39	1,01
	France	1 713	10 791	1,51	1,32	1,29	0,98
	Germany	1 562	9 696	1,52	1,12	1,41	0,63
	Italy	1 478	7 916	1,41	1,21	1,49	0,99
	Spain	1 090	7 310	1,60	1,30	1,51	0,83
	Norway	928	4 149	1,19	1,13	1,51	3,35
	Netherlands	773	5 836	1,73	1,30	1,45	0,90
	Russian Federation	642	1 955	0,66	0,75	0,99	0,89
	Portugal	500	3 625	1,78	1,25	1,57	1,57
	Poland	489	796	0,45	0,55	1,20	0,84
	Greece	418	2 024	1,19	1,08	1,23	1,50
	Denmark	414	2 410	1,62	1,23	2,20	1,17
	Sweden	334	1 463	0,98	1,22	1,44	0,59
	Belgium	315	2 057	1,23	1,27	1,32	0,65
	Switzerland	312	2 865	1,75	1,37	1,10	0,49
	Romania	217	637	0,73	0,53	1,21	0,83
	Croatia	190	417	0,55	0,71	1,01	2,06
	Finland	190	1 268	1,62	1,29	1,43	0,67
	Ireland	185	964	1,23	1,53	1,62	0,99
	Austria	169	1 072	1,46	1,16	1,71	0,50
	Czech Republic	78	470	1,56	1,01	1,44	0,24
	Serbia	73	126	0,40	1,10	1,71	0,60
	Estonia	57	258	N/C	0,93	1,42	1,33
	Slovenia	55	135	N/C	0,94	2,00	0,59
	Ukraine	51	106	N/C	0,80	1,22	0,40
	Slovakia	43	258	N/C	0,96	1,57	0,43
	Bulgaria	40	117	N/C	0,70	0,94	0,66
	Hungary	38	153	N/C	1,06	1,23	0,24
	Lithuania	32	46	N/C	N/C	2,71	0,52
	Iceland	18	170	N/C	N/C	0,56	0,81
	Latvia	14	18	N/C	N/C	3,50	0,53
	Luxembourg	13	125	N/C	N/C	1,75	0,62

Table Annex F.8. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Malta	10	15	N/C	N/C	2,50	1,88
	Belarus	7	9	N/C	N/C	5,00	0,26
	Former Yugoslav Rep. of Macedonia	7	29	N/C	N/C	2,00	0,73
	Montenegro	6	3	N/C	N/C	N/C	1,30
	Monaco	3	16	N/C	N/C	1,00	1,63
	San Marino	2	3	N/C	N/C	N/C	11,17
	Bosnia and Herzegovina	2	2	N/C	N/C	N/C	0,17
	Albania	1	1	N/C	N/C	N/C	0,24
	Andorra	1	1	N/C	N/C	N/C	6,57
	Rep. of Moldova	1	0	N/C	N/C	N/C	0,15
Asia		**16 410**	**49 133**	**0,78**	**0,87**	**1,57**	**1,21**
	China	9 519	23 299	0,69	0,75	1,72	1,45
	Rep. of Korea	1 724	5 090	0,81	0,97	1,44	1,43
	Japan	1 477	5 400	0,86	1,01	1,25	0,73
	India	1 314	5 166	0,91	1,07	1,30	0,99
	Iran	689	2 184	1,02	1,07	1,74	1,17
	Turkey	534	2 498	1,11	1,18	1,23	0,86
	Singapore	415	2 687	1,71	1,28	1,41	1,48
	Malaysia	408	1 703	1,07	1,04	2,48	1,38
	Israel	160	706	0,91	1,26	1,08	0,51
	Saudi Arabia	160	997	1,24	1,33	2,29	0,87
	Thailand	105	538	1,17	1,04	0,93	0,62
	Indonesia	103	403	0,78	0,92	1,33	2,17
	Pakistan	68	266	0,75	1,05	1,70	0,46
	Viet Nam	67	149	0,62	1,04	2,75	1,41
	United Arab Emirates	66	388	1,09	1,29	1,40	1,73
	Cyprus	45	117	N/C	0,78	1,79	1,72
	Bangladesh	43	170	N/C	1,22	1,13	1,16
	Kuwait	34	56	N/C	0,82	0,88	2,05
	Qatar	29	65	N/C	N/C	4,00	1,47
	Oman	26	160	N/C	N/C	0,54	1,98
	Lebanon	22	101	N/C	N/C	3,00	0,89
	Philippines	18	65	N/C	N/C	1,60	0,71
	Sri Lanka	15	36	N/C	N/C	1,00	1,06

Table Annex F.8. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Jordan	15	65	N/C	N/C	2,00	0,51
	Iraq	11	31	N/C	N/C	2,00	0,74
	Lao People's Dem. Rep.	9	18	N/C	N/C	N/C	2,90
	Nepal	9	30	N/C	N/C	3,50	0,88
	Armenia	7	18	N/C	N/C	1,00	0,39
	Syria	6	7	N/C	N/C	N/C	0,81
	Kazakhstan	6	12	N/C	N/C	4,00	0,43
	Bahrain	6	21	N/C	N/C	1,50	1,45
	Yemen	5	48	N/C	N/C	1,00	1,23
	Azerbaijan	4	3	N/C	N/C	3,00	0,33
	Brunei Darussalam	4	44	N/C	N/C	0,50	1,89
	Myanmar	3	8	N/C	N/C	N/C	2,00
	Uzbekistan	3	20	N/C	N/C	N/C	0,37
	Cambodia	3	7	N/C	N/C	1,00	0,70
	Georgia	2	3	N/C	N/C	N/C	0,15
	Dem. People's Rep. of Korea	2	0	N/C	N/C	N/C	3,10
	Kyrgyzstan	2	9	N/C	N/C	N/C	1,04
	Mongolia	1	0	N/C	N/C	N/C	0,22
Africa		**626**	**2 588**	**1,04**	**1,14**	**1,75**	**0,76**
	Egypt	172	607	0,90	1,16	1,74	0,95
	South Africa	162	821	1,32	1,11	1,73	0,66
	Tunisia	71	267	1,09	1,00	2,16	0,88
	Algeria	63	202	N/C	1,00	2,40	1,06
	Morocco	49	225	N/C	1,11	1,50	1,19
	Nigeria	27	100	N/C	N/C	1,30	0,50
	Kenya	17	101	N/C	N/C	1,80	0,54
	Ethiopia	17	93	N/C	N/C	1,60	0,94
	Ghana	11	41	N/C	N/C	0,43	0,78
	United Rep. of Tanzania	8	40	N/C	N/C	N/C	0,49
	Senegal	7	12	N/C	N/C	4,00	0,83
	Benin	5	2	N/C	N/C	N/C	0,87
	Uganda	5	42	N/C	N/C	0,33	0,28
	Libya	5	5	N/C	N/C	3,00	1,03
	Namibia	4	1	N/C	N/C	2,00	1,41

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Table Annex F.8. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Niger	4	26	N/C	N/C	N/C	1,83
	Sudan	4	20	N/C	N/C	N/C	0,52
	Rwanda	3	13	N/C	N/C	N/C	1,06
	Burkina Faso	3	2	N/C	N/C	N/C	0,46
	Mozambique	3	5	N/C	N/C	N/C	0,83
	Mauritius	3	5	N/C	N/C	N/C	1,11
	Madagascar	3	32	N/C	N/C	1,00	0,65
	Botswana	2	7	N/C	N/C	1,00	0,39
	Côte d'Ivoire	2	7	N/C	N/C	N/C	0,38
	Zambia	2	14	N/C	N/C	1,00	0,36
	Cameroon	2	2	N/C	N/C	N/C	0,13
	Burundi	2	7	N/C	N/C	1,00	3,89
	Lesotho	1	6	N/C	N/C	N/C	1,71
	Dem. Rep. of the Congo	1	1	N/C	N/C	N/C	0,35
	Mauritania	1	0	N/C	N/C	N/C	1,85
	Zimbabwe	1	10	N/C	N/C	N/C	0,14
	Cabo Verde	1	3	N/C	N/C	N/C	2,66
	Guinea	1	0	N/C	N/C	N/C	1,24
	Chad	1	5	N/C	N/C	N/C	2,51
	Malawi	1	7	N/C	N/C	N/C	0,13
	Seychelles	1	2	N/C	N/C	N/C	1,38

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1 % and HCP 10 % (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

Table Annex F.9. Bibliometric indicators by country in the Ocean Observation and Marine Data category (2010–2014)

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
World		**40 415**	**256 440**	**1,00**	**1,00**	**1,22**	**1,00**
South America		1 906	9 481	0,81	0,90	1,25	1,24
	Brazil	1 060	4 408	0,69	0,85	1,26	1,03
	Argentina	334	1 821	0,93	1,03	1,48	1,52
	Chile	308	2 006	1,08	0,94	1,08	1,84
	Colombia	100	666	0,72	0,71	0,70	1,08
	Venezuela	62	522	0,63	0,92	0,85	2,12
	Peru	51	469	N/C	1,18	1,15	2,43
	Uruguay	46	493	N/C	1,04	2,00	2,20
	Ecuador	40	134	N/C	1,08	4,00	3,57
	Bolivia	18	54	N/C	N/C	5,50	3,30
	El Salvador	5	25	N/C	N/C	1,00	4,34
	Nicaragua	5	17	N/C	N/C	N/C	2,73
	Paraguay	2	1	N/C	N/C	N/C	1,09
	Guyana	1	0	N/C	N/C	N/C	1,65
Oceania		2 884	26 142	1,37	1,18	1,28	1,87
	Australia	2 457	22 601	1,41	1,20	1,35	1,82
	New Zealand	500	5 135	1,22	1,13	1,02	2,20
	Papua New Guinea	12	106	N/C	N/C	1,50	4,09
	Fiji	8	27	N/C	N/C	3,00	2,67
	Vanuatu	8	64	N/C	N/C	1,00	15,50
	Palau	7	40	N/C	N/C	1,00	37,75
	Cook Islands	6	89	N/C	N/C	0,67	54,42
	Solomon Islands	3	48	N/C	N/C	N/C	7,48
	Tonga	1	48	N/C	N/C	N/C	8,31
	Fed. States of Micronesia	1	4	N/C	N/C	N/C	4,16
	Marshall Islands	1	17	N/C	N/C	N/C	12,47
North America		15 585	131 771	1,21	1,12	1,17	1,31
	United States	13 335	118 464	1,26	1,13	1,16	1,29
	Canada	2 597	23 130	1,28	1,16	1,25	1,54
	Mexico	493	2 565	0,70	0,84	1,28	1,54
	Costa Rica	37	359	N/C	1,14	1,33	3,05
	Cuba	33	238	N/C	0,85	1,00	1,43
	Panama	28	244	N/C	N/C	2,38	3,19
	Trinidad and Tobago	18	168	N/C	N/C	1,00	3,48

Table Annex F.9. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Bahamas	17	160	N/C	N/C	1,50	26,50
	Jamaica	8	54	N/C	N/C	1,50	1,55
	Barbados	7	105	N/C	N/C	4,00	3,68
	Dominican Republic	6	22	N/C	N/C	N/C	4,06
	Belize	4	51	N/C	N/C	1,00	9,50
	Honduras	4	67	N/C	N/C	0,50	3,00
	Saint Kitts and Nevis	3	5	N/C	N/C	N/C	6,30
	Dominica	2	82	N/C	N/C	N/C	5,47
	Guatemala	2	21	N/C	N/C	N/C	0,62
	Grenada	2	11	N/C	N/C	N/C	0,64
	Haiti	1	6	N/C	N/C	N/C	0,76
Europe		**16 803**	**126 315**	**1,14**	**1,09**	**1,22**	**1,10**
	United Kingdom	3 801	41 692	1,54	1,25	1,28	1,34
	France	3 126	31 593	1,43	1,20	1,25	1,60
	Germany	2 740	27 080	1,33	1,18	1,32	0,98
	Italy	2 093	16 144	1,18	1,05	1,26	1,25
	Spain	1 912	15 970	1,17	1,11	1,20	1,30
	Norway	1 188	11 046	1,31	1,17	1,33	3,83
	Netherlands	1 069	11 871	1,58	1,22	1,24	1,11
	Russian Federation	787	4 259	0,77	0,69	1,13	0,97
	Portugal	747	5 170	1,10	1,03	1,19	2,09
	Denmark	722	7 939	1,71	1,20	1,34	1,82
	Sweden	659	6 794	1,38	1,22	1,44	1,05
	Belgium	554	5 699	1,36	1,22	1,13	1,02
	Switzerland	544	7 762	1,75	1,26	1,36	0,77
	Greece	506	3 441	1,07	0,94	1,21	1,62
	Finland	367	3 427	1,32	1,18	1,54	1,15
	Poland	345	1 846	0,94	0,84	1,75	0,53
	Ireland	312	2 522	1,26	1,10	1,18	1,49
	Austria	232	2 695	1,56	1,16	1,63	0,62
	Czech Republic	190	1 014	0,94	0,98	1,20	0,52
	Croatia	169	735	0,63	0,83	1,13	1,63
	Romania	157	402	0,58	0,74	1,11	0,54
	Estonia	150	815	0,83	0,93	1,69	3,13
	Hungary	89	461	0,79	0,96	1,38	0,51
	Iceland	86	764	1,31	1,10	1,67	3,46

Table Annex F.9. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Bulgaria	83	330	0,56	0,71	1,11	1,22
	Lithuania	74	360	1,02	0,99	1,80	1,07
	Slovenia	69	434	1,15	1,02	1,21	0,66
	Ukraine	68	243	0,68	0,68	1,48	0,48
	Luxembourg	39	333	N/C	0,99	1,50	1,67
	Slovakia	38	258	N/C	0,90	1,23	0,34
	Serbia	36	157	N/C	0,82	1,58	0,26
	Latvia	27	126	N/C	N/C	3,40	0,91
	Monaco	23	159	N/C	N/C	1,63	11,17
	Malta	22	112	N/C	N/C	3,50	3,69
	Albania	17	28	N/C	N/C	0,44	3,66
	Montenegro	11	30	N/C	N/C	3,50	2,12
	Former Yugoslav Rep. of Macedonia	6	25	N/C	N/C	0,50	0,56
	Belarus	6	13	N/C	N/C	1,00	0,20
	Bosnia and Herzegovina	5	8	N/C	N/C	0,67	0,38
	Rep. of Moldova	2	2	N/C	N/C	N/C	0,27
Asia		**11 357**	**53 332**	**0,76**	**0,84**	**1,40**	**0,75**
	China	5 247	24 608	0,78	0,82	1,48	0,71
	Japan	2 101	13 020	0,90	1,00	1,18	0,93
	India	1 315	5 325	0,61	0,75	1,55	0,89
	Rep. of Korea	972	3 863	0,63	0,86	1,49	0,72
	Turkey	519	2 319	0,71	N/C	0,99	0,74
	Iran	300	1 139	0,66	0,77	1,49	0,46
	Malaysia	300	1 047	0,64	0,73	2,16	0,91
	Israel	207	1 408	0,90	1,16	1,12	0,59
	Thailand	162	764	0,82	0,84	1,54	0,85
	Singapore	158	1 089	1,07	1,05	1,53	0,50
	Saudi Arabia	152	868	0,99	0,90	3,30	0,74
	Indonesia	141	810	1,10	1,01	2,03	2,65
	Viet Nam	98	417	0,81	0,94	1,93	1,84
	Philippines	72	744	1,30	N/C	0,93	2,54
	Pakistan	62	283	0,59	0,71	1,09	0,37
	Bangladesh	54	277	N/C	0,88	1,35	1,30
	United Arab Emirates	49	195	N/C	0,88	2,50	1,15
	Cyprus	42	254	N/C	0,87	1,58	1,44
	Oman	38	194	N/C	0,97	1,58	2,59
	Sri Lanka	29	412	N/C	N/C	1,50	1,83

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Table Annex F.9. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Kuwait	26	116	N/C	N/C	1,25	1,40
	Jordan	23	121	N/C	N/C	0,91	0,70
	Lebanon	15	44	N/C	N/C	3,33	0,54
	Qatar	14	82	N/C	N/C	2,00	0,63
	Syria	11	97	N/C	N/C	0,33	1,33
	Bahrain	9	24	N/C	N/C	1,50	1,94
	Nepal	8	69	N/C	N/C	5,00	0,70
	Armenia	8	15	N/C	N/C	N/C	0,40
	Iraq	7	22	N/C	N/C	0,75	0,42
	Kyrgyzstan	7	88	N/C	N/C	1,50	3,26
	Azerbaijan	6	13	N/C	N/C	1,00	0,45
	Mongolia	6	43	N/C	N/C	1,00	1,18
	Georgia	6	11	N/C	N/C	2,00	0,41
	Cambodia	5	17	N/C	N/C	2,00	1,05
	Yemen	5	69	N/C	N/C	1,50	1,10
	Kazakhstan	5	17	N/C	N/C	0,50	0,32
	Lao People's Dem. Rep.	5	37	N/C	N/C	0,50	1,44
	Uzbekistan	3	1	N/C	N/C	N/C	0,33
	Dem. People's Rep. of Korea	2	30	N/C	N/C	N/C	2,77
	Brunei Darussalam	2	8	N/C	N/C	1,00	0,85
	Afghanistan	1	15	N/C	N/C	N/C	0,83
	Myanmar	1	0	N/C	N/C	N/C	0,59
	Turkmenistan	1	2	N/C	N/C	N/C	2,19
	Maldives	1	1	N/C	N/C	N/C	4,43
Africa		**1 187**	**7 709**	**1,05**	**0,93**	**1,68**	**1,29**
	South Africa	458	4 141	1,40	1,01	1,85	1,66
	Egypt	172	578	0,53	0,71	1,53	0,85
	Tunisia	119	605	0,82	0,85	1,91	1,31
	Kenya	70	638	1,42	1,17	1,55	1,98
	Morocco	60	403	N/C	1,06	1,55	1,31
	Nigeria	59	159	N/C	0,69	1,33	0,97
	Algeria	38	197	N/C	0,93	1,75	0,57
	Senegal	32	252	N/C	0,87	0,86	3,40
	United Rep. of Tanzania	32	206	N/C	1,05	1,45	1,74
	Ghana	26	165	N/C	N/C	0,43	1,64
	Ethiopia	25	216	N/C	N/C	2,17	1,23

Table Annex F.9. *Continued*

Continent	Country	Paper	Citation	ARC	ARIF	GR	SI
	Seychelles	24	235	N/C	N/C	2,33	29,56
	Mozambique	17	238	N/C	N/C	1,60	4,21
	Cameroon	15	81	N/C	N/C	2,33	0,88
	Uganda	15	82	N/C	N/C	1,80	0,74
	Namibia	14	176	N/C	N/C	2,67	4,42
	Zimbabwe	12	59	N/C	N/C	1,25	1,54
	Benin	12	49	N/C	N/C	N/C	1,87
	Madagascar	12	96	N/C	N/C	0,80	2,34
	Côte d'Ivoire	10	10	N/C	N/C	2,00	1,71
	Gabon	9	124	N/C	N/C	2,00	3,05
	Cabo Verde	9	89	N/C	N/C	7,00	21,38
	Zambia	9	38	N/C	N/C	1,33	1,44
	Mauritius	8	37	N/C	N/C	0,75	2,64
	Congo	7	108	N/C	N/C	2,00	2,66
	Malawi	7	29	N/C	N/C	0,33	0,82
	Angola	7	14	N/C	N/C	6,00	6,85
	Libya	6	56	N/C	N/C	0,20	1,10
	Botswana	6	22	N/C	N/C	1,00	1,04
	Mali	6	96	N/C	N/C	0,67	1,53
	Niger	6	92	N/C	N/C	N/C	2,45
	Sudan	5	55	N/C	N/C	0,25	0,58
	Eritrea	5	77	N/C	N/C	1,50	12,96
	Burkina Faso	4	32	N/C	N/C	2,00	0,55
	Swaziland	3	27	N/C	N/C	N/C	2,67
	Mauritania	3	14	N/C	N/C	N/C	4,95
	Dem. Rep. of the Congo	3	20	N/C	N/C	2,00	0,93
	Burundi	2	2	N/C	N/C	N/C	3,47
	Togo	2	8	N/C	N/C	1,00	1,28
	Comoros	1	6	N/C	N/C	N/C	13,30
	Guinea	1	3	N/C	N/C	N/C	1,11
	Guinea-Bissau	1	37	N/C	N/C	N/C	1,30
	Djibouti	1	15	N/C	N/C	N/C	4,54
	Lesotho	1	0	N/C	N/C	N/C	1,52

Note: ARC and ARIF are not computed (N/C) for countries with less than 30 relative citation scores or 30 relative impact factors (see methods tab). The same applies for HCP 1 % and HCP 10 % (these need at least 30 relative impact factors). A growth rate (GR) is not computed when one of the periods (2010–2011 or 2013–2014) contains 0 articles. Colour coding indicates performances above (green) or below (red) the world level.

Source: Computed by Science-Metrix from WoS data (Thomson Reuters)

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Annex G

IODE regional grouping

The regional groupings are based on geographic location. A country can be listed in only one regional group. The list only refers to countries with National Oceanographic Data Centres or Associate Data Units, which are part of the analysis presented in chapter 6.

LATIN AMERICA

Argentina
Barbados
Chile
Colombia
Ecuador
Trinidad and Tobago
Venezuela

EUROPE (INCL. RUSSIAN FEDERATION)

Belgium
Bulgaria
Croatia
Cyprus
Denmark
Estonia
Finland
France
Georgia
Germany
Greece
Iceland
Ireland
Israel
Italy
Netherlands
Spain
Sweden
Russian Federation
Ukraine
UK

AFRICA

Benin
Cameroon
Comoros
Congo
Côte d'Ivoire
Kenya
Madagascar
Mauritania
Mozambique
Nigeria
Senegal
Seychelles
Togo
United Republic of Tanzania

ASIA/PACIFIC

Australia
China
India
(Islamic Republic of) Iran
Japan
Kazakhstan
Malaysia
New Zealand
USAViet Nam

Global Ocean Science Report

The Current Status of Ocean Science around the World

The Global Ocean Science Report (GOSR) assesses for the first time the status and trends in ocean science capacity around the world. The report offers a global record of how, where, and by whom ocean science is conducted: generating knowledge, helping to protect ocean health, and empowering society to support sustainable ocean management in the framework of the United Nations 2030 Agenda.

The GOSR identifies and quantifies the key elements of ocean science at the national, regional and global scales, including workforce, infrastructure and publications. It is the first collective attempt to systematically highlight opportunities as well as capacity gaps to advance international collaboration in ocean science and technology. This report is a resource for policy-makers, academics and other stakeholders seeking to harness the potential of ocean science to address global challenges.

A comprehensive view of ocean science capacities at the national and global levels takes us closer to developing the global ocean science knowledge needed to ensure a healthy, sustainable ocean.

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