# Global Ocean Science Report 2020

## Charting Capacity for Ocean Sustainability

United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental
Oceanographic
Commission

**Sustainable
Development
Goals**

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# Global Ocean Science Report 2020

## Charting Capacity for Ocean Sustainability

UNESCO Publishing

United Nations
Educational, Scientific and
Cultural Organization

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# Foreword


Audrey Azoulay
Director-General of UNESCO

*Oceans are the defining physical feature of Earth*

Long before compasses, sextants and clocks were invented, Polynesian navigators travelled the Pacific Ocean using their knowledge of the winds, waves and stars. By observing the sky, they charted their course through the water. By watching birds and other marine animals, they determined whether land was near. In doing so, they acknowledged the fundamental connection between humans and the sea.

Indeed, oceans are the defining physical feature of Earth, giving it its name as the Blue Planet. They regulate the climate, absorbing up to 90% of excess heat generated by humans. Marine and coastal areas are home to incredible biodiversity, which an estimated 3 billion people depend on for their livelihoods. In other words, oceans are essential, yet our knowledge of them is limited. It is often said that we know more about the surface of the moon than we do about the ocean floor.

This is where ocean science comes in. Ocean science seeks to improve our understanding and knowledge of the ocean and its processes and identify solutions to address climate change and ocean stressors, including marine pollution, ocean acidification and deoxygenation, the loss and shifts of marine species, and the degradation of marine and coastal environments. Ocean science is not just about protecting the ocean; it is also about protecting our planet and our future.

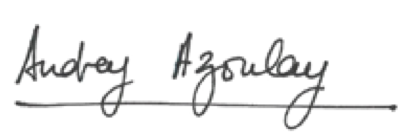
In recent years, the scientific community, along with the international community, has become increasingly aware of these issues. This is reflected in the growing number of publications in this field, which has increased by 179% in 18 years — 89% over the past 12 years, and 28% over the last 6 years. And yet, despite all this, only around 1.7% of total national expenditure on research and development is allocated to ocean science.

Given that a healthy and sustainably managed ocean is necessary to achieve the Sustainable Development Goals, we urgently need to take action. This is why the United Nations General Assembly proclaimed the UN Decade of Ocean Science for Sustainable Development, starting in January 2021, in response to a proposal by UNESCO's Intergovernmental Oceanographic Commission.

Gathering ocean stakeholders worldwide, the 'Ocean Decade' will be a unique opportunity to boost ocean science and services for generations to come. By exploring creative funding mechanisms, it will strengthen partnerships around the world. By improving communication strategies, it will reinforce the uptake of scientific knowledge. By bolstering cutting-edge scientific research and innovative technologies, it will ensure that science responds to the needs of society — without leaving anyone behind.

Because, when it comes to ocean science, considerable differences continue to exist between countries and regions, including in terms of access to facilities and knowledge. The Global Ocean Science Report, the second edition of which you are reading, is therefore an indispensable means of understanding where we are in developing and sharing ocean science capacity. Understanding and action are closely linked — as an honest and objective benchmark, this Report encourages the international community to address existing discrepancies.

Ocean science is a journey — and one we are only just embarking on. Like the navigators of old, we need to pool knowledge, join forces and stay on course, in order to deliver the 'Science We Need for the Ocean We Want'.



# Message
## by the IOC Chairperson and the IOC Executive Secretary



Ariel Troisi
Chairperson of the Intergovernmental Oceanographic Commission of UNESCO

Vladimir Ryabinin
Executive Secretary of the Intergovernmental Oceanographic Commission of UNESCO

*The ocean plays a key role in the achievement of practically all Sustainable Development Goals*

The Statutes of the Intergovernmental Oceanographic Commission (IOC) of UNESCO read: 'the purpose of the Commission is to promote international cooperation and to coordinate programmes in research, services and capacity-building, in order to learn more about the nature and resources of the ocean and coastal areas and to apply that knowledge for the improvement of management, sustainable development, the protection of the marine environment, and the decision-making processes of its Member States'. The GOSR2020 is the most comprehensive and objective, quantitative answer to the question of how IOC is able to fulfil its purpose in 2020, 60 years after its establishment by UNESCO.

The ocean plays a key role in the achievement of practically all Sustainable Development Goals. A consensus is emerging that the future 'ocean that we want' should be one that is managed sustainably based on the best available science; and the GOSR measures such adequacy. Building on the knowledge and lessons learned from the first GOSR edition that saw the light in 2017, this second edition is more robust and more representative in terms of the ability to measure the state of oceanographic infrastructure, human potential and its use. Many estimates published in 2017 were reconfirmed in 2020. One such case that challenges us is a relatively stable estimate indicating that approximately 1.7% of total national expenditure on research and development is currently attributed to ocean science. As Chair and Executive Secretary of IOC, we find this percentage dramatically insufficient. We urge Member States, public and private initiatives to maintain and reinforce ocean science investment! We cannot insist more on the use of the word 'investment' rather than 'expenditure'. Every dollar invested in ocean science has an approximate return rate of five dollars. Intangible benefits accrue in many areas. They make our planet healthier and improve human health, livelihood and wellbeing.

From a historical perspective, ocean science has its origins in human curiosity, the spirit of discovery and a pragmatic interest in some of the ocean's uses. However, at present, the ocean science has become an existentially important factor of sustainability. With this in mind, the IOC proposed to the UN a Decade of Ocean Science for Sustainable Development, starting in 2021.

The proposal was accepted, and the Implementation Plan for the Decade outlines a process of strengthening ocean science and directing it to address the most important challenges of humanity. GOSR2020 is our observation of the initial condition for the Decade, setting the baseline from which we are starting this unique decadal journey. The current status quo is that ocean science is under-resourced on average and that its capacity is distributed unevenly around the world. The science is qualified to sound an alarm on a number of issues but needs to be further strengthened to systematically offer effective solutions to those issues. The Decade gives us a once-in-a-lifetime opportunity to take transformative actions and change conceptual frameworks towards such needed paradigm shift in ocean science, and the GOSR becomes an indispensable tool to strengthen and further develop fundamental synergies and partnerships to address the Decade challenges.

The future GOSR process will be a dynamic one, turning continuously more and more robust, and, hopefully, will both trigger and reflect positive changes in the capacity of ocean science. The GOSR portal will facilitate the submission, updating and completing data for many nations. It will allow regular progress assessments with insights on the efficiency and impact of national, regional and global strategies to build and further develop ocean science capacity.

We cordially invite all ocean stakeholders to read this report, question it if needed, act on the conclusions if you agree with them, and rely on it for a steadfast development of ocean science. We sincerely thank the GOSR leads and authors, contributing Member States, and the IOC Secretariat for this major effort and its good result.

# Preface


Jacqueline Uku,
Co-Chair of the
GOSR2020 Editorial Board


Jan Mees
Co-Chair of the
GOSR2020 Editorial Board

*The Decade is a 'chance in a lifetime' for our Ocean, for its health and biodiversity, and for humankind that depends on its wellbeing and the goods and services it provides*

Dear Reader,

We are proud and excited to present the second edition of the *Global Ocean Science Report*. GOSR2020 is a flagship publication of the IOC, and we consider the current edition to be a milestone in several ways.

Firstly, released only three years after the first edition of 2017, it is fair to say that the series has reached maturity. The production of GOSR2017 was a challenge and a learning process, both for the report team and for the IOC Member States. The former had to advise on content and structure, and organize and synthesize global data and information flows through novel questionnaires and analyses of global databases, while the latter had to set up procedures for collecting and reporting nationwide data. This learning process paid off in the process of making the GOSR2020 we could build on an experienced secretariat and an engaged community, robust materials and methods, an improved questionnaire and helpdesk, and other 'lessons learned'. This resulted in more and better data, including a first opportunity to assess progress through the analysis of time series of data, and fewer data gaps.

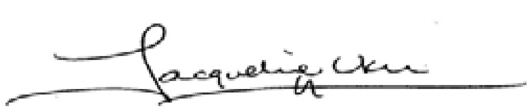
Secondly, the *Global Ocean Science Report* is now demonstrably a flexible instrument. It is not static, but can rather be seen as a 'living' product, that can accommodate new insights and can respond to changing societal and ocean science community needs. While several chapters of GOSR2017 still stand and have not been revisited, GOSR2020 includes important novelties. We specifically refer to the inclusion of an analysis of 'blue' patents capacity development in ocean science, and a chapter on the contribution of ocean science to sustainable development. Similarly, we can already predict that the next edition of the GOSR is very likely to include a chapter on the impact of the COVID-19 pandemic on global ocean science.

This brings us to our third and final point, arguably the most important one: the release of GOSR2020 is very timely, since it is framed around and will feed into the UN Decade of Ocean Science for Sustainable Development (2021-2030). The Decade has been proclaimed in support of the 2030 Agenda and its Sustainable Development Goals (SDGs). The SDG crosscutting target 14.a (IOC has been designated as the custodian agency for the corresponding indicator), focuses on developing adequate capacity in ocean science and specifies the need for increasing scientific knowledge. It is for this indicator — the only one that focuses on ocean science — that GOSR2020 and its underlying portal provides the updated data.

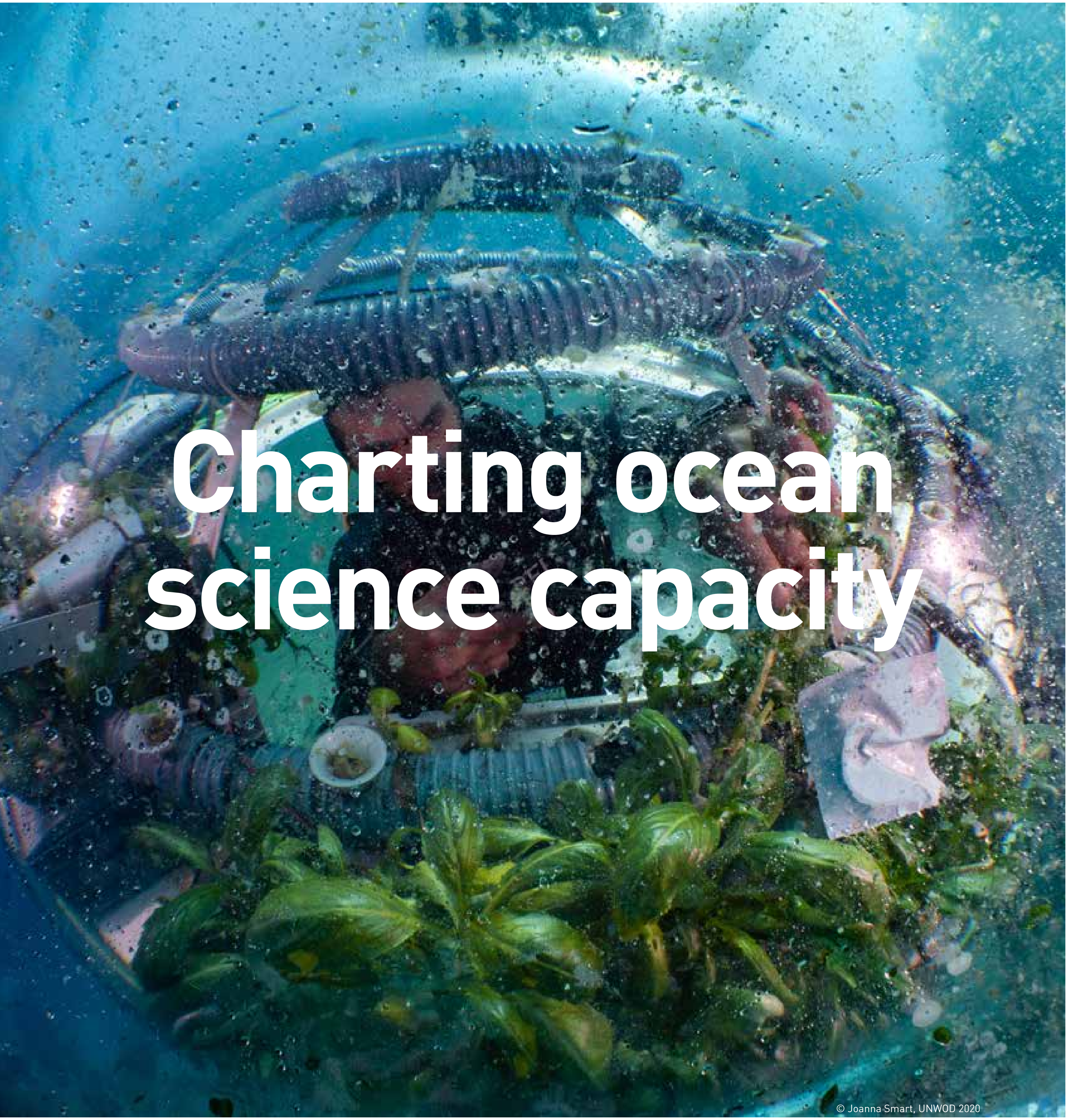
The Decade formally starts on January 1, 2021, and with GOSR2020 we now have the critical updated baseline information on existing human and technical capacity before it begins. This will allow us to monitor and assess progress and — ultimately — the success or failure of the Decade.

The Decade is a 'chance in a lifetime' for our Ocean, for its health and biodiversity, and for humankind that depends on its wellbeing and the goods and services it provides. With the production of GOSR2020, the global ocean research community shows that it stands ready to deliver on the Decade's mission and goals. The Report provides the baseline that will allow us to measure progress in ocean science funding, research capacity, transfer of technology, scientific output and much more. We are confident that we will collectively succeed.

On behalf of the Editorial Board, we want to thank all authors, referees and the Secretariat for their excellent work. And we want to thank you, reader, for taking up the main messages of this report and to use them to advance global ocean science to shape 'the ocean we want'.



# Executive summary



# Charting ocean science capacity

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The *Global Ocean Science Report* (GOSR) is a resource for a wide range of stakeholders, including policymakers and academics, seeking to understand and harness the potential of ocean science for addressing global challenges. The GOSR can inform strategic decisions related to funding for ocean science, reveal opportunities for scientific collaborations and foster partnerships for further developing capacity in ocean science. This capacity is illustrated through a set of eight integrative, interdisciplinary and strategic themes for national and international ocean science strategies and policies:

1. Blue growth (ocean economy)
2. Human health and well-being
3. Marine ecosystems functions and processes
4. Ocean crust and marine geohazards
5. Ocean and climate
6. Ocean health
7. Ocean observation and marine data
8. Ocean technology

A total of 45 countries, responsible for 82% of ocean science publications over the time period 2010–2018, contributed data and information directly to the second edition of the GOSR (GOSR2020). This allowed analyses to be conducted at the global, regional and national scales.

Building on the success of the first edition of the GOSR in 2017, and the broad interest generated by that report, the GOSR2020 addresses four additional topics:

I. Contribution of ocean science to sustainable development
II. Science applications reflected in patents
III. Extended gender analysis in ocean science human resources
IV. Capacity development in ocean science.

The international community has aligned around the UN 2030 Agenda, a blueprint for peace and prosperity for people and the planet, now and into the future, as outlined by the Sustainable Development Goals (SDGs). These 17 goals reflect the shared societal, economic and environmental aspirations of all countries and chart the journey towards a future that is free of poverty and hunger, one that adapts to the impacts of climate change and to the increasing human demand for natural resources. Progress on this journey is reported through SDG targets and indicators. The GOSR is the recognized method and repository of related data to measure progress towards the achievement of SDG target 14.a: '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 (TMT), 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'. Reporting ocean science capacity in a transparent and timely manner is a significant responsibility for IOC-UNESCO, and an opportunity to support and measure progress in capacity development globally.

The ambition of the 2030 Agenda is also evident in the upcoming UN Decade of Ocean Science for Sustainable Development (2021–2030, hereafter 'the Ocean Decade'), where the definition of 'ocean science' encompasses natural and social science disciplines, including interdisciplinary approaches; the technology and infrastructure that supports ocean science; the application of ocean science for societal

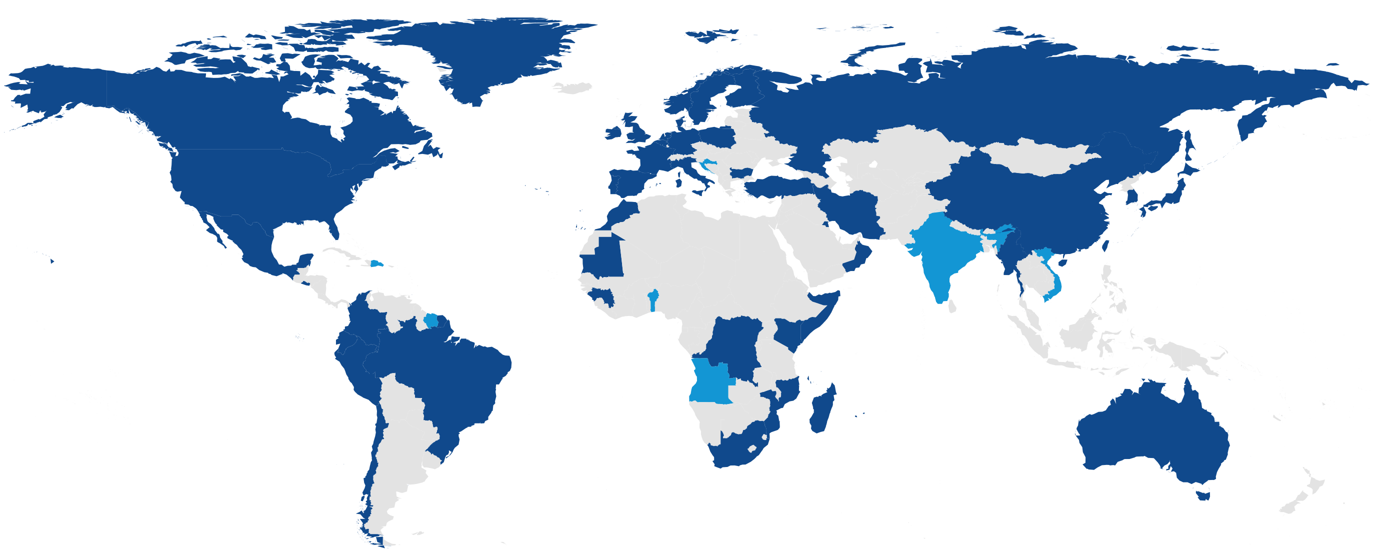

**Figure ES.1.** Global map indicating the Member States that responded to the GOSR2020 questionnaire (dark blue); countries where data from the GOSR2017 are used in the GOSR2020 assessments are shown in light blue. *Sources*: GOSR2017 and GOSR2020 questionnaires.

benefits, including knowledge transfer and applications in regions that are currently lacking science capacity; as well as science-policy and science-innovation interfaces.

There is an increased demand from relevant policy processes for easier access to the findings of ocean science, and for information on ocean science efforts and capacity related to research and observations. This is reflected, for example, in the agreement of the Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) at its 25th session to establish an Ocean and Climate Dialogue under the auspices of the Convention's Subsidiary Body for Scientific and Technological Advice. The data, information and analyses presented in the GOSR can inform the discussions and deliberations of the Parties to the UNFCCC and the 2015 Paris Agreement, as well as other relevant policy forums, including the Convention on Biological Diversity and the process related to an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction.

Data and information presented in the GOSR2020, in future editions of the report and in the new GOSR online portal[1] will form part of the monitoring and evaluation process to track the progress of the Ocean Decade in achieving its vision 'The science we need for the ocean we want', via the objectives, challenges and seven goals outlined in the Ocean Decade Implementation Plan. The baseline information collected and published in the GOSR2020 immediately before the start of Ocean Decade will guide all ocean science actors, support the involvement of all countries in the Ocean Decade and help to remove barriers related to gender, generation and origin for all participants.

[1] See https://gosr.ioc-unesco.org.

# Top findings

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I. The findings of ocean science have direct implications for sustainable development policies and are applied in the management strategies and action plans of multiple societal sectors. They are converted into numerous applications of direct societal benefit, such as the production of new pharmaceuticals and applications in industry; however, their potential remains underused.

II. Despite its relevance to society, funding for ocean science is largely inadequate; this lack of support undermines the ability of ocean science to support the sustainable provision of ocean ecosystem services to humanity.

III. Women in ocean science continue to be under-represented, particularly in the highly technical categories.

IV. Recognition of young ocean scientists, and the level of support offered to them, differs widely among countries. In general, early career ocean scientists and professionals are not appropriately recognized as the intellectual source and workforce that will confront the challenge of ocean sustainability in the next decade and beyond.

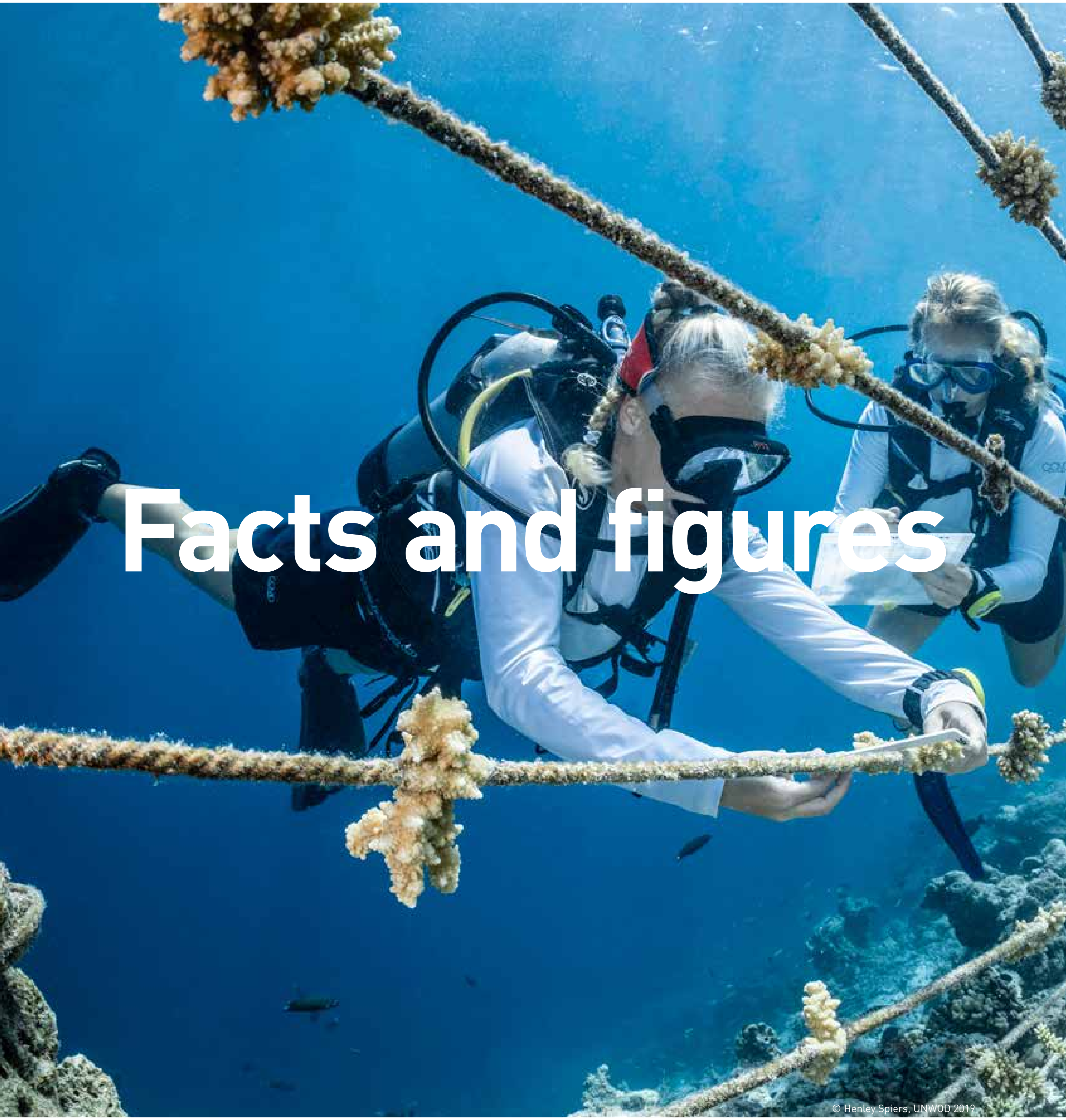
V. The technical capacity of ocean science remains unequally distributed among countries and regions; this imbalance is further accentuated by short-term or ad hoc funding for ocean science.

VI. The number of ocean science publications[2] worldwide continues to increase, especially in countries of Eastern and South-Eastern Asia.

VII. Countries are inadequately equipped to manage their ocean data and information, which hampers open access and data sharing.

VIII. The GOSR process offers a systematic approach to measure ocean science capacity internationally (SDG target 14.a). Similar mechanisms need to be put in place to measure progress towards the achievement of the 2030 Agenda as a whole, and SDG 14 in particular. To date, this has been done in an ad hoc manner; systematic enabling frameworks and strategies are missing in many parts of the world.

[2] 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 considered. In addition, articles that are not written in English, or do not at least have an English abstract, are not included in the database and are therefore not part of this study.

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# Ocean science human capacity

## Ocean science thrives when the people behind it thrive

There is a growing understanding of the critical role of the human component in the ocean science enterprise and in the science-to-management and science-to-innovation value chains. There is also an increased recognition of the important contribution of ocean science to a sustainable blue economy, and to sustainable development in general.

## National numbers of ocean science researchers vary between <1 to >300 employees per million inhabitants — these ratios do not relate directly to GDP

European countries have the highest ratio of researchers as a proportion of the total population. For example, Norway and Portugal have more than 300 employed researchers per million inhabitants (Figure ES.2). However, if measured in relation to the gross domestic product (GDP), the numbers of ocean researchers in some developing countries (e.g. Benin, Guinea, Mauritania and South Africa) are comparable to or even higher than numbers in some developed countries (e.g. Belgium, Denmark, Ireland and Sweden, Figure ES.3).

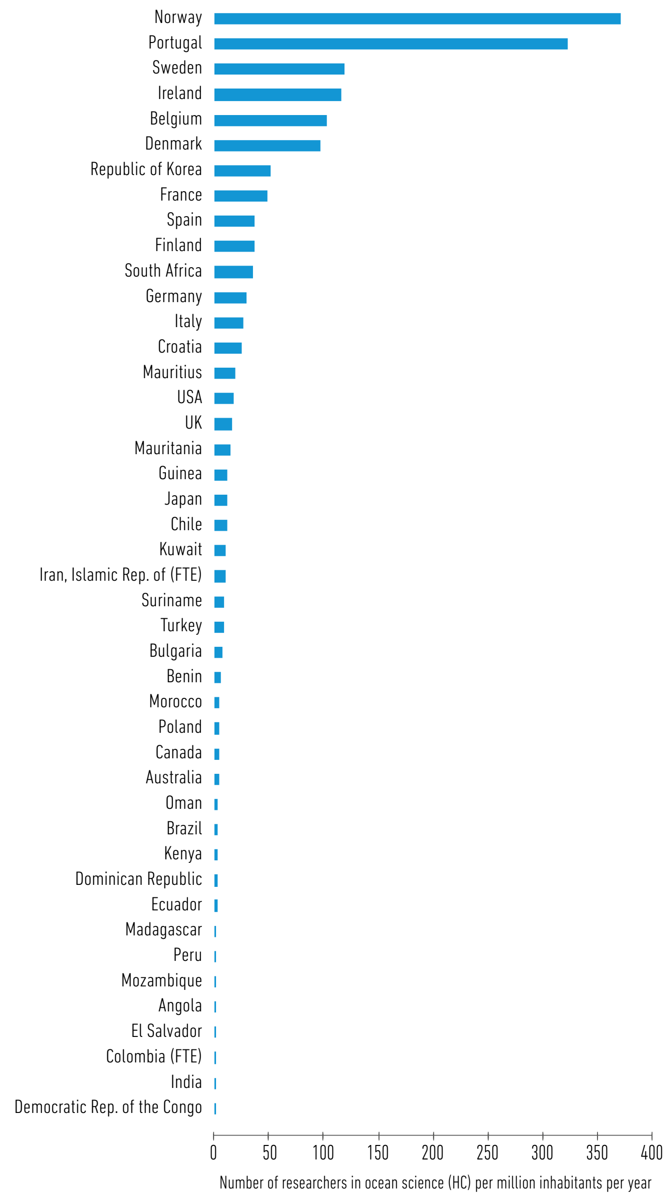



**Figure ES.2.** Number of national ocean science researchers (headcount — HC; full time equivalent — FTE, for the Islamic Republic of Iran and Colombia) employed per million inhabitants. Based on the subset of data presented in Table 4.1. (see GOSR2020 Chapter 4), researchers employed in ocean science per million inhabitants were extracted for the year indicated for each country. *Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires (researchers) and World Bank DataBank (inhabitants).[3]

[3] See https://databank.worldbank.org/source/world-development-indicators (accessed 17 December 2019).

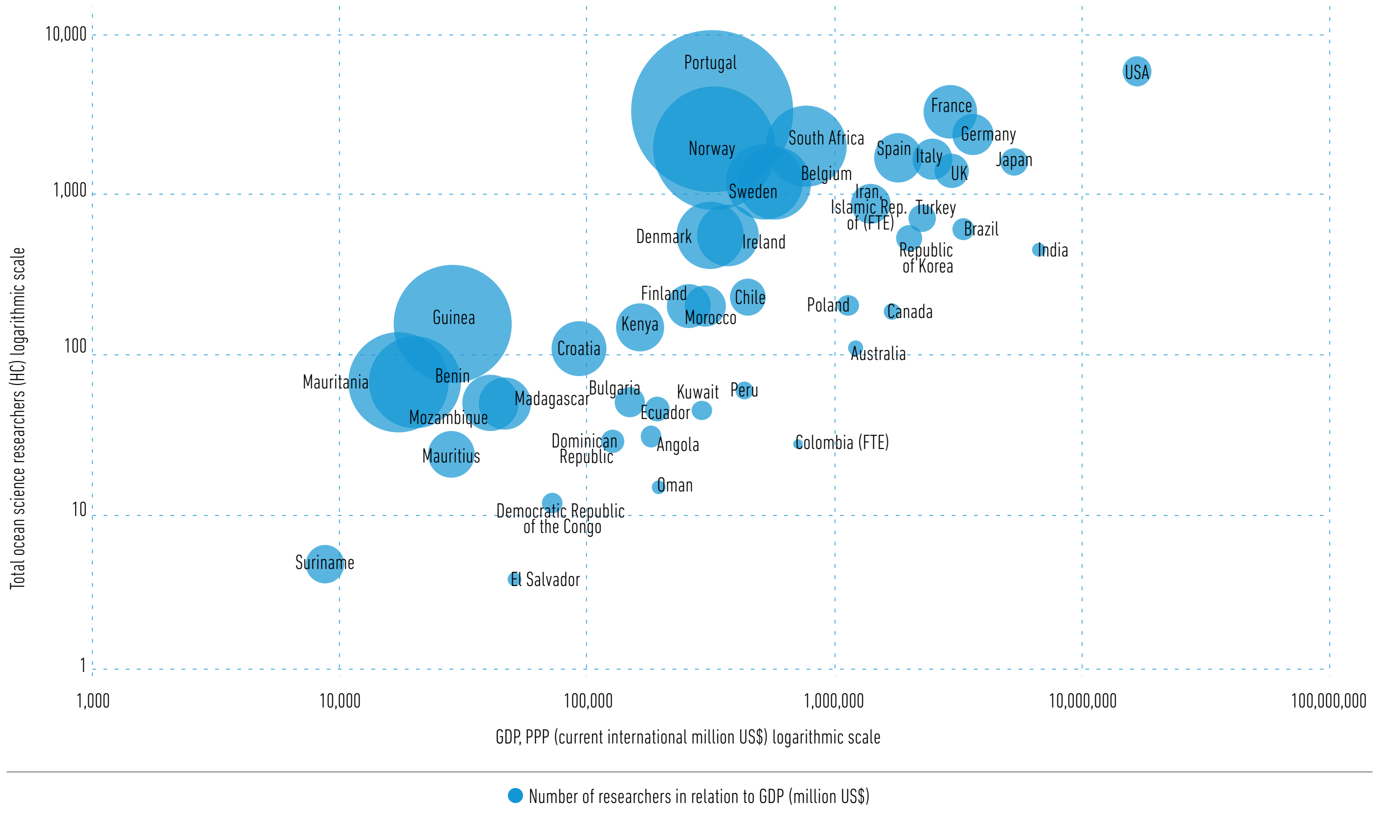



**Figure ES.3.** Number of national ocean science researchers (HC) in relation to the GDP purchasing power parity (PPP) (current million US$) extracted for each country and year. The size of the bubble is proportional to the ratio of researchers vs GDP for each country.
*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires (researchers) and the Global Economic Monitor (GDP, current million US$, seasonal adjustment), available at the World Bank Databank.[4]


[4] See https://databank.worldbank.org/home.aspx (accessed 12 February 2020).

## Gender equality in ocean science is far from having been achieved but the challenge to reach it is realistic

Female ocean science personnel range from about 7% (Democratic Republic of the Congo) to 72% (Ireland) of all ocean science personnel, including researchers and technical support staff in the different countries. The global average stands at 37%. The percentage of female ocean science personnel is equal to or higher than 50 in countries such as Angola, Bulgaria, Croatia, El Salvador, Ireland, Poland and Turkey.

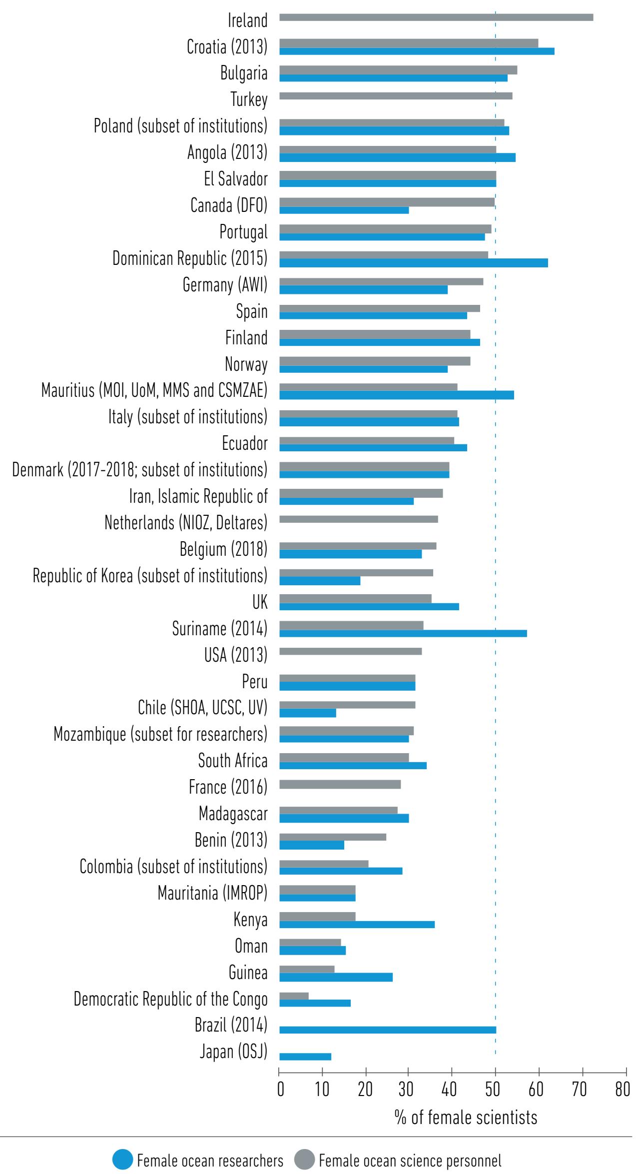



**Figure ES.4.** Proportion (% of total HC) of female ocean science personnel and female ocean researchers in 2017. In the absence of data for 2017, the latest available year is shown in brackets (see Chapter 4).
*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires.

## Female researchers account for 39% of global ocean scientists, 10% higher than the global share of female researchers in natural sciences

The percentage of female researchers in ocean science ranges from about 12% (Japan) to more than 63% (Croatia). In Angola, Brazil, Bulgaria, Croatia, Dominican Republic, El Salvador, Mauritius, Poland and Suriname, 50% or more of ocean science researchers are women (Figure ES.4). On average, 38.6% of total ocean science researchers are female — a similar level to that reported in 2017 (38%) and one which remains 10% higher than the global share of female researchers in natural sciences.

## Female ocean scientists are increasingly talking to the world

Participation of female scientists in international conferences is another indicator used to assess the involvement of women in ocean science. Female participants account for 29% to 53% of total conference participants, depending on science category and region (Figure ES.5). Compared to the assessment presented in the GOSR in 2017, the number of female participants per category and per region is higher in the GOSR2020 analysis.

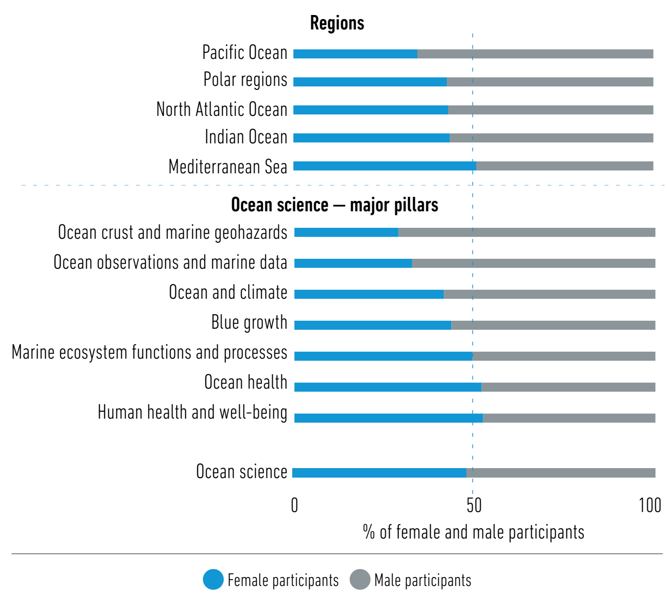



**Figure ES.5.** Proportion (%) of female and male participants at international scientific conferences/symposia held from 2015 to 2018. Upper section focuses on regional conferences/symposia; lower section on topic-specific conferences/symposia.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2015 to 2018.

## Ocean science needs to become younger to open the door for truly innovative transformative solutions

It is important to promote early career scientist networks in the field of ocean science and to facilitate the involvement of young scientists in determining research priorities. To date, only a few countries, developing countries in particular, reported a relatively young community of researchers. Madagascar, for example, reported that more than 50% of their ocean researchers are younger than 34 years. At the same time, Canada, Finland, Italy, Japan and Oman reported that more than 50% of their ocean science researchers are over 45 years old.

## Country of origin defines early career scientists' access to international forums

Students from different parts of the world have unequal access to international exchange programmes, e.g. for participation in international conferences. Students from Europe and Northern America account for 69% of the total number of students globally attending ocean science conferences (Figure ES.6).

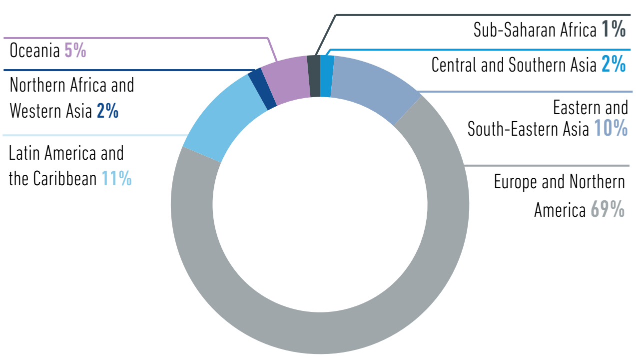



**Figure ES.6.** Proportion (%) of students per region attending international conferences/symposia, excluding regional conferences from the Pacific Ocean.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2011 to 2018.

# Ocean science generates both knowledge and applications

## Global ocean science outputs are continuously rising (with regional differences emerging)

There has been an increase in the number of peer-reviewed ocean science publications, both in absolute and relative terms, in most SDG regions over the past 18 years (Figure ES.7). The most obvious change has been a 10% increase in output from the Eastern and South-Eastern Asia region, largely driven by China, and to a lesser extent by Japan and the Republic of Korea. The publication output in Europe and Northern America did not increase to the same extent, resulting in a relative reduction of its contribution to overall science publications by ~17%, from roughly two-thirds to one-half (Figure ES.8).

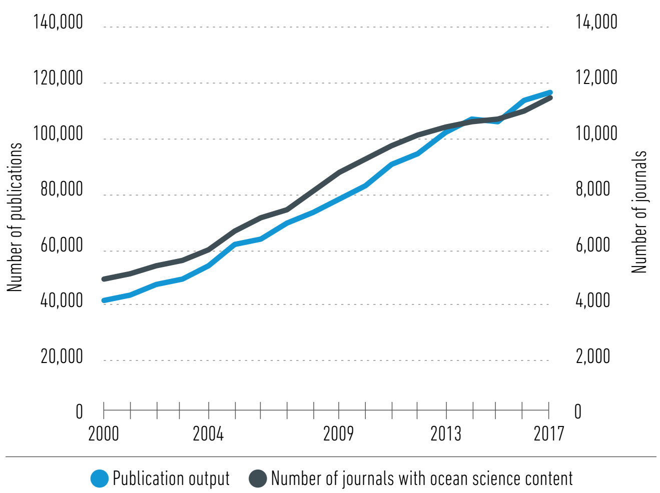



Figure ES.7. Global yearly trend in number of peer-reviewed ocean science publications (blue) and number of journals with content in ocean science (black) between 2000 and 2017.
*Source:* Authors Chapter 5, based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

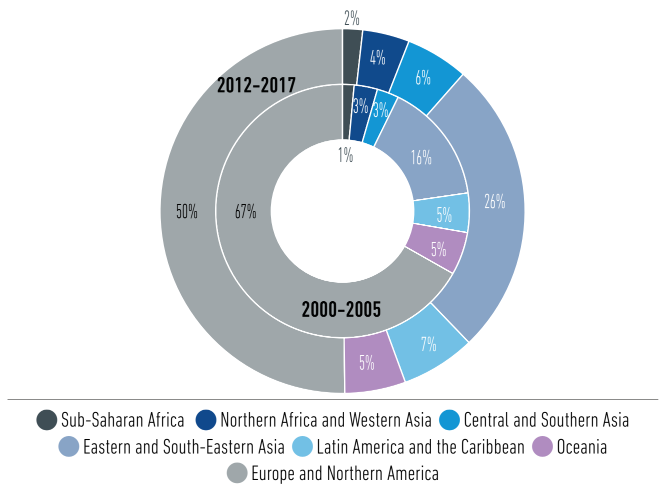



Figure ES.8. Changes in the proportion of global publication output by SDG regions from two different periods: 2000–2005 and 2012–2017.
*Source:* Authors Chapter 5, based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

## Competitive ocean science is driven by international partnerships

In the period 2012–2017, 61% of the papers published by ocean scientists globally had at least one co-author from a foreign country, compared with approximately 56% from 2006 to 2011 and 52% from 2000 to 2005 (Figure ES.9). Increased collaboration among scientists from different countries is a sustained trend and should be seen as a very valuable and positive development.

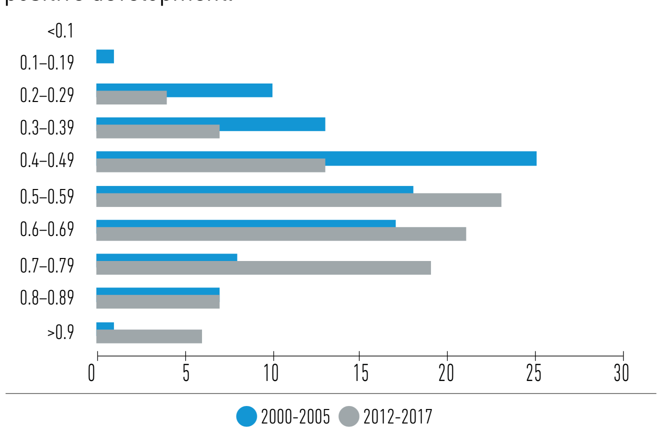



Figure ES.9. Changes in international co-publication rate of the 100 most publishing countries during the periods 2000–2005 and 2012–2017.
*Source:* Authors Chapter 5, based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

## International collaboration results in a higher quality of work

A positive correlation between the average relative impact factor of the publication and the international co-publication rate is reconfirmed (Figure ES.10).

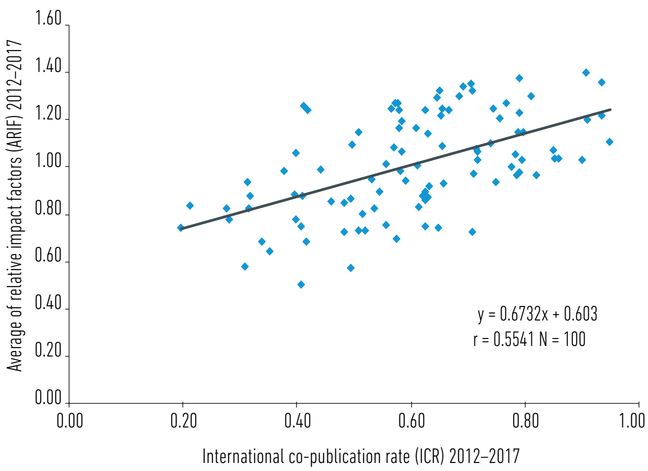



**Figure ES.10.** Comparison of ICR and average of relative impact factors (ARIF) of the ocean science community and ocean practitioners.
*Source:* Authors Chapter 5, based on the bibliometric analysis of Scopus (Elsevier) data 2012–2017 by Science-Metrix/Relx Canada.

## Ocean science findings are converted into applications for society

'Technologies' or 'Applications for mitigation' or 'Adaptation to climate change' are the most frequent ocean science-related technologies in the Cooperative Patent Classification (CPC) (Figure ES.11). This reflects the increasing recognition of the ocean's role in regulating the climate and the negative impact of anthropogenic change on ocean health. Ocean science discoveries feed into nearly all sectors of the economy.

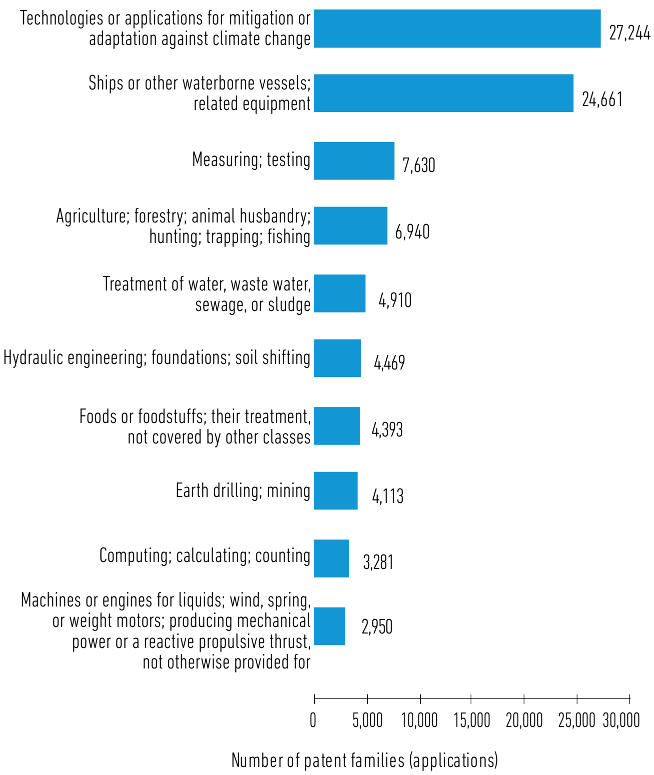



**Figure ES.11.** Top ten most frequent CPC technical field classes in the total number of ocean science patent families (applications) using fractional counts.
*Source:* Based on the technometric analysis of 2000–2018 data provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the China National Intellectual Property Administration by Science-Metrix/Relx Canada.

# Ocean science in support of sustainable development and management of ocean resources

## National priorities and needs guide the focus of ocean science

Nations continue to specialize in particular areas of research reflecting their priorities; these patterns remain consistent over time among the eight considered main ocean science categories (Figure ES.12).

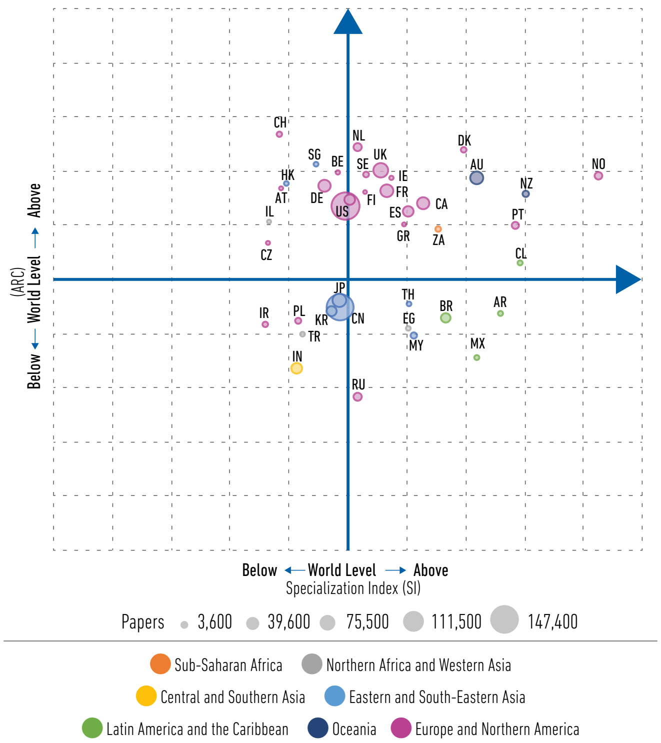



**Figure ES.12.** Positional analysis for the 40 countries included in the comparison group for ocean science output for the period 2012–2017. This analysis combines three separate indicators: the number of peer-reviewed ocean science publications, the specialization index (SI) and the average relative citation score (ARC). The size of the bubble is proportional to the number of publications for that country over the study period. Abbreviations: Argentina (AR), Australia (AU), Austria (AT), Belgium (BE), Brazil (BR), Canada (CA), Chile (CL), China (CN), China Hong Kong SAR (HK), Czechia (CZ), Denmark (DK), Egypt (EG), Finland (FI), France (FR), Germany (DE), Greece (GR), India (IN), Iran (Islamic Republic of) (IR), Ireland (IE), Israel (IL), Italy (IT), Japan (JP), Malaysia (MY), Mexico (MX), Netherlands (NL), New Zealand (NZ), Norway (NO), Poland (PL), Portugal (PT), Republic of Korea (KR), Russian Federation (RU), Singapore (SG), South Africa (ZA), Spain (ES), Sweden (SE), Switzerland (CH), Thailand (TH), Turkey (TR), United Kingdom of Great Britain and Northern Ireland (GB), United States of America (US).
*Source:* Based on the bibliometric analysis of Scopus (Elsevier) data 2012–2017 by Science-Metrix/Relx Canada.

## Sustainable development is not possible without ocean science

The ocean represents the largest biome on the globe. It provides essential resources supporting human nutrition, health and recreation, and is part of the cultural identity of many coastal communities. Hence, by working towards the achievement of SDG 14, nations also profoundly contribute to attaining all other SDGs.

## Many countries lack a specific strategy to measure progress towards the achievement of SDG 14

Of the 37 countries that responded to the related GOSR2020 question, over 70% have strategies and a roadmap to achieve the goals of the 2030 Agenda. However, only 21% reported that they have a specific strategy focusing on the ocean and SDG 14 (Figure ES.13).

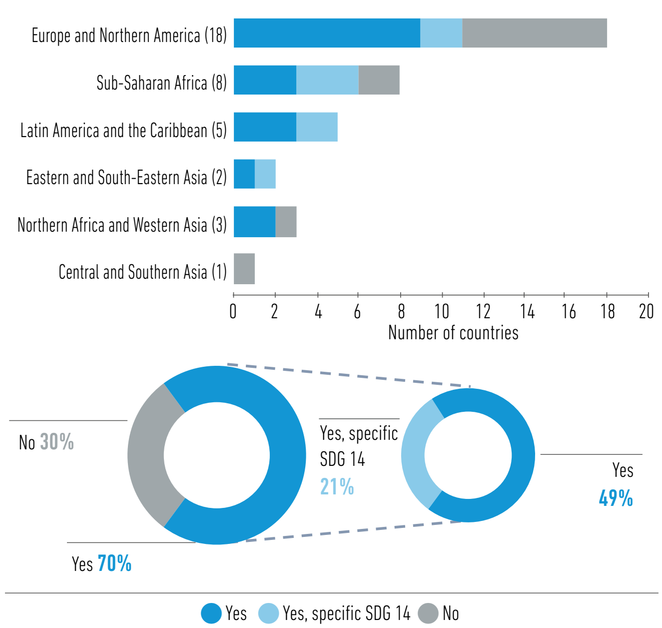



**Figure ES.13.** Distribution of countries that reported to have a national strategy to achieve the 2030 Agenda ('Yes') and/or SDG 14 within the different regional groups and globally, or not.
*Source:* Data based on the GOSR2020 questionnaire.

## Preparedness for reporting towards the achievement of the different SDG 14 targets varies both among regions and targets

Of the respondents, 25 countries confirmed that they have reporting mechanisms in place for the individual SDG 14 targets and indicators (Figure ES.14).

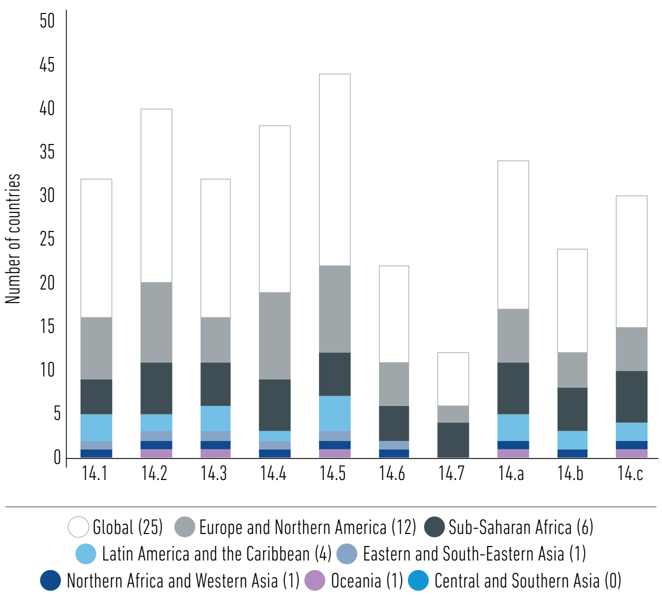



**Figure ES.14.** Number of countries with reporting mechanisms addressing the different SDG 14 targets in the different SDG regions. *Source:* Data based on the GOSR2020 questionnaire.

# Ocean data and information management

## Capacity and infrastructure supporting the management of ocean data and information do not exist in every country but ocean data and information services already support diverse users

Globally, only 57 countries have a designated national oceanographic data centre. The top four services the centres offer to clients are: (i) metadata and data archival; (ii) access to documented methods, standards and guidelines; (iii) data visualization; and (iv) web services (Figure ES.15). The clients and end users of data, products or services represent many sectors of society, reflecting the broad relevance of oceanographic data and information to the economy, research, public administration and, in particular, to businesses. The dominant users of data, products or services are the national and international science communities, students and the private sector, as well as the general public and policymakers.

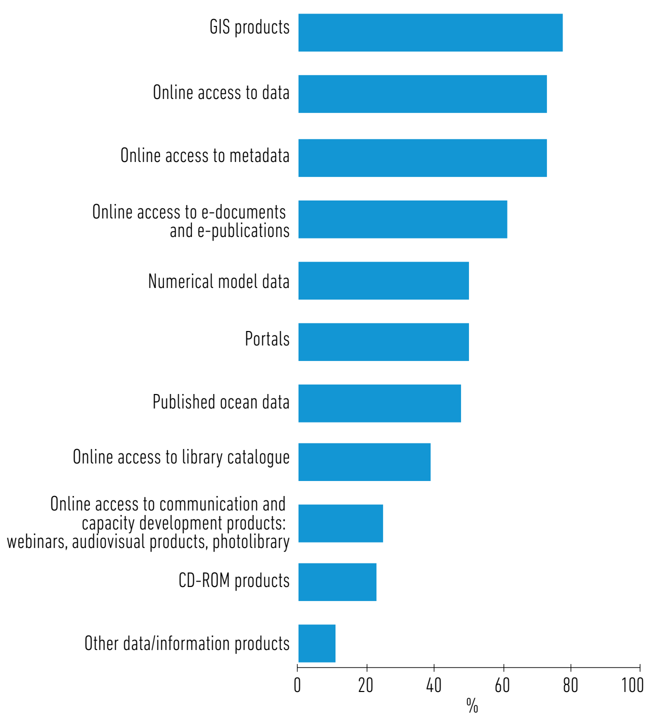



**Figure ES.15.** Proportion (%) of data/information products and services provided by countries' data centre(s) to their clients (multiple answers possible, 44 submissions).
*Source:* Data based on the GOSR2020 questionnaire.

## Ocean data tend to be recognized as a common good; however, open access to ocean data is still far from being the norm

Data sharing and open access ensure that a variety of societal groups have access to data, data products and services. More than 80% of the countries apply institutional, national or international data-sharing policies. 74% of data centres have established relationships to exchange part of their data and information with other international data systems. This percentage varies greatly among the regions. In Europe and Northern America, for example, more than 90% of data centres have this kind of exchange, while in Latin America and the Caribbean fewer than 50% do (Figure ES.16). While countries reported that 58% of ocean data centres comply with the FAIR principles (Findability, Accessibility, Interoperability and Reusability), 60% of data centres still restrict access to 'certain' data types and 58% of them do so for a certain period of time. Only 16% of data centres apply no restrictions at all to data access (Figure ES.17).

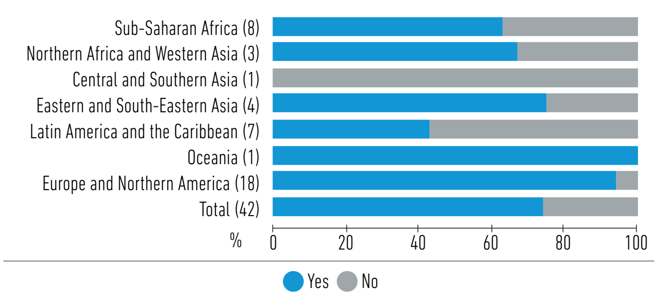



**Figure ES.16.** Percentage of countries' data centre(s) contributing data and information to international systems such as ICS World Data System, GDACs, WMO Global Telecommunication System (GTS) and others (42 submissions).
*Source:* GOSR2020 questionnaire.

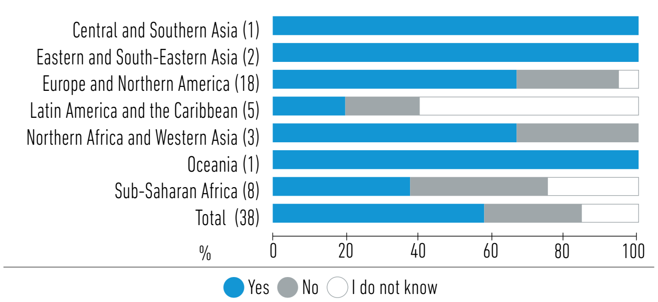



**Figure ES.17.** Compliance of national data centre(s) with the FAIR data management criteria (percentages based on 38 submissions).
*Source:* GOSR2020 questionnaire.

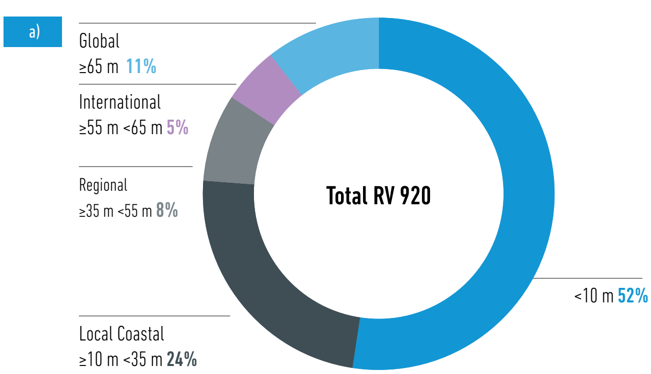
# Transfer of marine technology and investments in ocean science

## Access to technical infrastructure required for ocean science remains unequally distributed

Information about specific technical equipment used for ocean science was provided by 42 countries. Full access to a wide range of technical infrastructure is reported by five countries from the Northern Hemisphere: USA, Germany, Norway, Japan and Canada. Countries in the southern hemisphere only have limited access to ocean science technologies and infrastructure.

## Access to the open ocean is not a given

A total number of 1,081 vessels serve ocean science, comprised of 924 research vessels almost exclusively used for ocean science and 157 ships of opportunity. More than a third of this global research fleet is maintained by the USA. Based on information obtained for 920 research vessels, local and coastal research is the primary purpose of 24% of these research vessels in 35 countries, 8% of the vessels operate at regional, 5% at international and 11% at global scale (Figure ES.18). Vessels plying globally are retained by 23 countries.



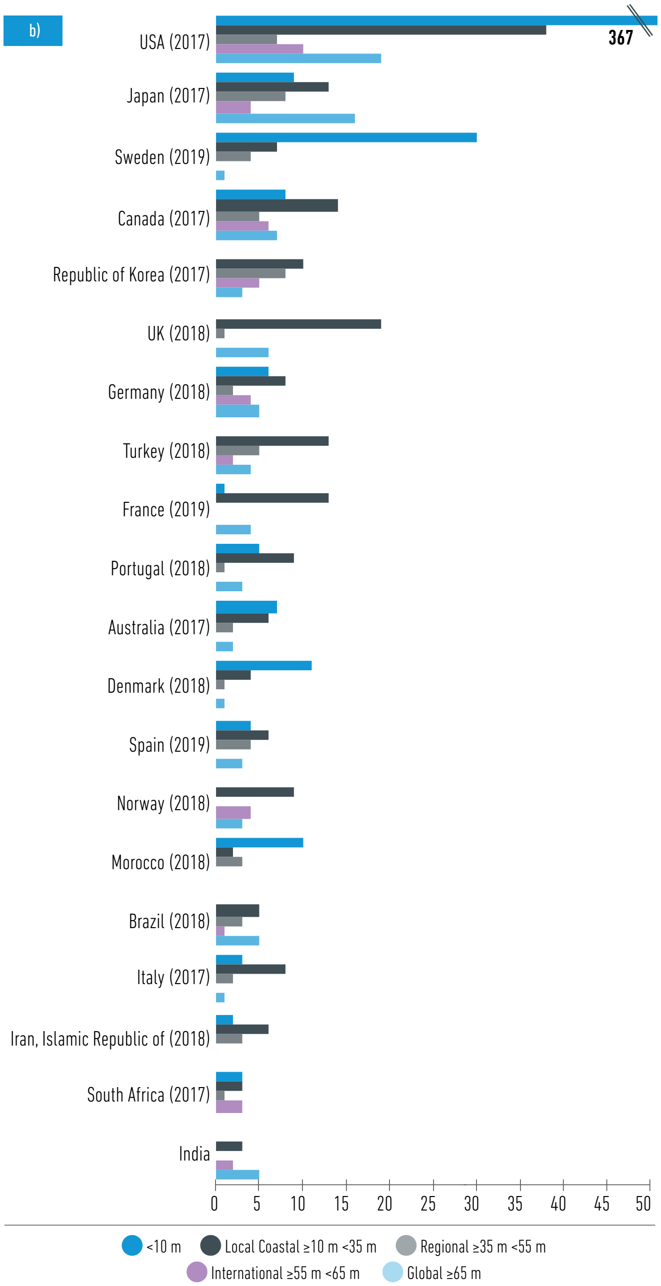
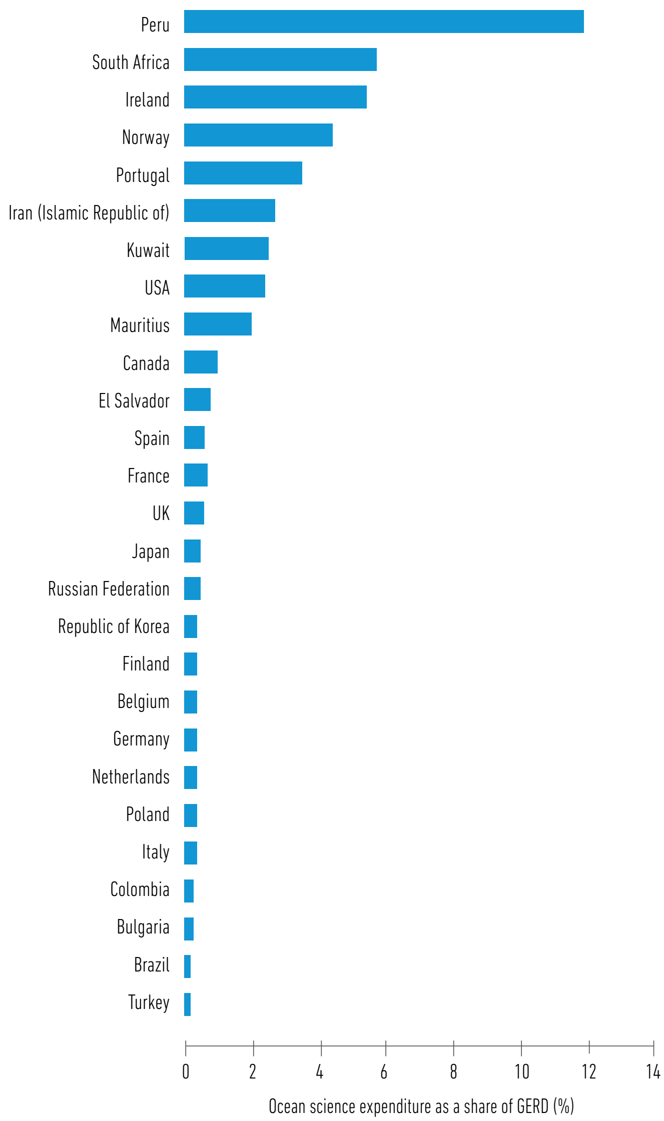




**Figure ES.18.** Number of nationally maintained RVs (a), classified by ship size. Detailed information is provided for the top 20 countries only (b). *Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires.

## There are large differences in countries' investment in ocean research

Overall, the portion of gross domestic expenditure on research and development (GERD) devoted to ocean science is noticeably smaller than for other major fields of research and innovation. On average, only 1.7% of national research budgets are allocated for ocean science, with percentages ranging from around 0.03% to 11.8% (Figure ES.19). This is a small proportion compared to the modestly estimated US$1.5 trillion contribution of the ocean to the global economy in 2010. Some countries are 'punching above their weight' in the field of ocean science, as they allocate a large proportion of their GERD to ocean science, despite having very low overall GERD.



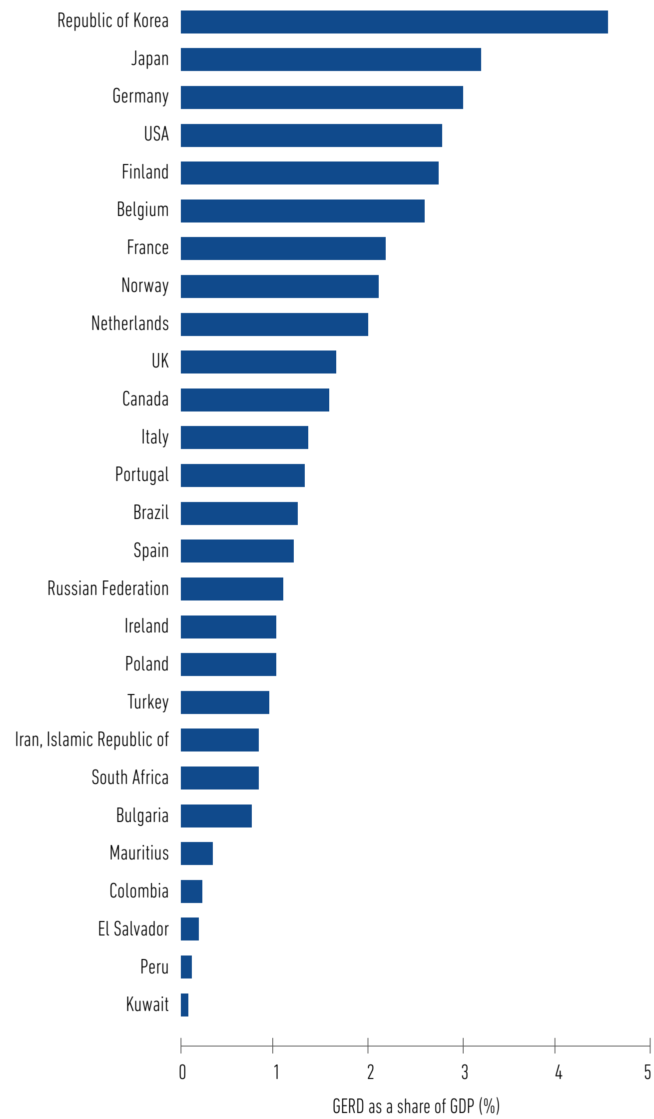




**Figure ES.19.** Estimates of ocean science funding as a share of GERD and GERD as a share of GDP in 2017.
*Sources:* Data adapted from GOSR2020 questionnaire and UNESCO Institute for Statistics database. Note that ocean science funding is not identified as such in GERD data and can be found in natural sciences and other categories.[5]

[5] The latest available data for Peru, Portugal and the USA are from 2016. The earliest available data for Iran (Islamic Republic of) and Portugal are from 2014. The latest available GERD data for South Africa are from 2016.

## Maintenance and improvement of technical and human capacity in ocean science is at risk

Ocean science budgets vary significantly among countries and over time. Based on the datasets received, 14 countries increased their average budgets between estimates for years 2013 and 2017 (the Russian Federation had the highest annual growth rate, peaking at 10.4%, followed by the UK and Bulgaria), while 9 have reduced their budgets, in some cases quite markedly (particularly Japan, Ecuador, Turkey, Brazil and Italy) (Figure ES.20).

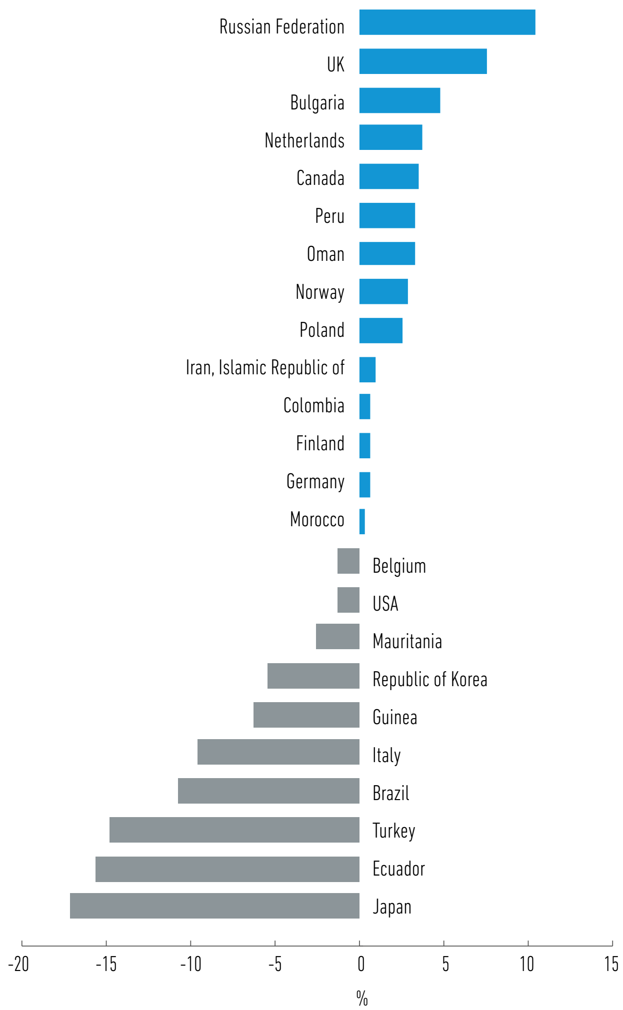



**Figure ES.20.** Change in % in ocean science expenditure over time based on average annual change of ocean science expenditure in local currency, at constant prices (2010=100), from 2013 to 2017. *Sources:* Data adapted from the GOSR2020 questionnaire and the International Monetary Fund's International Financial Statistics Database.[6]

## Funding for ocean science no longer lies exclusively with governments

The sources of funding for ocean science have diversified over the years and today they include national administrations, international programmes, the private sector, foundations and philanthropic organizations. Although the majority of funding for ocean science will certainly remain institutional, private foundations and donors could play a larger role in the funding of small- and large-scale ocean science projects during the next decade. Like other scientific domains, ocean science is also starting to benefit from innovative funding mechanisms. These include transdisciplinary research funds, crowdfunding, lotteries and levies.

## International cooperation in ocean science is encouraged by multiple strategies

Partnerships across countries and different sectors are recognized as a key strategy for more effective resource use and increased participation in ocean science, reinforcing its application in policy. Multiple measures are being put in place to encourage the strengthening of international cooperation and exchange, such as financial and in-kind support to facilitate international board memberships, exchange programmes, advisory positions in national and regional bodies, as well as guest researcher positions in the academic sector.

[6] The latest available data for Peru, Portugal and the USA are from 2016. The earliest available data for Iran (Islamic Republic of) and Portugal are from 2014.

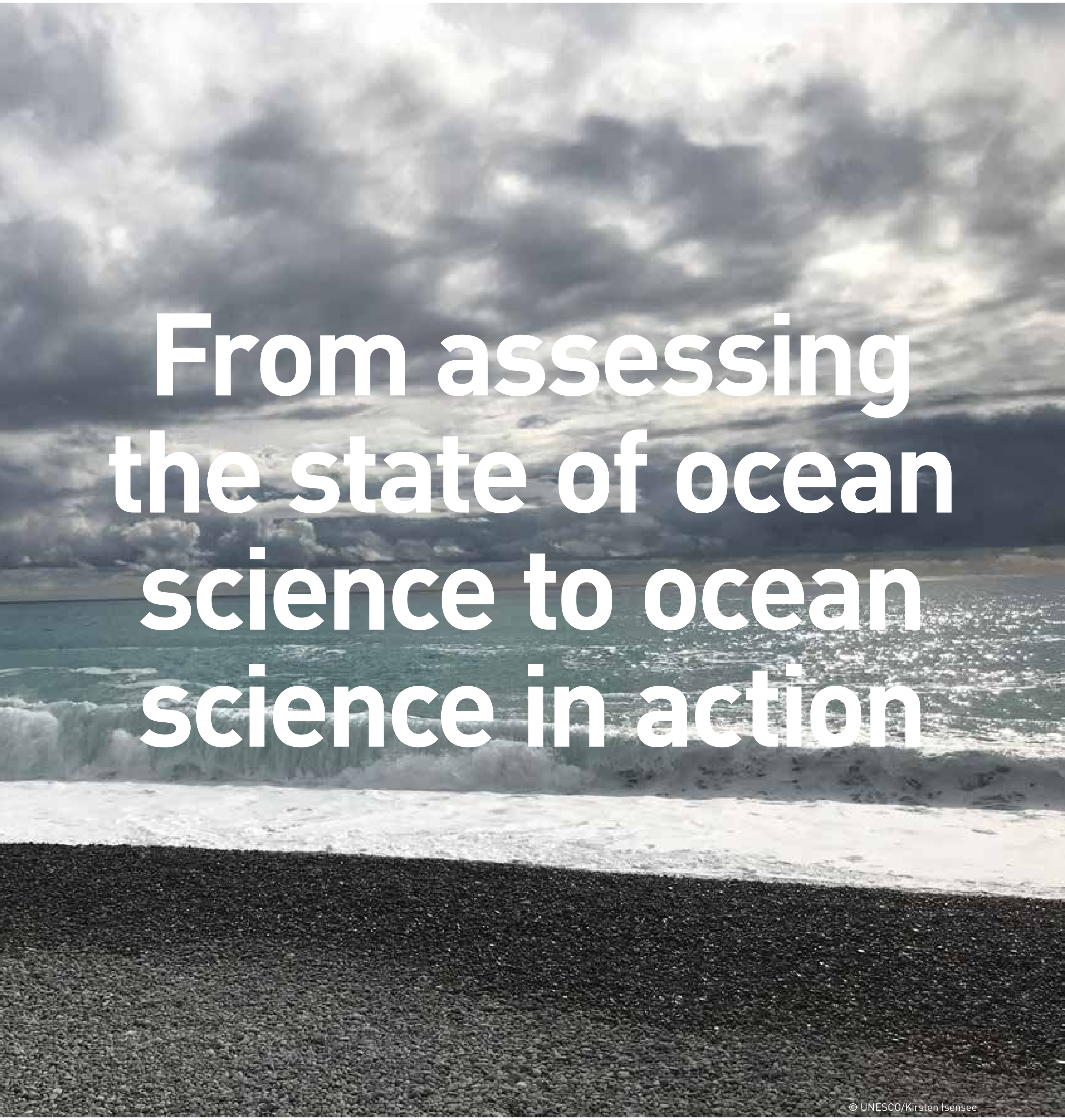
# Potential impact of COVID-19 on ocean science

## Ocean observations are negatively impacted by the COVID-19 pandemic

The immediate impact of COVID-19 on ocean observations during the first half of 2020 has been dramatic. Almost all research vessels have been called to their home ports. Almost all work to maintain vital mooring arrays that monitor major ocean currents and air-sea exchange has been cancelled. A number of arrays are therefore at risk of failure in the coming months. In June 2020, this situation affected between 30–50% of the 300+ moorings. Some of them had already ceased to send data as batteries ran out. However, up to June 2020, the global observation system showed some resilience, due to its inherent inertia, use of autonomous observing platforms, a well-maintained base and the swift mitigation actions of many observing system operators. However, the system will not stay this way indefinitely and if current trends continue, recent assessments have led to serious concerns with regard to the outlook for the second half of 2020 and the first half of 2021.

## The impact of the COVID-19 pandemic on ocean science at large is still unknown

Evaluating the impacts of COVID-19 on ocean research requires a different approach than the way in which impacts on ocean observations have been assessed and described to date. The data contained in the GOSR2020 are pre-COVID-19. The next edition of the report will aim to measure the full impact of the pandemic on ocean science infrastructure, human and technical capacities, core funding, investment by the private sector, scientific output, conferences, observations, trends in R&D, employment and the gender dimension of ocean science.


From assessing the state of ocean science to ocean science in action

**The 2030 Agenda for Sustainable Development, the targets of SDG 14 and the desired outcomes of the UN Decade of Ocean Science for Sustainable Development (2021–2030)[7] require collaborative efforts by all stakeholders in ocean science. To turn the vision of the Ocean Decade — 'The science we need for the ocean we want' — into reality, the GOSR2020 calls for the following actions by governments, organizations, scientists, philanthropy, the private sector and civil society:**

## 1. Enhance the current level of funding for ocean science

Overall, funding for ocean science is insufficient to fill existing knowledge gaps and deliver the information required for decisions, tools and solutions leading to a sustainable ocean (SDG 14). During the Ocean Decade, funding mechanisms at all levels, from government to institutions, philanthropy and corporations, are urged to accord explicit priority to ocean science and to seek better alignment between strategic funding initiatives.

## 2. Establish continuous collection of internationally comparable data on investments in ocean science

Monitoring of ocean science investments will be instrumental to identify their multiple socio-economic returns at the national, regional and global scale. Appropriate and regularly updated indicators, as defined in the GOSR, will also contribute to tracking ocean science capacity development internationally.

## 3. Facilitate co-design of ocean science by involving ocean science information users and producers

Co-design of science is necessary to identify challenges and opportunities for action in support of ocean sustainability. It should involve not only representatives of governmental institutions, national and international policy frameworks, but also private foundation donors, and users and producers of ocean science products. The Ocean Decade can serve as the platform for ocean science co-design.

[7] Implementation Plan for the United Nations Decade of Ocean Science for Sustainable Development Version 2 available at: https://oceanexpert.org/document/27347.

## 4. Promote multistakeholder partnerships in ocean science and operationalize transfer of marine technology

Partnerships, South-South and North-South in particular, and broad cross-sectoral cooperation should be promoted as vehicles to improve marine research capacities, and to optimize research infrastructure and human potential. TMT and innovation play a fundamental role in supporting developing countries to sustainably exploit the ocean and associated resources. Leaders in ocean science are urged to help operationalize the provisions of the UN Convention on the Law of the Sea with regard to capacity development and TMT.

## 5. Move towards ocean science capacity development with the equal participation of all countries, genders and ages, embracing local and indigenous knowledge

Ocean science capacity development should be governed by the principle of 'leaving no one behind', to be understood as providing equal opportunities for all countries, genders and age groups, and embracing local and indigenous knowledge. It should rely on ocean science best practices and follow community-approved guidelines, taking into account specificities at the national and regional level and corresponding jurisdictions.

## 6. Develop strategies and implementation plans to support the career needs of women and young scientists

Collaborative strategies that fully account for the gender and intergenerational dimensions of ocean science need to be developed and implemented to address the specific career needs of women and young scientists. In turn, the views of these critical stakeholders will be paramount for co-designing ocean science that is capable of supporting sustainable development and serving society.

## 7. Find solutions to remove barriers for open access to ocean data

Access to data is one of the starting elements of the ocean science value chain, which culminates in creating the capacity to inform decisions, ensuring long-term sustainability of the ocean. Therefore, two of the key transformations to be pursued during the upcoming Ocean Decade should be identifying and mainstreaming incentives for open data access. There is a need to change the view of ocean data by recognizing it as common good.

### 8. Foster education and training in professions related to ocean sciences

The world will need more professionals in the various fields of ocean management, for example in ocean data and information management, an area of expertise where there is currently no formal education. Increased support for education and training in all domains of ocean affairs therefore needs to be provided.

### 9. Assess the impact of the COVID-19 pandemic on human and technical capacity in ocean science

Possible temporary and longer-lasting impacts of the COVID-19 pandemic on the international ocean research and observations should be assessed. The data contained in the GOSR2020 reflects the pre-COVID-19 era, while the next edition of the report will examine the impact of the pandemic on ocean science, including core funding, investments by the private sector, scientific production, conferences, observations, trends in R&D, employment and the gender dimension of ocean science. An intermediary study will therefore be undertaken starting in 2021, based on the GOSR2020 approach, to reflect the specificity of the COVID-19 pandemic, relying on tailor-made variables and indicators. Cooperation and input to that study will be requested.

**The next edition of the GOSR is expected to be published in 2025, halfway through the Ocean Decade. The continuously improved data collection and updated information submitted to the GOSR portal will make future analyses more robust. It will enable the accurate measurement of how ocean science capacity contributes towards the goals of the 2030 Agenda, help to gauge the effectiveness and efficiency of ocean science and to find innovative and transformative ways of directing growing investment towards fulfilling the emerging needs of society.**

# 1

# Introduction

© Jong Moon Choi

# 1. Introduction

***Jacqueline Uku, Jan Mees, Salvatore Aricò***

Uku, J., Mees, J. and Aricò, S. 2020. Introduction. IOC-UNESCO, *Global Ocean Science Report 2020–Charting Capacity for Ocean Sustainability*. K. Isensee (ed.), Paris, UNESCO Publishing, pp 45-50.

## 1.1. The importance of ocean science and how to measure related capacity

In 1967, at the 22nd session of the General Assembly of the United Nations, Ambassador Arvid Pardo of Malta gave a powerful and moving statement on the critical role of the oceans for human life and prosperity, the need to protect the world's oceans and the obligation to do so in the context of international law, specifically the law of the sea.[1] More than half a century later, intergovernmental recognition of the ocean's crucial role in human well-being is still linked to Ambassador Pardo's statement. In 2017, the General Assembly of the United Nations proclaimed the United Nations Decade of Ocean Science for Sustainable Development (the 'Ocean Decade') for the ten-year period beginning on 1 January 2021.

Further, Principle 9 of the Rio Declaration on Environment and Development reads:

> *States should cooperate to strengthen endogenous capacity-building for sustainable development by improving scientific understanding through exchanges of scientific and technological knowledge, and by enhancing the development, adaptation, diffusion and transfer of technologies, including new and innovative technologies (United Nations, 1992).*

The recognition of the contribution of science and related capacity to the quest for sustainable development remains valid, 28 years after the adoption of the 1992 Rio Declaration. In *The Future We Want* — the outcome document of the United Nations Conference on Sustainable Development (United Nations, 2012) — heads of state and government and high-level representatives declared:

> *We engage in our countries as well as through international cooperation to promote investment in science, innovation and technology for sustainable development. We recognize the importance of strengthened national, scientific and technological capacities for sustainable development. This can help countries, especially developing countries, to develop their own innovative solutions, scientific research and new, environmentally sound technologies, with the support of the international community. To this end, we support building science and technology capacity, with both women and men as contributors and beneficiaries, including through collaboration among research institutions, universities, the private sector, governments, non-governmental organizations and scientists.*

*The Future We Want* recognizes science as a multistakeholder enterprise providing the foundation for sustainable development. In 2015, with the adoption of the 2030 Agenda for Sustainable Development, heads of state and governments and high-level representatives agreed on Sustainable Development Goal (SDG) 14: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'. Target a of SDG 14 reads:

> *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,[2] 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.*

Progress in the attainment of this target is to be measured through the related indicator: 'Proportion of total research budget allocated to research in the field of marine technology'.

The Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) is the designated custodian agency for SDG Indicator 14.a.1.[3] Since 2014, IOC-UNESCO has incorporated as part of its mandate the production of the *Global Ocean Science Report (GOSR)* and the dissemination of its findings (as well as provision of open access to the underpinning data) on a systematic basis.

The first edition of the GOSR (GOSR2017), published in June 2017 by IOC-UNESCO, assessed for the first time the status and trends in ocean science capacity around the world. It offered a global record of how, where and by whom ocean science is conducted. The report identified and quantified the key elements of ocean science at the national, regional and global scales, including workforce, infrastructure and publications, taking into account sex-disaggregated data. It represented the first collective effort to systematically highlight opportunities, as

[1] Excerpts of the passionate and highly stimulating debates on the promises held by the oceans for human health and well-being can be found in the official records of the First Committee of the General Assembly (see https://www.un.org/depts/los/convention_agreements/texts/pardo_ga1967.pdf).

[2] See IOC-UNESCO, 2005. The United Nations Convention on the Law of the Sea (United Nations, 1982) recognizes the importance of the transfer of marine technology as a central element in the realization of the provisions under the Convention.

[3] According to the IAEG SDG UNSD the tasks of a custodian agency are: develop internationally agreed standards, coordinate the indicator development, and support increased adoption and compliance with the internationally agreed standards at the national level; collect data in relevant domain from countries (or regional organizations) as appropriate through existing mandates and reporting mechanisms to provide internationally comparable data and calculate global and regional aggregates; strengthen national statistical capacity and improve reporting mechanisms.

well as lack of capacity, to advance international collaboration in ocean science and technology.

While the GOSR2017 concentrated on the feasibility of a methodology to measure SDG Indicator 14.a.1 (see Chapter 2), this report — GOSR2020 — goes a step further and takes on the new challenge of providing a baseline for the forthcoming Ocean Decade. The GOSR will feed into the strategic monitoring and evaluation framework that is being developed for the Ocean Decade and its future editions will thus contribute to evaluating the impact of the Ocean Decade on ocean science capacity. In addition, the GOSR2020 attempts to progressively assess investments in ocean science as a central element of the sustainable development equation, from understanding how humans impact natural ocean processes to informing a sustainable blue economy.

## 1.2. Evolution of the GOSR: Towards measuring ocean science to guide strategic investments for sustainable development

The GOSR is a resource for policymakers, academics and other stakeholders seeking to harness the potential of ocean science to address global challenges, by informing strategic decisions related to funding for ocean science, identifying opportunities for scientific collaborations and fostering partnerships aimed at further developing capacity in ocean science.

In July 2018, the IOC-UNESCO Executive Council reaffirmed the importance of the GOSR as the main mechanism to measure progress towards the achievement of SDG Target 14.a and recognized that investments in ocean science are key to developing sustainable ocean economies.

The GOSR2020 is intended to be part of a transformative process aiming to provide the needed capacity in ocean science in the context of the Ocean Decade (2021–2030). The Ocean Decade calls for ocean science to contribute to the necessary step change to ensure a clean, healthy, resilient, productive, safe, predicted and transparent ocean (IOC-UNESCO, 2019). Realizing the value of ocean science is a first step towards such a transformation. The role of the GOSR is to quantify and monitor efforts related to ocean science; the role of the Ocean Decade, on the other hand, is to ensure that we boost the application of the findings of science, and of science itself, to ensure sustainable societal benefits from the ocean.

Global ocean science is 'big science'. Conducting ocean science requires numerous staff and frequently involves substantial and costly equipment. It also requires the organization of large scientific gatherings, the development of thematic platforms for promoting coordinated international scientific research and observations, as well as the sharing of data. In other words, significant investment is needed to conduct ocean research and development (R&D). However, the global COVID-19 sanitary crisis might change future interactions — physical scientific gatherings are likely to be smaller and less frequent, while the number of remote interactions will increase. Furthermore, autonomous sensors and other new technologies less dependent on human interventions will be indispensable to sustain and increase ocean observation.

Assessing the status of the global ocean science economy, therefore, is critical to identifying strategic orientations for ocean science in the future, and to improving the efficiency of investment in ocean science as part of the R&D envelope. The GOSR2017 provided some major findings in this regard. National ocean science expenditure varies greatly worldwide. According to available data, ocean science accounts on average for 1.7% of total R&D expenditure and varies between 0.03% and 11.8%. From 2013 to 2017, ocean science expenditure trends differed among regions and countries; some increased their annual expenditure on ocean science, while others significantly reduced it (see Chapter 3).

It is beneficial to look at investments related to ocean science in the broader context of valuation of ocean spaces and resources. There are several estimates of the value of the world ocean in terms of its benefits to society (see, for example, Costanza et al., 2014). The OECD describes the importance of economic techniques in ocean economy in its 2016 publication The Ocean Economy in 2030. In this report, non-market valuation methods are used to estimate non-use values and some direct use values, which can be defined as unpriced benefits from coastal and marine ecosystems because they are not commonly traded in the market. Furthermore, some researchers have applied economic methods to evaluate the value of R&D activities. Florio and Giffoni (2017), for example, adopted the contingent valuation technique to identify willingness to pay (WTP) for science as a public good.

In summary, there is a need for further work and discussion for applying economic techniques to estimate the value of ocean R&D, with the intention of developing a standardized methodology. An immediate challenge before us is to define the main features of ocean R&D and compare relevant economic techniques for its evaluation. This should also make use of case studies on economic techniques that have been applied in certain ocean regions and/or ocean resources. These questions could be the focus of a future joint endeavour of IOC-UNESCO's GOSR together with the OECD.

The GOSR, therefore, can be seen as an important element of a nested approach to ocean valuation. One can neither manage nor undertake strategic decisions on what one cannot measure. Along with similar assessment reports on natural and social sciences, such as the *UNESCO Science Report* and the *World Social Science Report* (UNESCO, 2015; 2016) and relevant reports by the OECD (2014; 2016), the GOSR will continue contributing to systematic assessments of the science enterprise as a basis for harnessing international scientific collaboration to address global challenges.

## 1.3. Organization of the GOSR2020 and outlook for the report

This report is comprised of eight chapters:

**Chapter 1**
examines the evolution and organization of the GOSR;

**Chapter 2**
presents technical definitions and methods used to collect and analyse the data;

**Chapter 3**
focuses on ocean science funding;

**Chapter 4**
presents the status of research capacity and infrastructure;

**Chapter 5**
analyses research productivity and the impact of ocean science;

**Chapter 6**
presents the implications and applications of ocean science for sustainable development;

**Chapter 7**
addresses ocean data and information, from collation to management;

**Chapter 8**
presents conclusions and recommendations.

And while many of the issues addressed in the GOSR2020 were also discussed in the GOSR2017, Chapter 7 'International organizations supporting ocean science' and Chapter 8 'Contributions of ocean science to the development of ocean and coastal policies and sustainable development' of the GOSR2017 were not updated in the GOSR2020, as the information presented is still valid.

A new integral element of GOSR2020 is the online GOSR portal,4 which provides access to primary data provided by IOC-UNESCO Member States on the status of their efforts in ocean science via the GOSR2020 questionnaire. In contrast to the questionnaire informing GOSR2017, the questionnaire developed for the GOSR2020 included a request to provide information on ocean science capacity building and national infrastructures/activities related to the 2030 Agenda for Sustainable Development, with a particular focus on SDG 14. In addition to acting as a data repository, the GOSR portal allows the submission of further data and retrieval of data and metadata, offering multiple possibilities for visualization, in order to meet the needs of multiple stakeholders. The portal also gives access to quality-controlled survey data and information obtained via bibliometric analyses, as well as technometrics (patent analysis), which is a new feature of the GOSR2020. All data presented are pre-COVID-19, which allows us to measure the possible impact of the global pandemic on ocean science, including inter alia employment, diversity in ocean science, core funding, additional investments, conferences, observations and publications.

The health of the world ocean, as we know it, is under profound threat. There are multiple ocean stressors at work — acidification, deoxygenation, eutrophication, degradation of blue carbon ecosystems, plastics and overfishing, to name but a few. There is little understanding of how such stressors may interact and what those synergistic effects may be; at the same time, we have clear evidence that some of the crucial services the world ocean performs are being reduced, such as the capacity of the world ocean to store carbon.

There is an increasing demand by relevant policy processes for the findings of ocean science, and for information on ocean science efforts and capacity related to research and observations. This is reflected, for example, in the agreement of the Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) at its 25th session to establish an Ocean and Climate Dialogue under the auspices of the Convention's Subsidiary Body on Scientific and Technological Advice. The data, information and analyses presented in the GOSR can inform these discussions and the deliberations of

[4] See https://gosr.ioc-unesco.org.

Parties to the UNFCCC and the 2015 Paris Agreement, as well as other relevant policy forums, including the Convention on Biological Diversity and the process related to an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction.

The contribution of the GOSR to informing policy deliberations, combined with the recognition of the contribution of ocean and coastal areas to ecosystem services, livelihood systems, the global economy and, more generally, human well-being, call for a sustained reporting effort in support of SDG 14. This is what the GOSR2020 and subsequent editions of the report aim to do.

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# 2

# Definitions, data collection and data analysis

# 2. Definitions, data collection and data analysis

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## 2.1. Preparation of the report

A suite of complementary approaches and methods was used to underpin the information presented and discussed in the *Global Ocean Science Report 2020* (GOSR2020). 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 and patents), as well as supporting organizations, infrastructures and facilities.

A variety of open-source and quality-controlled resources, together with a customized GOSR2020 questionnaire, were used to collect the data and information that provide the foundation for this report. The GOSR2020 combines quantitative data, such as the number of peer-reviewed publications, number of ocean science-related patents, research vessels and the extent of national funding, with qualitative data, e.g. access to ocean science literature and data, as well as national ocean science priorities. Many of the results presented in this report are compared to data related to research and development (R&D) in general, to the national gross domestic product (GDP) and, for example, to countries' population size. These kinds of comparisons allow for the benchmarking of results obtained via the GOSR2020. Cross-references between independent quantitative indicators as provided in Chapters 3, 4, 5 and 7, based on the methodology described in this chapter, and findings from Chapters 6 and 8, help the reader to navigate through the report.

Data compilation tools include: i) a questionnaire;[1] ii) peer-reviewed literature, national reports and web-based sources; iii) bibliometric and technometric analyses based on international literature and patent databases; and iv) gender- and age-specific analyses of ocean scientists attending international conferences/symposia (Section 2.3.4). Unfortunately, access to some types of quantitative measurements is limited or unavailable, as national reporting mechanisms to obtain the type of information requested in the GOSR2020 questionnaire are often not in place.

The GOSR Editorial Board, led by two co-chairs, 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 as follows:

I. Provide strategic and substantive guidance on the framing of the GOSR2020, in order to deliver against the report's main goals:
   - Assess the status and trends of ocean science capacity around the world;
   - Build on and take into account lessons learned in the production of the first edition of the GOSR (GOSR2017).

II. Provide guidance to ensure quality assurance and quality control of the contents of the GOSR2020.

III. Provide guidance on the GOSR2020's contribution to refining the methodology used to measure progress towards achieving SDG 14 of the United Nations 2030 Agenda for Sustainable Development and, specifically, its indicator a.1 'Proportion of total research budget allocated to research in the field of marine technology'.

IV. Provide guidance on the design of the GOSR portal.

V. Design a methodology to evaluate the success of the GOSR2020, in terms of expected results and intended outcomes.

VI. Provide initial guidance on a methodology for assessing the contribution of ocean science to sustainable development.

VII. Provide guidance on communication efforts aimed at promoting GOSR2020 as a resource for policymakers, academics and other stakeholders.

## 2.2. Definition and classification of ocean science into 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 SDG 14: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'. Following the approach presented in the GOSR2017 (IOC-UNESCO, 2017) and the recommendations given by an ad hoc IOC-UNESCO group of experts in 2013 (IOC-UNESCO, 2017), the GOSR2020 Editorial Board 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; for definitions, see Section 2.2.1). These categories cover integrative, interdisciplinary and strategic ocean research areas.

[1] See GOSR portal https://gosr.ioc-unesco.org.

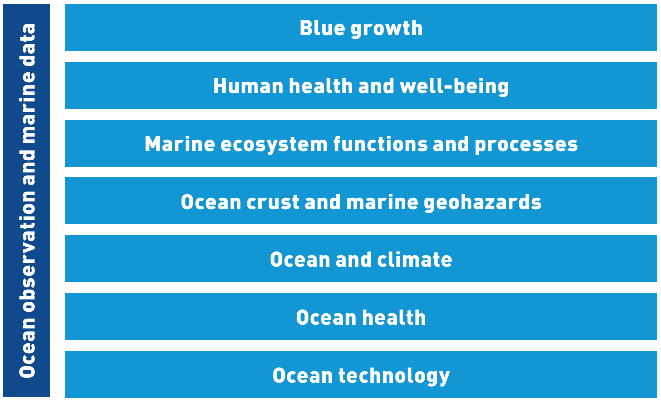


Figure 2.1. Ocean science categories applied in the GOSR2020.

In accordance with the GOSR2017 and building on the definition in the 2013 Expert Panel on Canadian Ocean Science report, the analysis presented here is based on the following definition of ocean science:

> *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 and multidisciplinary research on the relationship between humans and the ocean. Ocean science seeks to understand complex, multi-scale socio-ecological systems and services, which requires observations and multidisciplinary and collaborative research.*

The GOSR2020 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. Definitions of ocean science categories*

**Blue growth:** This category refers to research on — and in support of — sustainable use of marine resources, including research on economically important species with regard to food security (marine fisheries and mariculture). 'Blue growth' further covers studies on the utilization of new energy resources in the ocean and marine bioresources, research on exploitation of minerals (deep-sea mining, sand and gravel extraction), oil and gas (ocean drilling), as well as on the development of clean technologies, pharmaceuticals, cosmetics and desalination, 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 safety, as well as recreation, harmful algae blooms and human-related social, educational and aesthetic values, etc.

**Marine ecosystem functions and processes**: This category refers to the marine ecosystem structure, diversity and integrity, and includes abiotic and biotic characteristics. Marine ecosystem functions include biogeochemical, chemical, physical and biological processes. They are defined by nutrient cycles, energy flow and 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 'Marine ecosystem functions and processes' category in this report includes: biodiversity; physical setting; primary production; consumption; sedimentation; respiration; aerobic and anaerobic processes across the different trophic levels; biological pump, etc.

**Ocean crust and marine geohazards***:* This category refers to geological/geophysical marine research, including hydrothermal vents, seismology, 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 and climate**: This category refers to research on the ocean-climate nexus, i.e. the role of the ocean in the climate system and the effects of climate change on the ocean. The 'Ocean and climate' category includes: palaeoceanography; ocean warming; ocean acidification; deoxygenation; sea-level rise; changes in ocean stratification, circulation, air-sea interaction and related services such as weather forecasting, 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 species diversity, genetic diversity, phenotypic plasticity, habitat loss and alteration in ecosystem structure and processes. 'Ocean health' comprises studies on marine pollution (hazardous substances and litter), ocean noise, eutrophication, alien and invasive species, disruption of ecosystems, marine protected areas and marine spatial planning, etc.

**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. Ocean observation and marine data support 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.

**Ocean technology:** Research related to marine innovation and the design and development of equipment and systems for marine science and exploration and exploitation of ocean resources. This category covers studies on marine engineering for application in research and ocean industries. Examples are development of marine energy solutions, satellites and remote-sensing techniques, remotely operated vehicles (ROVs), gliders, floats, sensors, new measurement devices and techniques, as well as subsea power data transmission technologies, etc., in addition to marine geoengineering (e.g. solar radiation management and carbon dioxide removal techniques).

The eight ocean science categories were used to obtain bibliometric data to enable an analysis of ocean science performance (Chapter 5), and were also used to interpret some of the results derived from the analysis of the technometric (patent) data. According to the definition of the category, a set of keywords was selected (see GOSR portal).[2]

### 2.2.2. Regional assessments

The GOSR2020 analysis is intended to assist countries with achieving the goals and targets of the 2030 Agenda for Sustainable Development, specifically SDG 14. Therefore, the Editorial Board decided that the regional assessments presented in the GOSR2020 should be based on the SDG regional groupings.[3] This decision facilitates the SDG indicator reporting for 14.a.1 and allows for comparisons with other regional assessments conducted within the 2030 Agenda and the SDG reporting.

The regional groupings used for the SDG reporting are: Sub-Saharan Africa, Northern Africa and Western Asia, Central and Southern Asia, Eastern and South-Eastern Asia, Latin America and the Caribbean, Oceania, Europe and Northern America.

## 2.3. Data resources and analysis

### 2.3.1. Global Ocean Science Report questionnaire

A major tool in the data-gathering process for the report was the 'GOSR2020 questionnaire' (see GOSR portal), which asked for national information on ocean science conducted by IOC-UNESCO Member States. The questionnaire was developed based on the questionnaire from the first edition of the GOSR, the IODE survey (IOC-UNESCO, 2017) and reviewed by the Editorial Board and representatives of IOC-UNESCO Member States. The questionnaire collected core data and information to assess indicators and evidence to assess national capacity, progress and challenges for ocean science. It provided necessary definitions to avoid interpretations of questions. It was available online via an interactive portal and as a downloadable document. Member States were able to access the questionnaire in three languages: English, French and Spanish.

National coordinating bodies for liaison with IOC-UNESCO ensured coordination with the community of marine scientists and institutions in their respective countries and submitted data from September 2018 until November 2019.

In total, the questionnaire compiled information on 65 items, which were grouped under 7 themes:

**A — Respondent details**

Personal information about the respondent, including address, institution and email address.

**B — Ocean science governmental organization and general information**

Information about ocean science organization in the country, including governance within the country, ocean science institutions, ocean science strategies and focus areas.

**C — Ocean science spending**

The data requested in Part C should relate to actual expenses for ocean science made by the country. If they are not available, estimated data calculated using budget allocations for ocean science or other methodologies should be provided and explained as a note. Ocean science spending should be reported in the national currency (preferably) or US$ (using the conversion rate for the respective year).

**D — National research capacity and infrastructure**

Information about ocean science personnel in general, including data on the age distribution and gender of researchers, ocean observation, vessels and emerging ocean science technologies engaged in ocean science.

**E — Oceanographic data and information exchange**

Information about oceanographic data and information facilities, services and users, provided in-country.

**F — Capacity development and transfer of marine technology**

Information about ocean capacity development needs in the country, as well as related activities that the country contributes to, or benefits from.

**G — Sustainable development**

Information about ocean science-related actions corresponding to the 2030 Agenda, in particular SDG 14 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'.

[2] See https://gosr.ioc-unesco.org.

[3] See https://unstats.un.org/sdgs/indicators/regional-groups.

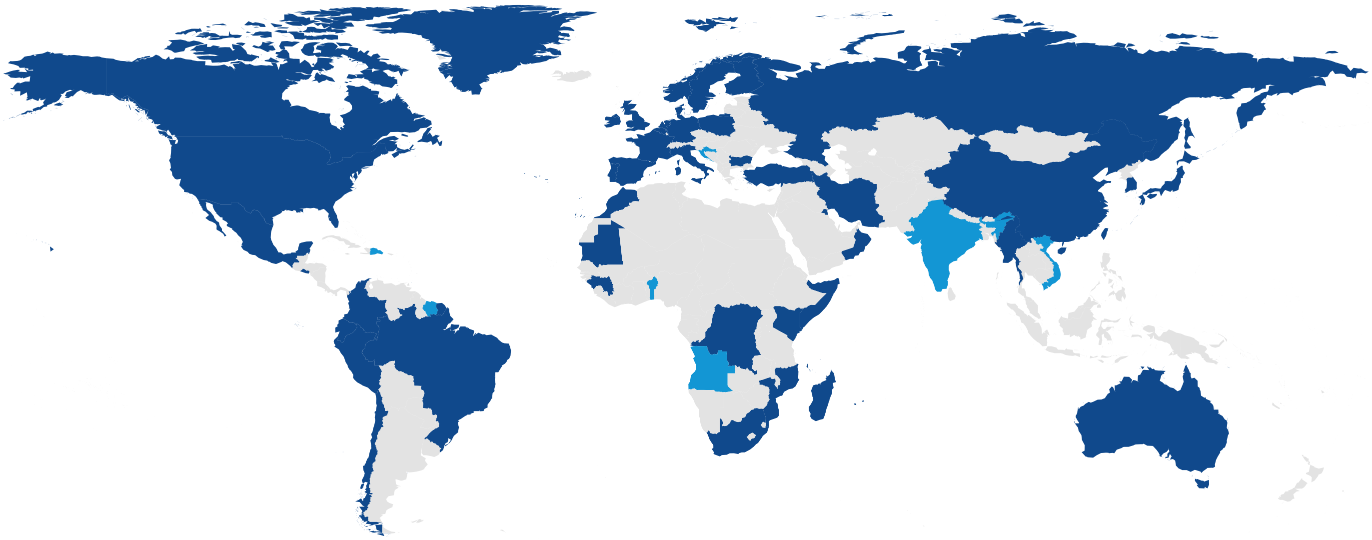

**Figure 2.2.** Global map indicating the Member States that responded to the questionnaire for GOSR2020 (dark blue); countries whose data from the GOSR2017 are used in the GOSR2020 assessments are shown in light blue.
*Source:* Based on the GOSR2020 questionnaire.

The IOC-UNESCO Secretariat received 45 national replies to the GOSR2020 questionnaire (30% of the IOC-UNESCO Member States): Australia, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Comoros, Democratic Republic of the Congo, Denmark, Ecuador, El Salvador, Finland, France, Germany, Guinea, Islamic Republic of Iran, Ireland, Italy, Japan, Kenya, Kuwait, Madagascar, Mauritania, Mauritius, Mexico, Morocco, Mozambique, Myanmar, Netherlands, Norway, Oman, Peru, Poland, Portugal, Republic of Korea, Russian Federation, Somalia, South Africa, Spain, Sweden, Turkey, United Kingdom of Great Britain and Northern Ireland, and the United States of America. Of the 34 Member States that submitted information to the GOSR2017, 11 did not answer the GOSR2020 questionnaire. As some of the questions were similar for both questionnaires, information submitted to the GOSR2017 was used if appropriate (Chapter 3 and 4). Information provided by Argentina, Croatia, Romania and Thailand to the GOSR2017 questionnaire could not be included, as the information provided did not concur with data requested for the GOSR2020 (Figure 2.2). It is important to note that the limited number of submissions from countries of several regions restricted part of the analysis in GOSR2020, such as ocean science funding and infrastructure (Chapters 3 and 4).The countries that submitted information to the GOSR2020 questionnaire produced about 82% of the global ocean science publications during the period 2012–2017. On average, the countries answered 88.3% of the questions, which is an increase of more than 10% compared to the 2017 assessment. This, together with the higher number of Member States providing information, demonstrates that the measures to improve the questionnaire, such as online accessibility, were successful. More detail on the proportion of answers received for each theme is provided in Figure 2.3.

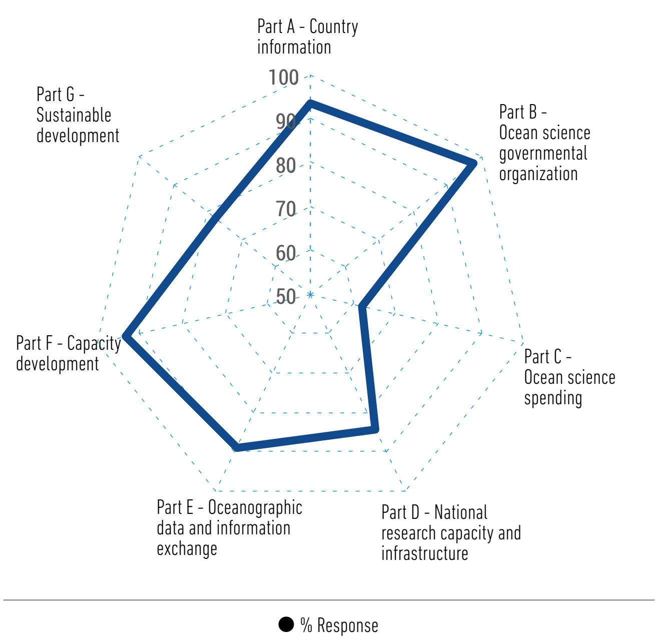


**Figure 2.3.** Questionnaire analysis — response rate by theme, calculated based on the total number of responses received to the questionnaire in general (n=45).
*Source:* Based on the GOSR2020 questionnaire.

Most of the data requested in the questionnaire cover the period 2013–2017. The information provided was partly verified with the national focal points in order to address individual inconsistencies, and analysed subsequently.

The analysis of the questionnaire showed that some of the questions, in particular the ones asking for ratings and categorization, were not filled in correctly and that the level of additional detail when provided varied greatly between the different submissions.

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

As explained previously, the GOSR2020 questionnaire submissions are provided by Member States only, questions asked did not specifically refer to the private sector or other relevant stakeholders of ocean science, and thus the information provided by Member States is insufficient to fully explore the private sector's role in ocean science.

The questionnaire from the first edition of the GOSR (GOSR2017 questionnaire; IOC-UNESCO, 2017) was used if appropriate for comparison, and to identify trends and changes over time and within countries (see Chapter 4). However, due to the fact that the questions in the two questionnaires were adapted to facilitate the submission of responses, the use of data published in the first edition of the GOSR was limited.

### *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 (King, 2004). 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. The 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. It enables the comparison of ocean science output between single countries. The analysis is also used to describe patterns of collaboration and output of organizations.

The bibliometric analysis was provided by Science-Metrix/RELX Canada.[4] The report covers worldwide scientific literature output in ocean science from 2000 to 2017. The main source of data is Scopus by Elsevier, which covers more than 43,000 scientific journals across 176 disciplines. It should be noted that the GOSR2017 bibliometric analysis was based on data and information derived from Web of Science and not Scopus, therefore some of the analysis in Chapter 5 cannot be directly compared with the bibliometric analysis published in the GOSR2017.

Data sets were constructed by combining four methods, based on the following:

- Science-Metrix/RELX Canada's journal-based classification
- Scientific journals
- Specific keywords
- Science-Metrix/RELX Canada has categorized the articles in the Scopus database under 7 domains, 23 fields and 176 subfields of science. If a subfield was deemed relevant to a pillar, all articles categorized in this subfield were inserted in the data set.

Similarly, all articles from scientific journals, the content and scope of which matched those of the pillars, were included in the corresponding pillar's data set.

Finally, keywords specific to a given pillar (or to ocean science) were identified (see GOSR portal). Articles containing the specific keyword in their title, author keywords or abstract were then attributed to the data set of the corresponding pillar.

The quality of the data sets was validated with precision and recall tests.

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.

#### 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.

[4] See http://www.science-metrix.com.

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.

**Growth ratio (GR):** This measures the percentage of increase of publications between two periods. A GR of 1 thus indicates stability, a value above 1 indicates an increase and a value below 1 indicates a decrease. For the purposes of this report, the GR of countries and regions was calculated comparing the output of the period 2000–2008 to that of the period 2009–2017.

**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. When the ARC is above 1, it means that an entity scores better than the world average; when it is below 1, it means that an entity publishes papers that are not cited as often as the world average. Science-Metrix/RELX Canada 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/RELX Canada computes and uses a symmetrical 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. 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 1, it means that an entity scores better than the world average; when it is below 1, it means that an entity publishes in journals that are not cited as often as the world average. For the analysis, 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:

$$SI = \frac{(X_S/X_T)}{(N_S/N_T)}$$

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).

**International co-publication rate (ICR):** For the calculation of the ICR, all international scientific publications indexed in literature databases, with the participation of at least two co-authors based in institutions/organizations in at least two different countries, were counted. Data were then converted into percentages of co-publication.

### *2.3.3. 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 considered. In addition, articles that are not written in English, or do not at least have an English abstract are not included in the database and are therefore not part of this study. 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, Scopus-Elsevier). 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 and the same speciality. 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.

### *2.3.4. Technometric analysis*

For the first time, the technometric analysis presented in the GOSR2020 provides an assessment of the worldwide patent data in ocean science for the period 2000–2018. The technometric data sets were provided by Science-Metrix/RELX Canada. Patent families were selected using an adapted set of keywords derived from the set used for selecting ocean science-related articles from five major patent offices: the United States Patent and Trademark Office, the European Patent Office (EPO), the Korean Intellectual Property Office (KIPO), the Japan Patent Office (JPO) and the China National Intellectual Property Administration (CNIPA, Chinese Patent Office).

Data are presented by World Intellectual Property Organization (WIPO) technical fields, Cooperative Patent Classification (CPC) classes, and by country and regions worldwide. The 35 WIPO fields[5] provide a high-level categorization of patents by technological area (e.g. biotechnology, chemical engineering), while the CPC classes (jointly developed by the United States Patent and Trademark Office (USPTO) and European Patent Office (EPO)) builds on the WIPO's International Patent Classification (IPC) to offer a more evolved and granular view of technology.

For this study, Science-Metrix/RELX Canada used the patent database PATSTATS,[6] which covers most major patents offices throughout the world. When not otherwise specified, countries assigned to patent families are the countries of the inventors. All inventor data were extracted from all applications from a DOCDB[7] family, and the authors' standardized names, which are available in PATSTAT, were used to attribute the equal weights. Then, in cases where an inventor was affiliated to multiple countries, the weight attributed to the inventor was split equally between all of that inventor's countries. However, in cases where no inventor data were indexed for a DOCDB family in PATSTAT, the missing data were patched using a method previously described in the literature (de Rassenfosse et al., 2013). If multiple offices received applications on the same date, an equal fraction of the family is applied to each country. In cases where this information does not link to a valid office, which is very rare, the country was mapped to 'Unknown'.

The applicants' countries were determined in an analogous process to the one described above, which instead gave priority to information about the applicants and patched the missing data using information about the inventors.

**Assignation of years to patent families:** A DOCDB patent family may contain multiple applications from different years. To better measure the moment at which the original invention was made, the year that was attributed to the DOCDB family corresponds to the filing year of the first application. In determining this, data from all possible applications were used, even those that were filed in offices outside the five used in the study.

**Assignation of activity sectors to patent families:** Patent statistics were presented by activity sectors (academic, private, government, individuals, other/unknown) of the applicants. The families were fractioned by activity sectors, giving equal weight to each distinct applicant by using the standardized names of the applicants indexed in PATSTAT. The attribution of sectors

[5] WIPO defines 35 technical fields based on the International Patent Classification (IPC).

[6] PATSTAT is an EPO database containing patent data from leading industrialized and developing countries.

[7] DOCDB is the main bibliographic database of the EPO. Data from PATSTAT comes partly from DOCDB.

to applicants was done by manual coding using the applicant names indexed in PATSTAT. In cases where this information was missing or not codable (e.g. because of a lack of information about the entity), the applicant was assigned to the 'Other/ Unknown' category. An important precision to be made is that state-owned, for-profit companies were coded as 'Private' because they are closer to the definition of private companies than to not-for-profit organizations funded by governments (e.g. the United States' federally funded R&D centres), which are coded as 'Government'.

**Assignation of technical fields to patent families:** Data from patents were presented by two kinds of technical fields: WIPO technical fields and CPC subclasses (which are all the CPC codes found at the third level of subcategories). The WIPO technical fields are a set of 35 high-level categories of patent, whereas the CPC subclasses are more granular. In both cases, the DOCDB families were fractioned with respect to the fields in which their applications were filed; fractioning in classes was first done at the application level, using the number of distinct technical field codes fitting in each WIPO technical field or CPC subclass as a weight. Subsequently, the DOCDB family fractioning was calculated by giving equal weight to each application.

It is important to note that the CPC classification scheme is used mainly by the EPO and the USPTO, and much less by the Asian patent offices. It was thus to be expected that the percentage of unclassified families would be higher for the Asian patent offices.

**Families citing ocean science publications:** PATSTAT includes data on citations from patents to non-patent literature. To be able to compute the number of patent families citing the relevant literature, these data were matched to publications in Scopus. Only citations to articles present in the scientific publications data set defined for the GOSR2020 bibliometric study were considered. To be included in the count of the number of all families citing ocean science scientific publications, a DOCDB family must have at least one application that contains a citation pointing to the relevant literature, otherwise it is counted as not citing the literature. The families are counted in the same way as the number of families, which is described above.

It is important to note that in the case of the Asian patent offices (CNIPA, KIPO, JPO), the citations to non-patent literature are often not well covered and, in many cases, may not be available in English, which limits the data sets for these offices.

### Technometric indicators

**Number of families (applications):** The number of DOCDB families at the level of countries was counted using a method known as fractional counting. This method divides publications based on the proportion of inventors from a country contributing to an article. The families were also fractioned with respect to the activity sectors of all their applicants. In cases where there were both multiple activity sectors and countries in the same family, both fractions were multiplied to obtain the final weight of the family for a given sector and country. When not otherwise specified, the indicators presented in this report were calculated based on this fractional counting. All families containing patents of inventions were counted, even those that did not contain granted patents. The year attributed to a given family corresponds to the filing year of its earliest application and the countries to those of the inventors.

**Growth ratio (GR):** The growth ratio measures the rate at which an entity's output changed between one period of time and another. A GR of 1 indicates no change, a GR above 1 indicates growth and a GR below 1 indicates decreased output. As patent data from 2017 and 2018 may not yet be complete, the growth ratio is computed using counts from the 2000–2007 and 2009-2016 subperiods. Data from 2008 are excluded to ensure the same number of years in both subperiods. The counts of all DOCDB families are used in the calculation, regardless of grant status and patent office.

**Specialization index (SI):** The specialization index (SI) indicates how much output a given entity produces in one field or subfield, relative to the global average of output produced in that field. For instance, if 10% of a given country's patents are in ocean science research but at the global level only 5% of patents are in this domain, the country is said to be specialized in ocean science, producing proportionately more output in that domain than is normally the case elsewhere around the world. The SI reference value is 1 (i.e. the world level is always equal to 1); accordingly, an SI above 1 shows that an entity produces proportionately more output than the average in a given area; an SI below 1 shows that an entity produces proportionately less output than the average in that area. The proportions of patent families are computed relative to all patent families from the same period in the database used.

### Limitations of technometric analysis

Technometric analysis shares many limitations with the bibliometric analysis. For instance, many inventions are not registered as patents, as their inventors and firms may choose other means of protection. Moreover, patents differ greatly in their commercial value and impact potential, which is also true for scientific articles — therefore, it is important to acknowledge that simple accruing of a patent count is not a direct measure of value of ocean science or development.

Some more specific limitations that should be taken into consideration are:

A technometric analysis always gives an advantage to countries which have a national patent office, in that registered patent applications might be incorrectly attributed to one country. In the case of the analysis done for the GOSR2020, this is mitigated by the fact that the offices cover a wide range of countries.

The patent application counts for the USPTO might be underestimated, as it is not mandatory to publish non-granted USPTO patent applications. However, this has been less of an issue in recent years, which in turn might have led to a slight overestimation of the growth rate for countries which publish most of their patents through the USPTO.

Despite most patents being published in English or with an English translation, this it is not an obligation for the EPO and the Asian patent offices. Therefore, the presented analysis might have a bias against patents which were not published in English, as the only way for those patents to be included in the data set would have been through the inclusion of CPC classes.

Further, the quality of data and information varies by patent office. While patent information from the EPO and the USPTO fulfilled the requirements of the technometric analysis, this was not always the case for the CNIPA, the KIPO and the JPO. Although this problem is mitigated by the usage of DOCDB families and the patching procedure described earlier, this can cause problems in the assignation of countries to patent families.

### *2.3.5. Additional resources*

In addition to the questionnaire and the data provided by Science-Metrix/RELX Canada, supplementary resources were used to improve the data sets available for 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 recognized 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 parity among researchers in ocean science and age distribution within ocean research community, in a different way (Chapter 4). For this purpose, lists of participants attending international ocean science conferences/symposia from 2009 to 2018 were used. The criteria for international conferences to be included in this assessment were: 1. Minimum of 50 participants from at least 10 different countries attending; 2. Experts of the hosting country never exceeding 50% of the total number of participants; 3. Open registration process; 4. Gender and country information available for at least 90% of the participants. The full list of conferences selected for each ocean science category indicates the number of participants, countries represented, the overall gender ratio of experts subscribed for the meeting, as well as of students, organizers and featured speakers, when this information was available (Supplementary material 4.1).

In addition, two regional assessments of ocean science or ocean-science-related Bachelor, Master and PhD programmes (or equivalents) are presented in Chapter 4. The analyses are based on data gathered with the support of two IOC-UNESCO projects. For Latin American and Caribbean countries, the information was collected for the academic year 2018–2019 in collaboration with the IOC Sub-Commission for the Caribbean and Adjacent Regions (IOCARIBE). The data analysed for Western African countries covers the time period of the 2019–2020 academic year and was obtained from institutional websites and with the support of national experts.

## 2.4. 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 variables (e.g. financial resources allocated for ocean science, technical and human resources) into perspective.

**Gross domestic product (GDP):**[8] GDP is the 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.

**Purchasing power parity (PPP):** PPP refers to the exchange rate of two different currencies that are going to be in equilibrium. The PPP formula can be calculated by multiplying the cost of

[8] Definition by the UNESCO Institute for Statistics (UIS).

a particular product or services with the first currency by the cost of the same goods or services in US dollars.

**GDP, PPP (current international $)**: GDP, PPP is the GDP converted to international dollars using PPP rates. An international dollar has the same purchasing power over GDP as the US dollar has in the United States. Data used in the GOSR2020 are in current international dollars.[9]

**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)). The UIS collects data on resources devoted to R&D through its R&D statistics survey.[10]

**Currency exchange rates:** A currency exchange rate is the rate at which two currencies can be exchanged. For the GOSR2020 currency exchange rates we used annual currency exchange rates between national currency other than US dollar (US$) and US$. A unit of a currency can be exchanged for another currency using the World Bank Global Economic Monitor (GEM) exchange rates.[11]

**Total population:** Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship. The values used are midyear estimates.[12]

**Coastline:** For the purpose of the GOSR2020 assessment, the values of coastline refer to the total length of the boundary between the land area (including islands) and the sea.[13]

For Chapter 3, three different types of indicators are provided based on the data collected:

**Annual ocean science expenditure in US$, by country:** This indicator displays national ocean science expenditure aggregates, as reported by respondents to the questionnaire and converted into US$.

**Ocean science expenditure as a share of gross domestic expenditure on R&D (GERD) in 2017, by country:** This indicator shows the relative portion of GERD allocated to ocean science in 2017 and is calculated as a ratio between total local ocean science expenditure and GERD, both expressed in local currency units, at current prices.

**Average annual growth rates in ocean science expenditure, from 2013 to 2017:** This indicator provides the average annual growth rate of ocean science expenditure in each country. To take into account inflation, Consumer Price Indexes (CPI) at constant 2010 local prices are used as deflators.

## 2.5. 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 complex data sets and potentially enables the identification of new patterns. Different visuals are used in the report, as described below.

**Positional analysis:** Positional analysis graphs visualize the composite performance of institutions (Figure 2.4 and Chapter 5).

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[9] *Source:* The World Bank, data as of December 2019.

[10] *Source:* UNESCO Institute for Statistics, data as of November 2019.

[11] *Source:* Global Economic Monitor, data as of September 2019.

[12] *Source:* The World Bank, data as of December 2019.

[13] *Source:* CIA World Factbook, data as of December 2019.

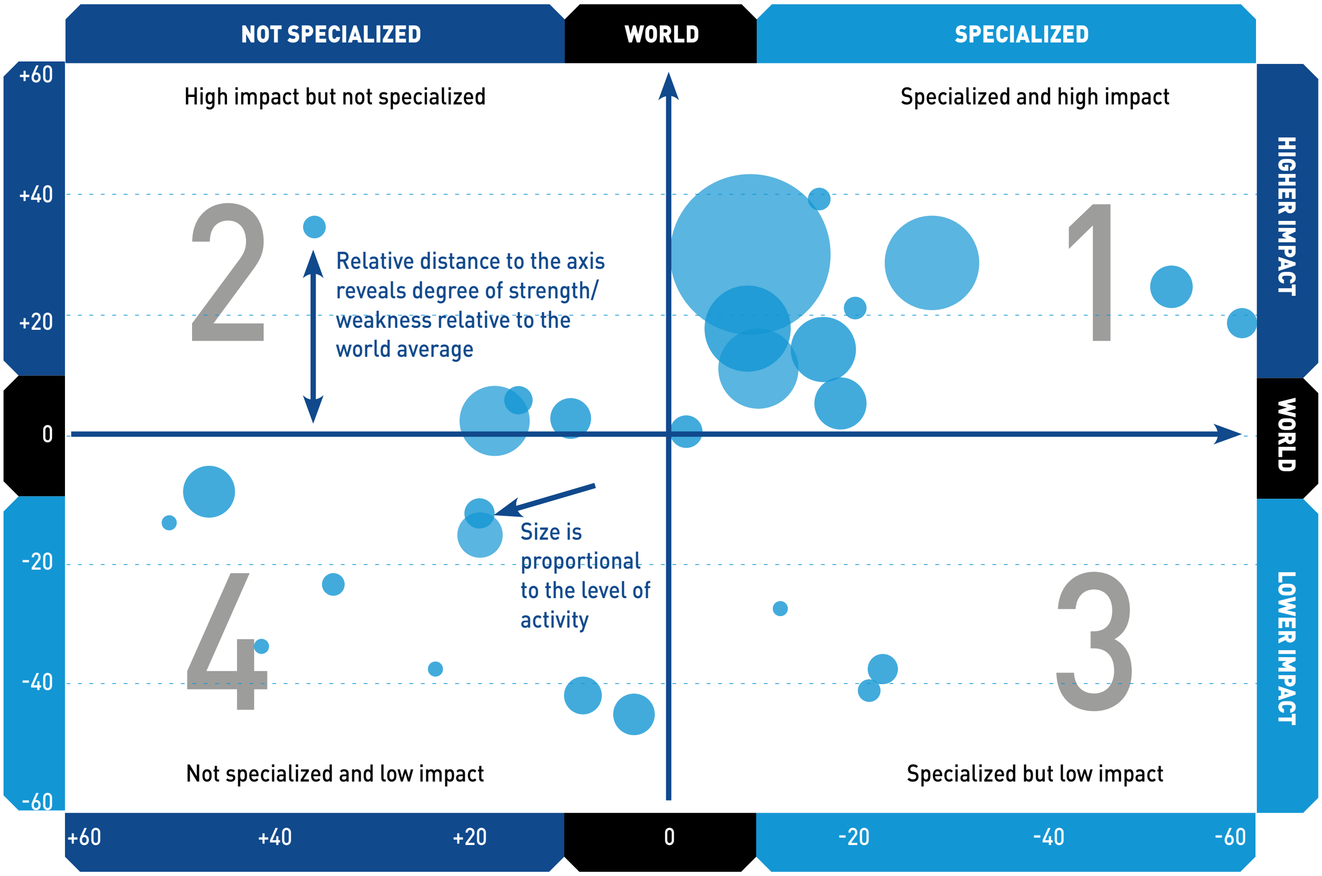


Figure 2.4. Example of figure illustrating the positional analysis, for the Specialization Index (SI) and the Average of Relative Citations (ARC), as presented in Chapter 5.
*Source:* IOC-UNESCO, 2017.

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.

**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 right of the graph, this quadrant signals specialization in the domain, whereas output impact is below the world average.

**Quadrant 4:** Located at the bottom left of the graph, institutions positioned in this quadrant show an intensity of activity and impact below the world average in the domain.

**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 publishing countries in each category were used for country networks and the top 40 publishing institutions in each pillar were selected for institution networks.

**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.

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# 3

# Funding for ocean science

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# 3. Funding for ocean science

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## 3.1. Introduction

Sustained and cost-effective funding for ocean science will be crucial to obtaining the knowledge and understanding to support a healthy and productive ocean, which finds itself under threat from accelerating climate change, ocean pollution and resource extraction (e.g. seabed mining, marine fisheries and mariculture).

Building on lessons learned from the chapter on ocean science funding and current international practices in the previous Global Ocean Science Report (GOSR2017), this chapter aims to:

- Deliver an overview of ocean science-related funding around the world, identifying key sources and mechanisms of funding;
- Provide a knowledge base of internationally comparable data on the state of investment in ocean science.

Continuous data collection at the level of ocean science investment, observing changes over time, will be required to obtain a long time series. The analysis of this type of data will provide further evidence on the wide socio-economic impacts of ocean science.

This chapter is presented as follows: Section 3.2 offers a strategic outlook on ocean science funding with a summary of the key findings; Section 3.3 then gives an overview of the different sources of funding (national institutional budgets, international programmes, private sector, foundations and philanthropy, as well as additional innovative funding instruments), with original data collected via the GOSR2020 questionnaire; and finally, selected national and international case studies on funding streams and mechanisms are examined in Section 3.4.

## 3.2. Strategic outlook on ocean science funding

The coronavirus (COVID-19) pandemic may have long-lasting impacts on the international ocean research landscape, with consequences for the re-prioritization of some programmes, long-term funding schemes and set-up of research infrastructures. In this context, the importance of ocean science will need to remain at the forefront, to face the challenges posed by intensifying economic activities in the ocean, its accelerating deterioration and the changing climate.

In this context, there are many motivations for national investment in ocean science. Today, the quest for knowledge about the marine environment, climate and coastal processes is strongly associated with socio-economic and security considerations. Improved understanding about ocean processes and its resources, generated by ocean science, will increasingly be the foundation for managing activities in the ocean in a sustainable way.



### *3.2.1. Key trends in ocean science funding*

**The availability and allocation of funding for ocean science continues to vary widely between countries and regions, with much lower budgets in developing countries.** Based on the results of the GOSR2020 questionnaire (see methodologies in Chapter 2), the USA reports the highest budget for ocean and coastal activities, a figure which includes ocean science as well as other ocean and coastal government programmes, with more than US$12 billion, followed by Japan (US$600 million) and Australia (US$511 million) in 2017. Six countries allocate budgets of over US$200 million to ocean science: Norway (US$367 million), France (US$333 million), Germany (US$312 million), the UK (US$293 million), the Republic of Korea (US$228 million) and Canada (US$220 million).

**Ocean science budgets have varied significantly between 2013 and 2017.** Based on the datasets, 14 countries increased their budgets on average over time (the Russian Federation had the highest annual growth rate, peaking at 10.4%, followed by the UK and Bulgaria), while 9 reduced them, in some cases quite markedly (particularly Japan, Ecuador, Turkey, Brazil and Italy).

**Overall, ocean science funding seems remarkably small when compared to many other fields of research and innovation.** The share of gross domestic expenditure on research and development (GERD) dedicated to ocean science is quite low. On average, around 1.7% of total GERD was attributed to ocean science in 2017, with shares ranging from around 0.03% to 11.8%. Peru (11.8%) is the leading country in this respect, followed by South Africa (5.6%), Ireland (5.3%), Norway (4.4%) and Portugal (3.5%).

**The number of private foundations, as well as the number of corporate donation programmes involved in ocean activities, is growing.** Approximately US$500.5 million were allocated to ocean-related projects in 2017, out of which US$149.4 million were allocated to more than 1,000 marine science projects. Over the five years from 2013 to 2017, private foundations and donors provided around US$668.2 million to marine science projects through more than 6,000 different grants.

### 3.2.2. Future perspectives: Challenges and opportunities

Looking ahead to ocean science funding in the next few years, several areas require particular attention: fostering the links and communication between science 'producers' and science 'users', such as governments, authorities and industry; finding the right balance between the investments in fundamental ocean research and infrastructure; enhancing the overall ocean science contribution to sustainable development; and fostering sustained cooperation and capacity building programmes between developing countries for the benefit of all.

One of the first areas requiring improvement concerns the links and communication between science 'producers' and science 'users', such as governments, administrative authorities and industry. Improving the connections between these stakeholders will help them address more effectively many of the challenges they face in the management of sustainable ocean activities. Moreover, increased awareness of the pertinence of ocean science may also provide immediate benefits, particularly to institutional and industry users (e.g. balanced marine conservation policies and more sustainable and profitable fisheries), while potentially discerning new channels of funding for selected fields of ocean research (see section 3.3.3).

Another concern for ocean science is the need to balance the allocation of funding (and other resources) between the provision and maintenance of ocean science infrastructure (e.g. crucial ocean observing systems) and fundamental research activities. This concern has been echoed by the US National Research Council in 2015, which noted a 37% decline in available funding for science investigation supported by the US National Science Foundation, while infrastructure costs increased by approximately US$10 million per year between 2011 and 2014 (National Research Council, 2015). While it is recognized that both elements must be supported if the important contribution of ocean science to sustainable development is to be maintained, the global trend of reduced science budgets could require some rebalancing between these research components. In this regard, it has been suggested that a fixed ratio of the total budget could be allocated to infrastructure, with an increasing 'long-term funding trajectory' targeting core ocean science research, although national cases would vary.

The imbalance in the allocation of funding between core science and infrastructure has also created new opportunities for increased collaboration among governments and research institutions. In recent years, this challenge has elicited a wider global response, with many countries, including those in the European Union (EU), the USA, South Africa and Brazil, agreeing to execute joint ocean research programmes through the sharing of various infrastructure platforms and related resources (Government Office for Science, 2018; European Commission, 2019; South Africa DST and Brazil MSTIC, 2017). Further opportunities for adopting and expanding such initiatives exist, including in Small Island Developing States (SIDS) (Hind et al., 2015), and the international research community can play an effective role in advocacy, coordination and capacity development.

Equally, while the contribution of ocean science to human development has been very important, much more can be achieved at the science-policy interface to ensure that investments in the vital area of research make an even greater contribution to sustainable development, in particular, SDG 14 (Rudd, 2015). This will likely require a judicious allocation of resources between 'pure' and 'applied' research, as well as the optimization of initiatives that exploit linkages among related SDGs, addressing, for example, food and energy security and transportation. This would not only contribute to the objective of achieving sustainable development but would simultaneously enhance collaboration among states through more effective deployment of human and technical resources, data sharing and avoidance of duplication of effort.

Finally, there has been much discussion over the years relating to the need for South-South collaboration and dialogue in ocean research, and a number of initiatives have been highlighted (Liu et al., 2016; Claassen et al., 2019). Some examples of cooperation are also provided in this chapter (see section 3.3.2). This demonstrates that research expertise in ocean science is not confined to developed countries, and that there is untapped ocean research capacity in some parts of the developing world that can be more widely and effectively deployed. However, sustaining these initiatives has often proved to be challenging for the nations involved.

Developed countries can support this process by leveraging funding specifically for this purpose, by providing assistance with logistics, and facilitating greater access to technology and existing platforms. The UN Decade of Ocean Science for Sustainable Development (the 'Ocean Decade') will contribute to bring momentum to further this international cooperation.

### 3.2.3. Looking ahead to the UN Decade of Ocean Science for Sustainable Development

Currently, national governments are the key sources of financing for ocean science. The volume of national investment in ocean science differs around the world; however, on average only 1% of national research budgets support ocean science (IOC-UNESCO, 2017). This is a small proportion compared to the estimated US$1.5 trillion contribution of the ocean to the global economy in 2010 (OECD, 2016).

Ocean science should remain a priority in view of the growing risks linked to climate change, loss of biodiversity and unsustainable uses of the ocean. If the ambitions of the Ocean Decade are to be achieved, national funding for ocean science would need to increase, and other sources could be further mobilized.

The Ocean Decade provides, for instance, a framework for convening philanthropic foundations around a set of common ocean science priorities. Philanthropic foundations are already important sources of financing for ocean science, as demonstrated in this chapter, and play complementary roles in awareness raising, education and advocacy.

In addition, industries represent major users of the ocean and could contribute significantly to the Ocean Decade in terms of resources, partnerships, technology and innovation to enhance ocean science. Benefits to the private sector include enhanced scientific knowledge that can contribute to reducing business risks and creating opportunities for sustainable economic development.

Civil society and non-governmental organizations (NGOs) form another group that can play a multitude of roles in the Ocean Decade, ranging from funding and generation of science to advocacy with national governments and policymakers, and education and outreach with local communities. Benefits to NGOs and civil society from engagement in the Ocean Decade are also wide and varied, ranging from increased access to resources and innovative partnerships, and improved access to data and information for use in their activities.

The resource base for the Ocean Decade will undoubtedly be broad and flexible, as a multiplicity of actors will be engaged in many programmes. The mobilization of resources for the Ocean Decade will take a variety of forms and all actors need to be advocates for identifying and securing support.



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## 3.3. Mapping sources of funding

The sources of funding for ocean science have diversified over the years and today include national administrations, international programmes, the private sector, foundations and philanthropy, as well as new and innovative financing instruments.

### 3.3.1. National institutional budgets

Countries around the world are funding ocean science through different ministries and administrations. Responses to the GOSR2020 questionnaire revealed the diversity of entities funding ocean science, some with obvious links to marine activities (e.g. ministries of fisheries, ministries of environment, ministries of defence for naval activities), and some more involved in science and technology development (ministries of science, food security, technology, space agencies), as well as some institutions with broad policy dimensions (ministries of the economy, trade) (Box 3.1). This is especially the case in small, developing countries in which government ministries, departments and statutory agencies are closely interlinked, making it difficult to effectively separate out specific budget elements in each entity that contribute to ocean research activities.

**Box 3.1.** Selected governmental agencies providing ocean science funding

Based on responses to the GOSR2020 questionnaire, this non-exhaustive listing provides an illustration of the diversity of agencies, departments and ministries involved in ocean science funding:

- Angola: Ministry of Fishery; Ministry of Transport; Ministry of Telecommunications
- Australia: Australian Antarctic Division (AAD); Marine Protected Areas Branch of the Department of Environment & Energy (DoEE)
- Belgium: federal governments' ocean science funding in development cooperation; Flanders region ocean science and innovation funding streams
- Brazil: Interministerial Commission for Sea Resources (CIRM)
- Bulgaria: Ministry of Education and Science
- Canada: Fisheries and Oceans Canada; Defence and Research Development Canada
- Colombia: Ministry of the Environment and Sustainable Development
- Congo (Democratic Republic of the): Ministry of Environment
- El Salvador: Ministry of the Environment and Natural Resources; Vice Ministry of Science and Technology; Ministry of Agriculture and Livestock
- Finland: Ministry of the Environment; Ministry of Transport and Communication; Ministry of Agriculture and Forestry; Ministry of Economic Affairs and Employment
- France: Ministry of Higher Education, Research and Innovation (MESRI)
- Germany: Federal Ministry of Education and Research (BMBF)
- Guinea: Ministry of Higher Education and Scientific Research; Ministry of Fisheries, Aquaculture and the Maritime Economy.
- Ireland: Ministry for Science and Technology (Department of Business, Enterprise and Innovation); Ministry for Fisheries (Department of Agriculture, Food and the Marine); Ministry for Defence (Department of Defence); Ministry for the Environment (Department of Communications, Climate Action and Environment); Ministry for Planning (Department of Housing, Planning and Local Government)
- Italy: Ministry of Education, University and Research (MIUR); Ministry for Environment, Land and Sea Protection (MATTM); Ministry of Economic Development (MISE)
- Japan: Ministry of Education, Culture, Sports, Science and Technology (MEXT); Ministry of Agriculture, Forestry and Fisheries (MAFF); Ministry of Economy, Trade and Industry (METI); Ministry of Land, Infrastructure, Transport and Tourism (MLIT); Ministry of the Environment (MOE)
- Korea (Republic of): Ministry of Oceans and Fisheries; Ministry of Environment (Korea Meteorological Administration)
- Kuwait: Public Authority for Environment; Public Authority for Agriculture and Fisheries; Kuwait Institute for Scientific Research
- Mauritania: Ministry of Fisheries and the Maritime Economy
- Mauritius: Ministry of Defence Department for Continental Shelf, Maritime Zones Administration and Exploration (CSMZAE)
- Morocco: Ministry of Fisheries; Ministry of Research; Ministry of Public Works
- Mozambique: National Marine Institute (INAMAR)
- Netherlands: Ministry of Education, Culture and Science (OCW); Ministry of Agriculture, Nature and Food Quality (MinLNV/Wageningen Marine Research WMR); Ministerie van Infrastructuur en Waterstaat (Deltares Institute)
- Oman: Ministry of Agriculture and Fisheries Wealth; Oman Development Bank
- Peru: Ministry of Defence; Ministry for Production
- Poland: Ministry of Science and Higher Education; Ministry of Marine Economy and Inland Navigation; Chief Inspectorate for Environment Protection
- Russian Federation: Ministry for Science and Higher Education; Ministry of Agriculture; Ministry of Natural Resources and Environment; Ministry of Industry and Trade
- Somalia: Ministry of Fisheries and Marine Resources; Ministry of Ports and Transport; Ministry of Health; Ministry of Environment; Ministry of Agriculture
- South Africa: Ministry of Science and Technology; Ministry of Environmental Affairs; Ministry of Agriculture and Fisheries; Ministry of Minerals Resources Ministry of Higher Education and Training
- Spain: Ministry of Science, Innovation and Universities
- UK: Department for Business, Energy & Industrial Strategy (BEIS); Department for Environment, Food and Rural Affairs (Defra)
- USA: Department of Agriculture; Department of Commerce; Department of Defense; Department of Energy; Department of Health and Human Services; Department of Homeland Security; Department of the Interior; Department of State; Department of Transportation; Department of Treasury; Environmental Protection Agency; Marine Mammal Commission; National Aeronautics and Space Administration; National Science Foundation; Smithsonian Institution

*Source*: Based on the GOSR2020 questionnaire.

The information presented in the following paragraphs provides conservative estimates and may not reflect the total national expenditure on ocean science for some countries. The analysis is limited by data availability, as some countries were not able to report detailed information for every year, nor the ministry or department allocating the funds.

Based on the results of the GOSR2020 questionnaire, the USA reported the highest institutional funding for ocean activities (Figure 3.1). The USA allocated more than US$12 billion to ocean and coastal activities in 2016, a figure which includes ocean science, as well as other ocean and coastal government programmes. Japan reported some US$1.4 billion for ocean science in 2013, decreasing over time to US$768 million in 2015 and to slightly less than US$600 million in 2017. Australia had an ocean science budget of US$511 million in 2017. Six countries allocate budgets over US$200 million to ocean science: Norway (US$367 million), France (US$333 million), Germany (US$312 million), the UK (US$293 million), the Republic of Korea (US$228 million) and Canada (US$220 million).


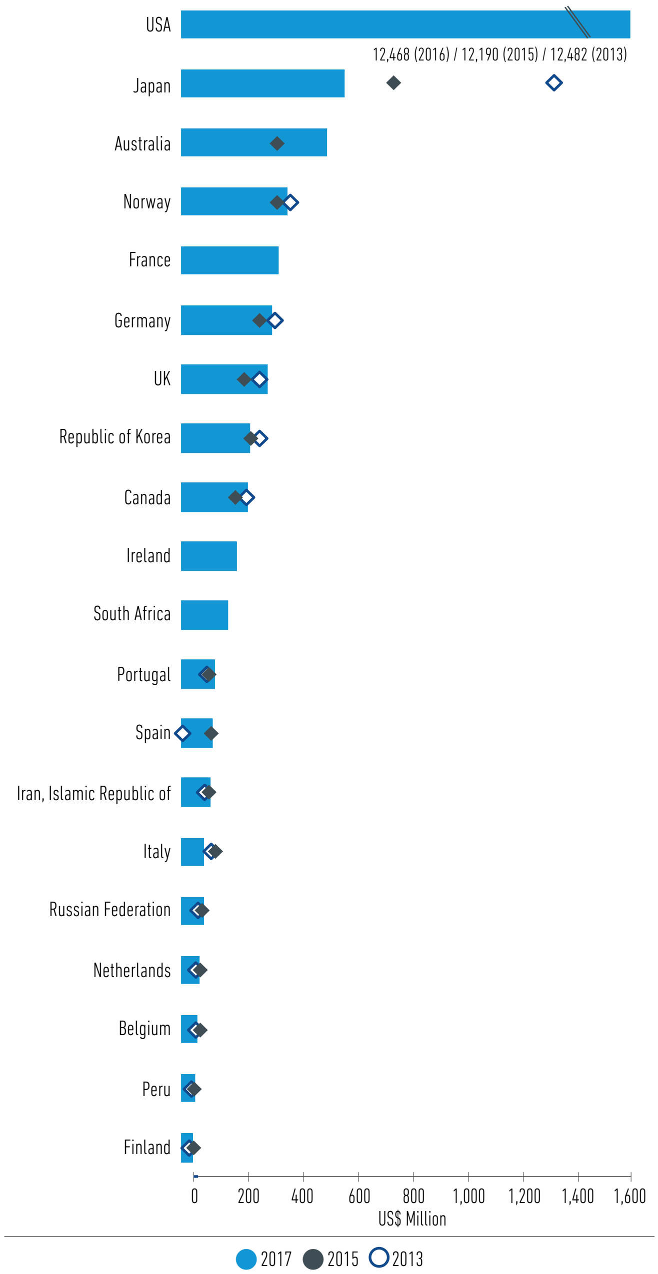


**Figure 3.1.** Estimates of ocean science funding by country (million US$), 2017 or latest available year. Estimates are based on responses to question 14 of the GOSR questionnaire, with the exception of the following countries, for which data come from question number 16: Finland, Norway, Portugal, South Africa, Spain and the UK. For the USA, the reported funding covers more than ocean science — it includes other ocean activities and coastal government programmes. The latest available data for Peru, Portugal and the USA are from 2016. Data for 2016 replace unreported 2015 data for Australia, the Russian Federation and Spain. The earliest available data for Iran (Islamic Republic of) and Portugal is from 2014.
*Source:* Data adapted from GOSR2020 questionnaire.

For some countries, ocean science funding varied significantly between 2013 and 2017, partly due to fluctuating exchange rates over time. Figure 3.2 displays the average annual growth rates of ocean science budgets, at constant prices,[1] for countries that provided data from at least the initial and the last year of the time window covered by the questionnaire.

Over time, 14 countries increased their budgets on average, while 9 reduced them — in some cases quite markedly. The Russian Federation is the country displaying the highest annual growth rate, peaking at 10.4%, followed by the UK (7.5%) and Bulgaria (4.7%). Colombia, Finland, Germany, the Islamic Republic of Iran and Morocco kept their expenditure stable. Meanwhile, decreases of between -9% and -10% were reported by Italy and Brazil, and between -15% and -17% by Turkey, Ecuador and Japan.

Overall, the share of GERD dedicated to ocean science is relatively low (Figure 3.3). Focusing on respondents for which GERD data are currently available, on average, around 1.7% of total GERD was attributed to ocean science in 2017, with shares ranging from around 0.03% to 11.8%. Peru (11.8%) is the leading country in this respect, followed by South Africa (5.6%), Ireland (5.3%), Norway (4.4%) and Portugal (3.5%). At the other end of the spectrum, Turkey allocated the smallest share of GERD to ocean science, preceded by Brazil, Bulgaria and Colombia.

It is possible to assess countries' relative 'specialization' in ocean science by comparing the ratio of ocean science funding over GERD with the ratio of GERD over GDP. This highlights whether or not ocean science is a priority within countries' GERD expenditure objectives. In practical terms, a comparison between the left and the right panels of Figure 3.3 shows which countries are 'punching above their weight' in the field of ocean science. This is the case for Peru, which displays a very low ratio of GERD over GDP (0.12%) but allocates a very high share (11.8%) of its GERD to ocean science (the highest in the group). Conversely, The Republic of Korea dedicates 4.6% of its GDP to GERD (highest in the group), and only 0.32% of GERD to ocean science.

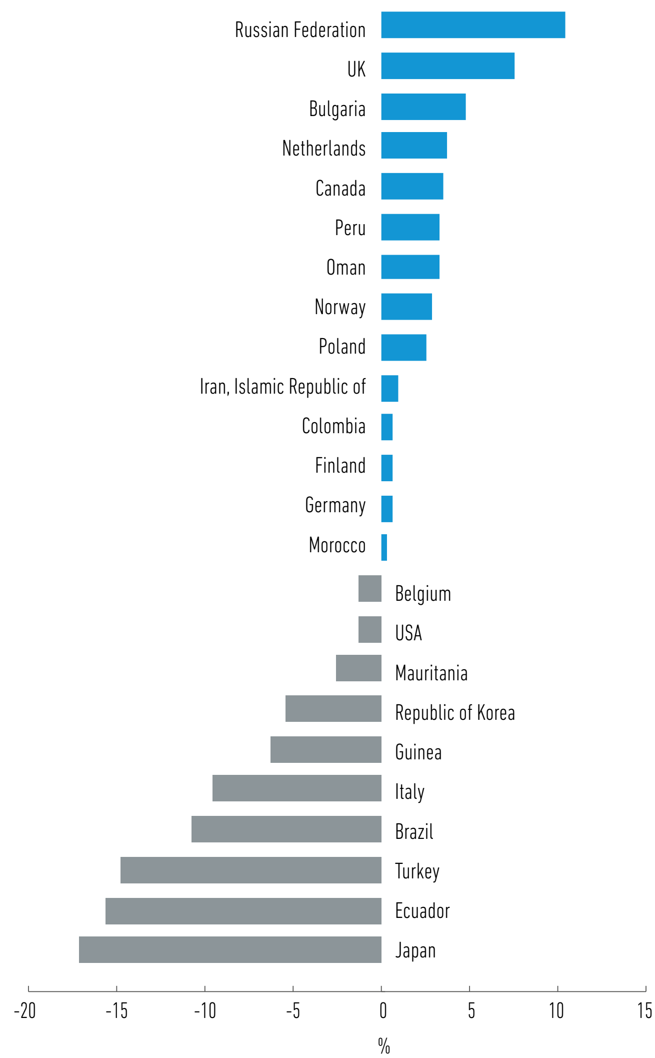


**Figure 3.2.** Growth rates in ocean science expenditure over time. *Average* annual growth rates of ocean science expenditure in local currency, at constant prices (2010=100), from 2013 to 2017. Estimates are based on responses to question 14 of the GOSR2020 questionnaire, with wthe exception of the following countries, for which data come from question number 16 (see GOSR portal): Finland, Portugal, Spain, Norway, South Africa and the UK. The latest available data for Peru, Portugal and the USA are from 2016. The earliest available data for Iran (Islamic Republic of) and Portugal are from 2014.
*Sources:* Data adapted from the GOSR2020 questionnaire and the International Monetary Fund's International Financial Statistics Database.

[1] See https://ec.europa.eu/eurostat/web/products-datasets/-/tec00115.

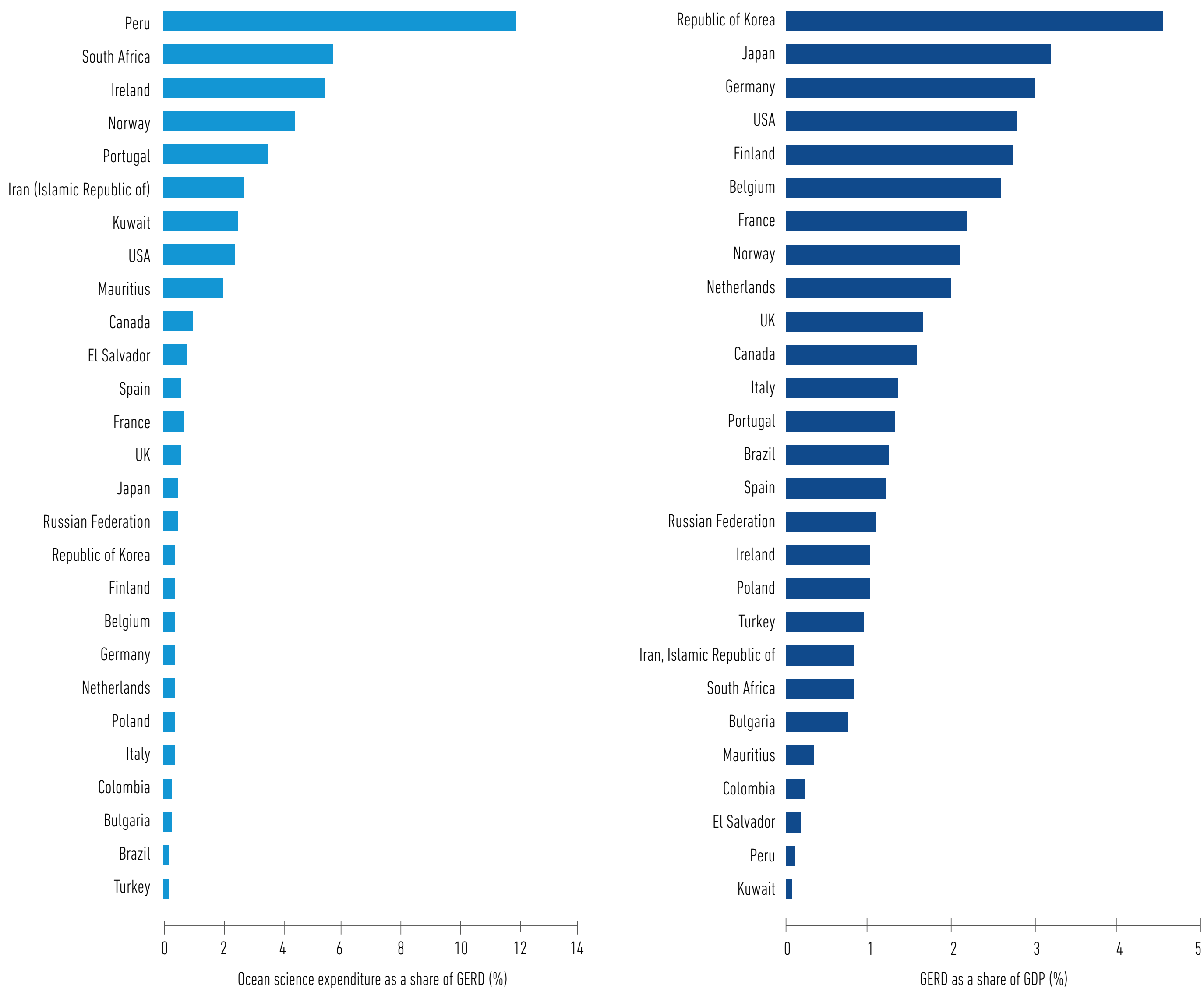


**Figure 3.3.** Estimates of ocean science funding as a share of GERD, and GERD as a share of GDP in 2017. Estimates of ocean science funding are based on countries' responses to question 14 of the GOSR2020 questionnaire, with the exception of the following countries, for which data come from question 16: Finland, Norway, Portugal, South Africa, Spain and the UK. The latest available data for Peru, Portugal and the USA are from 2016. The earliest available data for Iran (Islamic Republic of) and Portugal are from 2014. The latest available GERD data for South Africa are from 2016.
*Sources:* Data adapted from GOSR2020 questionnaire and UNESCO Institute for Statistics database. Note that ocean science funding is not identified as such in GERD data, and can be found in natural sciences and other categories.

**Table 3.1.** Selected ocean science-related international programmes with a global scope and participating countries.

| Selected international bodies and programmes | General information | Participating countries |
|---|---|---|
| Belmont Forum (funding of environmental change research) | Partnership of funding organizations, international science councils and regional consortia committed to the advancement of transdisciplinary science, providing knowledge for understanding, mitigating and adapting to global environmental change. | Argentina, Australia, Austria, Brazil, Canada, China and the Taiwan Province of China, Côte d'Ivoire, France, Germany, India, Italy, Japan, Mexico, Netherlands, Norway, Qatar, South Africa, Sweden, Thailand, Turkey, UK, USA |
| International Ocean Discovery Program (IODP) | International marine research collaboration using ocean-going research platforms to recover data recorded in seafloor sediments and rocks to monitor subseafloor environments. Scientists from participating countries can be selected for expeditions. IODP depends on facilities funded by three platform providers (USA, Japan, EU) with financial contributions from five additional partner agencies (Australia-New Zealand Consortium, Brazil, China, Republic of Korea, India). | Australia, Austria, Brazil, Canada, China, Denmark, Finland, France, Germany, India, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Republic of Korea Spain, Sweden, Switzerland, UK, USA |
| International Council for the Exploration of the Sea (ICES) | Intergovernmental marine science organization, which aims to advance and share scientific understanding of marine ecosystems and the services they provide in view of achieving conservation, management and sustainability goals. It works as a network of nearly 6,000 scientists from over 700 marine institutes and focuses on the Atlantic Ocean, the Arctic, the Mediterranean Sea, the Black Sea and the North Pacific Ocean. | Belgium, Canada, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Russian Federation, Spain, Sweden, UK, USA |
| Intergovernmental Oceanographic Commission (IOC) of UNESCO | Intergovernmental Oceanographic Commission (IOC) of UNESCO, established in 1960 as a body with functional autonomy within UNESCO, is the only competent organization for marine science within the UN system. The purpose of the Commission is to promote international cooperation and to coordinate programmes in research, services and capacity building, in order to learn more about the nature and resources of the ocean and coastal areas and to apply that knowledge for the improvement of management, sustainable development, the protection of the marine environment, and the decision-making processes of its Member States. | 150 Member States |
| North Pacific Marine Science Organization (PICES) | Intergovernmental scientific organization, established in 1992, which aims to promote and coordinate marine research in the North Pacific and adjacent seas, especially north of 30° N. It is working to advance scientific knowledge about the marine environment, weather and climate change, marine life and their habitats, as well the impacts of human activities on these. It promotes the collection and exchange of scientific information on these issues. | Canada, China, Japan, Republic of Korea, Russian Federation, USA |
| The Partnership for Observation of the Global Ocean (POGO) | The Partnership for Observation of the Global Ocean (POGO) was founded in 1999 by directors of oceanographic institutions around the world as a forum to promote and advance the observation of the global ocean. POGO is a UK-registered charity with member institutions from around the world, and works closely with other international and regional programmes and organizations. | Multistakeholder partnership |
| Scientific Committee on Oceanic Research (SCOR) | SCOR is an international non-governmental non-profit organization formed by the International Council for Science (ICSU) to help address interdisciplinary science questions related to the ocean. | Australia, Belgium, Brazil, Canada, Chile, China and the Taiwan Province of China, Ecuador, Finland, France, Germany, India, Ireland, Israel, Italy, Japan, , Mexico, Namibia, Netherlands, New Zealand, Norway, Pakistan, Poland, Republic of Korea, Russian Federation, South Africa, Sweden, Switzerland, Turkey, UK, USA |

*Source:* Data adapted from GOSR2020 questionnaire, particularly countries' responses to question 18, and other background research.

### 3.3.2. International programmes enhancing funding and capacity building

International cooperation has been a key aspect of ocean science for decades, based on the wide diversity of actors and scientific disciplines linked to study of the ocean.

#### 3.3.2.1. Selected cooperation programmes for ocean science funding

There are many aspects of international collaboration benefitting funding for ocean sciences, from opportunities for individual countries made available in the context of relevant treaties and intergovernmental organizations to facilitate cooperation at coastal and basins levels, to the setting up of dedicated coordination bodies with cross-border funding mechanisms for ocean research. Some of these initiatives are presented in Tables 3.1–3.4, based on information provided by countries in the GOSR2020 questionnaire. Table 3.1 is not exhaustive, and other initiatives are underway, some of which are also described in the next sections.

In Europe, many initiatives bring together different national research and scientific organizations to fund ocean science activities. Major ones are mentioned in Table 3.2 (the European Marine Board and JPI Oceans in particular), but the list is not exhaustive, as many other forums exist for the ocean science community. For example, the European Cooperation in Science and Technology (COST) is a funding organization for researchers to set up interdisciplinary research networks in Europe and beyond, or the Ocean Sciences Division of the European Geosciences Union (EGU), which fosters interactions with experts from different fields of Geosciences.



**Table 3.2.** Countries' participation in selected ocean science-related European bodies/programmes.

| Selected bodies and programmes | General information | Participating countries |
|---|---|---|
| European Marine Board | Non-governmental advisory body and pan-European Forum for seas and ocean research and technology, established in 1995. It performs marine research foresight and analyses, and provides policy recommendations to European institutions as well as national governments. The 34 members are national marine or oceanographic institutes, research funding agencies or national consortia of universities with a strong marine research focus, representing +10,000 scientists from 18 countries. | Belgium, Croatia, Denmark, Estonia, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Turkey, UK |
| Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans) | Intergovernmental platform created in 2011 with 20 member countries and one observing country, open to EU member states and associated countries which invest in marine and maritime research. The aim is to organize and participate in joint research initiatives, aligning objectives and pooling available national financial resources and capacities. For co-funded calls (ERANET Cofunds), national research budgets are supplemented by funding instruments from the European Commission. | Belgium, Croatia, Denmark, Estonia, France, Germany, Greece, Iceland, Ireland, Italy, Malta, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Turkey, UK |
| European Consortium for Ocean Research Drilling (ECORD) | Consortium of 15 countries responsible for funding and implementing ocean drilling scientific expeditions, as part of the International Ocean Discovery Program (IODP) 'Exploring the Earth under the Sea', since 2003. | Austria, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK |
| EuroMarine Network | An association of 60 research and academic organizations from 22 countries assembled in a European marine science network created in 2014 to support the development of emerging scientific topics in marine sciences. It organizes internal competitive calls for proposals, funded from the EuroMarine budget, leveraging larger projects under European, national or joint research funding programmes. The association is self-sustained by membership fees. | Belgium, Croatia, Denmark, Finland, France, Germany, Ireland, Israel, Italy, Morocco, Netherlands, Norway, Peru, Poland, Portugal, Slovenia, South Africa, Spain, Sweden, Tunisia, Turkey, UK |

*Source:* Data adapted from GOSR2020 questionnaire, particularly countries' responses to question 18, and other background research.

In addition to European coordination bodies, many ocean science projects and larger programmes are funded by the European Commission, allowing interactions with a wide range of stakeholders. There were more than 77 projects in the different series of calls for the Horizon 2020 programme,[2] in view of the cross-cutting nature of marine ecosystems, marine and maritime research. Funding takes many forms, depending on the objectives of the projects (e.g. research and innovation actions, coordination and support actions). The European Research Area (ERA) Networks Cofund is a funding instrument designed to support public-public partnerships in the preparation and establishment of networking structures in Europe. The instruments 'top up' existing funding for single joint calls and transnational actions. In ocean sciences, several ERA-Net Cofunds are ongoing (Table 3.3).

**Table 3.3.** Countries' participation in selected European Research Area (ERA) Networks, linked with ocean sciences.

| Selected ERA Net | General information | Participating countries |
|---|---|---|
| BioDivERsA ERA Net | Network of national and regional funding organizations promoting pan-European research on biodiversity and ecosystem services, offering innovative opportunities for the conservation and sustainable management of biodiversity. | Full partners: Austria, Belgium, Bulgaria, Czechia, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Israel, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Switzerland, Turkey, UK |
| Associate partner: Latvia | Intergovernmental platform created in 2011 with 20 member countries and one observing country, open to EU member states and associated countries which invest in marine and maritime research. The aim is to organize and participate in joint research initiatives, aligning objectives and pooling available national financial resources and capacities. For co-funded calls (ERANET Cofunds), national research budgets are supplemented by funding instruments from the European Commission. | Belgium, Croatia, Denmark, Estonia, France, Germany, Greece, Iceland, Ireland, Italy, Malta, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Turkey, UK |
| Cooperation in Fisheries, Aquaculture and Seafood Processing (COFASP) ERA Net | ERA-net cofund coordinating activities to improve the contribution of the marine bioeconomy (i.e. fisheries, aquaculture and seafood processing) to Europe's economic well-being. | Belgium, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Italy, Norway, Portugal, Romania, Spain, UK |
| MartERA ERA Net | ERA-net cofund aiming to strengthen the European Research Area in maritime and marine technologies, as well as blue growth. | Argentina, Belarus, Belgium, France, Germany, Ireland, Italy, Malta, Netherlands, Norway, Poland, Portugal, Romania, South Africa, Spain, Turkey |

*Source:* Data adapted from GOSR2020 questionnaire, particularly countries' responses to question 18, and other background research.

In Africa, many conventions have been established to promote collaboration in the management of basins and coastal areas, contributing to marine scientific cooperation regionally, examples of which are presented in Table 3.4. A number of scientific organizations are active, such as the Western Indian Ocean Marine Science Association (WIOMSA). The Association is dedicated to promoting the educational, scientific and technological development of all aspects of marine sciences throughout the Western Indian Ocean region (consisting of ten countries: Comoros, France (La Réunion), Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia, South Africa and Tanzania).

In the Asia-Pacific region, many regional bodies also support ocean science programmes. As one key international coordination group, the IOC Sub-Commission for the Western Pacific (WESTPAC) was established in 1989 and consists of 22 Member States, mainly in East Asia, South-East Asia, South Pacific and the eastern Indian Ocean. It has several collaborative scientific programmes on ocean processes and climate change, marine biodiversity, seafood safety and security, and the health of ocean ecosystems.

[2] Horizon 2020 has been the biggest EU Research and Innovation programme ever, with nearly €80 billion of funding available over seven years (2014 to 2020) so far. Horizon 2020 is the financial instrument implementing Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness.

Table 3.4. Countries' participation in selected African conventions or programmes, linked to ocean sciences.

| Selected conventions and cooperation mechanisms | General information | Participating countries |
|---|---|---|
| Abidjan Convention | Convention for cooperation in the protection, management and development of the marine and coastal environment of the Atlantic coast of the western, central and southern African regions | Benin, Cameroon, Congo, Côte d'Ivoire, Gabon, Gambia, Ghana, Guinea, Liberia, Nigeria, Senegal, Sierra Leone, South Africa, Togo |
| Barcelona Convention | The Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean is a regional convention to prevent and abate pollution from ships, aircraft and land-based sources in the Mediterranean Sea. This includes but is not limited to dumping, run-off and discharges. Signers agreed to cooperate and assist in dealing with pollution emergencies, monitoring and scientific research. | Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, the European Community, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syria, Tunisia, Turkey |
| Benguela Current Convention & Commission | Multisectoral, intergovernmental initiative based on an environmental treaty for sustainable management and protection (Benguela Current Large Marine Ecosystem BCLME) sustaining human and ecosystem well-being in the south-west African region | Angola, Namibia, South Africa |
| Nairobi Convention | Partnership between governments, civil society and the private sector, providing a mechanism for regional cooperation, coordination and collaborative actions towards a prosperous western Indian Ocean region with healthy rivers, coasts and oceans | Comoros, France, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia, Tanzania, South Africa |

*Source:* Data adapted from GOSR2020 questionnaire, particularly countries' responses to question 18 (see GOSR portal), and other background research.

The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) also regularly convenes large conferences in coordination with different ocean research communities. The Association of Southeast Asian Nations (ASEAN) in its Science and Technology Action Plan (2016–2025) also encourages ocean science cooperation in the region and beyond. Founded in 1947, the Pacific Community (SPC), an international development organization with 26 member countries and territories, aims to harnesses science, knowledge and innovation for sustainable development, for the benefit of their populations in the Pacific. It is home to the Pacific Community Centre for Ocean Science (PCCOS).

### 3.3.2.2. Ocean science funding in developing countries

Many developing countries are home to leading expertise on local coastal and environmental processes. Numerous efforts in these countries are developed to broaden the knowledge base on ocean science with the support of international programmes and by applying mutual learning. However, they are also in need of resources to build up human and technical capacity at the national level, to appropriately translate science into policy actions. Collaboration, partnerships and joint ventures are effective ways of leveraging ocean research funding, as seen in Section 3.3.1, particularly when establishing scientific programmes with and between developing countries, although there are some important challenges in mainstreaming the implementation of these strategies on a wider basis and in establishing long-term programmes. Nonetheless, by sharing personnel and other expertise between research institutes (e.g. modelling, quality assurance and control skills, training), equipment and laboratory facilities, ocean science research can be made more efficient, more accessible and less costly for participating countries and institutions, with clear mutual benefits. This approach can also be encouraged as one component of South-South cooperation.

A few models for establishing such initiatives already exist, providing guidance and best practice, beneficial for the development of new activities:

- The United Nations Economic and Social Commission for Asia and the Pacific includes several capacity building programmes aimed specifically at achieving SDG 14 goals (UN ESCAP, 2018).
- The South-South Framework for Scientific and Technical Cooperation in the South and Tropical Atlantic and the Southern Oceans is a bilateral agreement between South Africa and Brazil for marine and oceanic research, signed in 2017, including joint academic and ship-based training (South Africa DST and Brazil MSTIC, 2017).
- The International Indian Ocean Expedition (IIOE-2) is a large collaborative oceanographic and atmospheric research programme, aiming to gather observational data and research outputs from coastal environments to the deep

sea (IIOE-2, 2020). The 2015–2020 programme engages closely with countries in the region and is also supported by three entities: the Indian Ocean Global Ocean Observing System (IOGOOS) Regional Alliance, an association of over 25 marine operational and research agencies; the Scientific Committee on Oceanic Research (SCOR) in the International Science Council; and the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

- The All Atlantic Cooperation for Ocean Research and innovation (AANChOR) programme is a European H2020 project that promotes the implementation of the Belém Statement on Atlantic Research and Innovation Cooperation[3] — a triangular declaration between South Africa, Brazil and the EU that seeks to increase the understanding of the relationship between marine ecosystems and climate (Claassen et al., 2019). This cooperation aims to integrate the research efforts of many national and international bodies all across the Atlantic, linking with parallel initiatives that focus on the North Atlantic, such as the Galway Statement on Atlantic Ocean Cooperation and the Atlantic Ocean Research Alliance (AORA) between Canada, the EU and the USA.

In addition, international initiatives have programmes that may be linked to funding for ocean science capacity building. The Global Environment Facility (GEF) gathers 183 countries in partnership with international institutions, civil society organizations and the private sector to address global environmental issues, while providing financial support to national sustainable development initiatives. The World Bank serves as the GEF Trust Fund trustee, administering the GEF Trust Fund and channelling funds from donor countries (World Bank, 2020*a*).

Over the past 20 years, the Global Environment Facility (GEF) has provided support, through the GEF International Waters programme (GEF-IW), to assist at least 124 recipient countries to work together within 23 of the world's 66 Large Marine Ecosystems (LMEs, including two LME equivalents, the Pacific Warm Pool and the Caspian Sea). These 66 Large Marine Ecosystems (LMEs) are often referred to as the most productive regions but also those that are also under the greatest pressure. The GEF support in the LME projects (US$285 million, leveraging US$1.14 billion in financing from other partners) enables countries to collectively identify the root causes of the priority issues affecting their shared LMEs through a Transboundary Diagnostic Analysis (TDA), and to develop joint actions to address the root causes through a Strategic Action Programme (SAP) to aid the recovery of ecosystem goods and services.

Since the early 1990s, together with USA's National Oceanic and Atmospheric Administration (NOAA), the International Union for Conservation of Nature (IUCN), United Nations Development Programme (UNDP) and others, IOC-UNESCO has promoted the LME approach both from a conceptual and methodological point of view, as well as on the ground, by contributing to the formulation and implementation of GEF LME projects in various regions, resulting in the development of a wide network of practitioners.

The GEF-5 strategy recognized the above fact and the need to provide nations with additional support to specifically address the challenges of climate variability and change (sea-level rise, ocean warming, ocean acidification, shifts in productivity and fish stocks, and the loss of 'blue forests' and ecosystem resilience). The GEF-7 strategy reconfirmed that IW:LEARN, which incorporates the LME:LEARN, is the GEF-funded cross-agency and multi-actor platform of knowledge exchange and capacity building that supports facilitating partnerships between a range of actors to stimulate conversation and capacity between, and beyond, GEF-funded activities. The GEF further recognized the need to help states to address these challenges through cross-sectoral governance reforms at the local, national and regional levels, by integrating ecosystem-based approaches at the immediate coastal interface through improved Marine Spatial Planning (MSP) and Integrated Coastal Zone Management (ICZM) practices within LMEs and across transboundary water systems. MSP and ICZM practices require examining trade-offs of policy decisions in terms of ecosystem health, as well as ecosystem services and human well-being.

The LME:LEARN and IW:LEARN4 projects were prepared under the leadership of UNDP/GEF with technical input and support from IOC-UNESCO, and are being executed by IOC-UNESCO. The implementation of the projects started in 2016 and was completed in 2020, with a fifth phase of IW:LEARN expected to start in 2021. For the execution of the projects, a Project Coordination Unit (PCU) has been established at IOC-UNESCO.

One of these GEF LME programmes was initiated, under UNDP implementation, between 2008 and 2013 in the South-East Africa region to support the Agulhas and Somali Current Large Marine Ecosystems (ASCLME). It aimed to institutionalize cooperative and adaptive management of this ecosystem, and included the Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, South Africa and Tanzania. It delivered individual marine ecosystem diagnostic analyses (MEDAs) for

[3] The Belém Statement on Atlantic Research and Innovation Cooperation, available at: https://ec.europa.eu/research/iscp/pdf/belem_statement_2017_en.pdf.

each participating country. Another project now follows, the Western Indian Ocean Large Marine Ecosystems Strategic Action Programme Policy Harmonisation and Institutional Reforms (WIO LME SAPPHIRE), including the same countries as those listed above, plus Somalia (UNDP, 2020). SAPPHIRE is implemented by UNDP and executed by the UNEP-based Nairobi Convention Secretariat.

### 3.3.3. Private sector

The private sector is increasingly contributing to funding ocean science programmes, directly and indirectly. Many ocean-related industries require different types of ocean data, from geophysical datasets to information covering whole marine ecosystems, to sustain ongoing or future activities at sea, such as the exploration and extraction of fossil fuels and mineral resources, as well as fisheries. Many companies have developed strong expertise, by partnering with researchers to improve their science-based decision-making, respect regulations and avoid negative environmental impacts on the ocean.

Different data uses lead to different partnerships within the private sector, and various groups of the ocean science community are increasingly being set up for mutual benefit, contributing to the development of fundamental scientific knowledge, but also supporting the mapping, collection, storage and management of relevant ocean data required for commercial companies' operations in a sustainable way.

Some of the financial instruments used by the private sector in these partnerships may typically include grants for PhD programmes and in-kind support via ships of opportunity, provision of archived data to scientists and access to observation (and mooring) stations. Some additional information about the private sector as a user and collector of ocean science data can be found in Chapter 7.

Since the publication of the GOSR2017, a new development in the environment of ocean science funding can be observed: the role of financial investors. These investors increasingly expect the companies which they fund to systematically manage the challenges and opportunities related to sustainable uses of the ocean in a transparent manner.

The objective of most private investment strategies is to achieve the highest possible return within reasonable risks, whether they be financial, technical or reputational. In this context, the broader environmental and social consequences of business operations have become an important marker for many private funds involved in ocean investments.

In Norway, the Government Pension Fund Global was established in the 1990s to ensure responsible and long-term management of revenue from Norway's oil and gas resources to benefit current and future generations. In 2018, Norges Bank Investment Management, which manages the fund and the assets of more than 9,000 companies, developed standards for sponsored companies to promote ocean sustainability in their business strategy (Norges Bank Investment Management, 2018). These standards are closely aligned with international guidelines, such as the UN Global Compact, the UN Guiding Principles on Business and Human Rights, the G20/OECD Principles of Corporate Governance and the OECD Guidelines for Multinational Enterprises, and also provide practical measures: companies, for instance, are required to conduct environmental impact assessments vis-à-vis the ocean, adopt precautionary approaches, improve the transparency of ongoing and planned activities, and put in place strategies to prevent or significantly reduce ocean pollution due to commercial activities. Since 2018, many other investment funds have included requirements concerning sustainable use of the ocean in their corporate funding strategies.

### 3.3.4. Foundations and private donors

Philanthropy is becoming an increasingly important source of funding to advance science. As already recognized in the GOSR2017, funding from private foundations and donors resulted and continues to result in groundbreaking research, while catalysing new collaborations and additional resources (IOC-UNESCO, 2017).

Philanthropic funding may take different forms, such as endowments, donations from companies and individuals (including high-net-worth individuals and crowdfunding) and legacies, as well as income from royalties, dividends and lotteries.

Although data remain scarce, the number of private foundations, as well as the number of corporate donation programmes involved in ocean activities, seem to be growing. Based on grant data collected by the Foundation Centre, a total of some US$500.5 million were allocated to ocean-related projects in 2017, out of which US$149.4 million were allocated to more than 1,000 marine science projects (Figure 3.4) Over 5 years, from 2013 to 2017, private foundations and donors provided around US$668.2 million to marine science projects through some 6,000 different grants.[4]

[4] See Foundation Maps Platform website: https://fundingtheocean.org/funding-map.

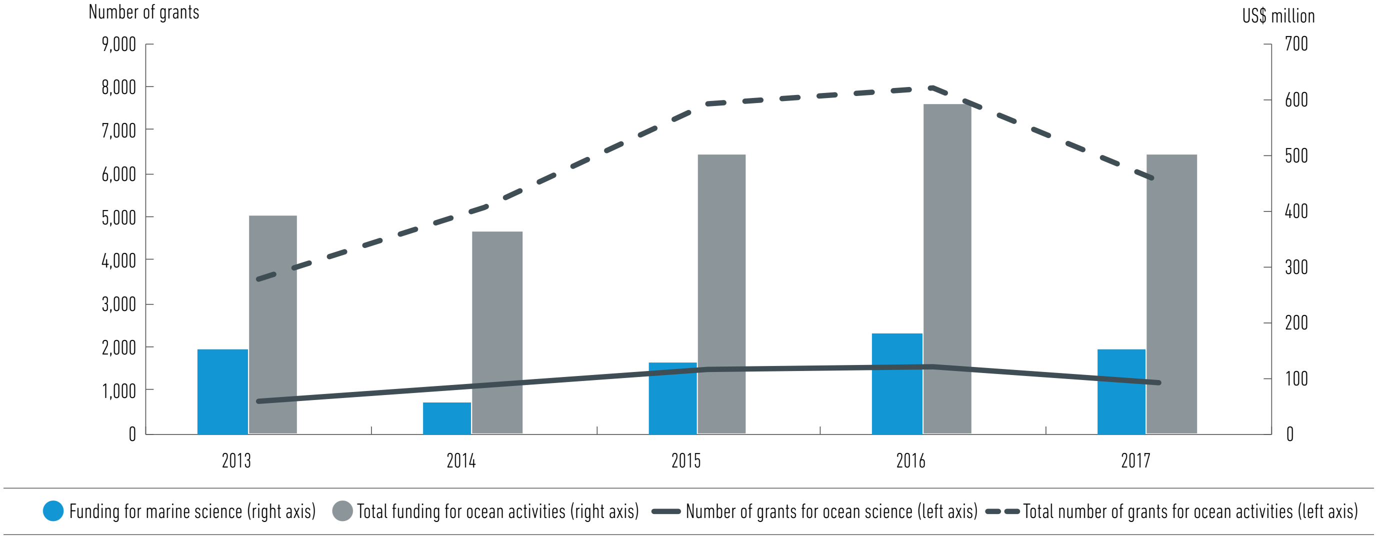


**Figure 3.4.** Funding of marine science projects and number of grants by private foundations and donors (2013–2017). Categories based on the taxonomy used by the Foundation Centre. Only private foundations and donors are included in this graph, and include the following categories: corporate giving programme, community foundation, company-sponsored foundation, independent foundation, NGO, operating foundation and public charity. Excluded from the assessment are US federal agencies and public foundations supported by government funding (e.g. US National Science Foundation). The Foundation Centre divides funding among four main categories, although there may be overlaps: marine science, oceans and coastal waters, coral reefs and aquatic wildlife protection, aquaculture and fisheries, all aggregated here under the term 'ocean activities' to compare the share of ocean science funding with overall ocean activities funding.
*Source:* Information adapted from the Foundation Centre's Foundation Maps Platform: https://fundingtheocean.org, accessed March 2020.

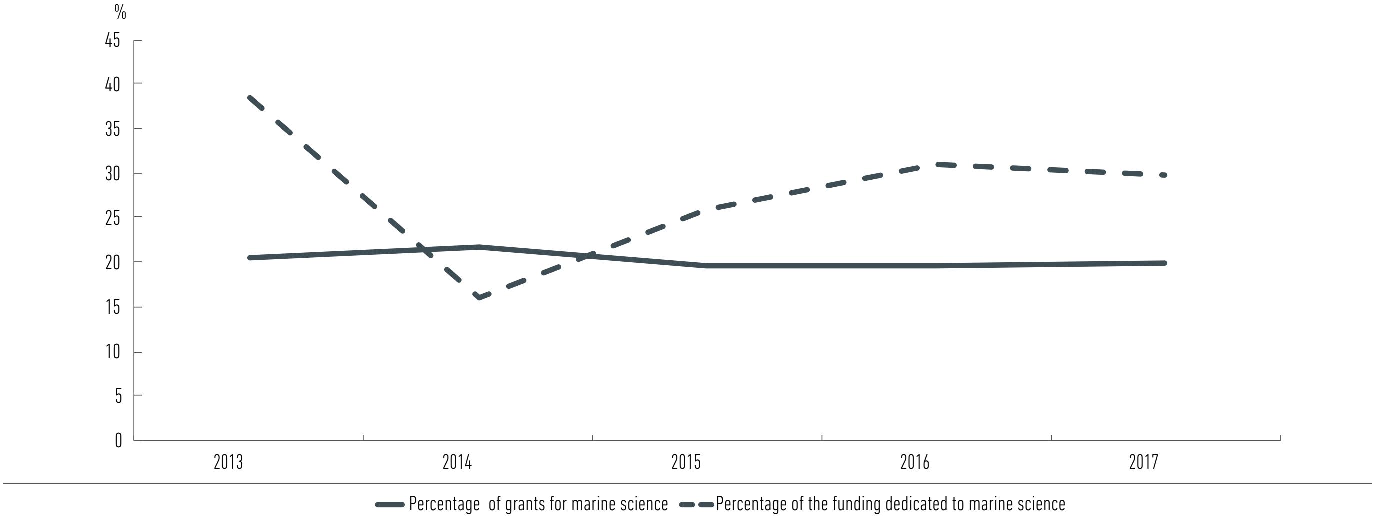


**Figure 3.5.** Percentage of funding and number of grants dedicated to marine science as a share of total funding and number of philanthropic grants to ocean-related projects (2013–2017).
*Source:* Information adapted from the Foundation Centre's Foundation Maps Platform: https://fundingtheocean.org, accessed in March 2020.

Although the data presented do not account for all grants and projects (many of which are funded for three years or longer) and some may be double-counted, it can be estimated that marine science projects received an average of 25–30% of all ocean-related philanthropic funding between 2015 and 2017 (Figure 3.5).

Foundations, many of which are based in the USA, support ocean-related projects, including large-scale ocean science programmes. In 2017, for example, the David and Lucile Packard Foundation provided 12 grants with a value of US$53 million for marine science projects, with the Monterey Bay Aquarium Research Institute as the largest beneficiary (US$43.4 million). Further, the Gordon and Betty Moore Foundation provided about US$30 million for 29 ocean science projects, with the NGO The Ocean Conservancy receiving the largest grant that year (approximately US$7 million).[5]

In order to foster further collaboration between the various foundations in the lead-up to the Ocean Decade, the Foundations Dialogue for the Ocean Decade was initiated in early 2020. It brought together for the first time the world's leading ocean philanthropies, with the aim of encouraging resource mobilization and partnerships for financing scientific innovation (IOC-UNESCO, 2020). Private foundations and donors will certainly play a key role in the funding of small- and larger scale ocean science projects during the forthcoming ten years.



### *3.3.5. Exploring additional innovative approaches to fund ocean science*

Like other scientific domains, ocean science is starting to benefit from innovative funding mechanisms. They include transdisciplinary research funds, crowdfunding, lotteries and levies.



[5] See Foundation Maps Platform website. Available at: https://fundingtheocean.org/funding-map.

### 3.3.5.1. Allocation of funds from sources not traditionally accessed by ocean science: Transdisciplinary research

Various global portfolios of funds exist that were not specifically established for marine research and development; nevertheless, their target disciplines are integrally related to ocean science and can benefit from the synergies created with other disciplines.

Critical global concerns and priorities, such as ocean warming, deoxygenation and acidification, coral bleaching, habitat damage, resource degradation and loss of fish stocks are frequently cross-cutting issues, offering opportunities for transdisciplinary research. Facilities such as the Adaptation Fund, the Least Developed Countries Fund and the Green Climate Fund *inter alia* may be worth exploring more closely with a view to establishing closer collaborations between projects funded from these sources. This might be accomplished without altering the governing rules or disadvantaging countries already eligible for such funds.

### 3.3.5.2. Crowdfunding

As in other fields, crowdfunding can be a valuable and productive tool to obtain financial resources for ocean science research, especially for private institutions, NGOs and individuals involved in micro, small- and medium-scale projects that have the potential to yield tangible, immediate local and community benefits. This method of fundraising has proven to be attractive to independent benefactors, philanthropists and small donors committed to equitable and sustainable development of access to ocean resources, locally, regionally and globally. Some examples of projects funded by this mechanism include:

- The 'Ocean Cleanup' project, initiated in Amsterdam on the INDIEGOGO crowdfunding platform, raised in excess of US$2.0 million in 100 days from the contributions of more than 38,000 supporters. The aim of the initiative is to assist with the removal of plastics from the world's oceans.
- A crowdfunding initiative launched by the Fathom Fund to assist with rehabilitation of habitats and monitoring of contaminants entering the Salish Sea (a network of coastal waterways extending from the south-west of British Columbia, Canada, to the north-west of Washington State in the USA).[6]
- A project on the island of Palau in the Pacific which established a 'no-take marine protected area' covering 600,000 km$^2$ of the country's territorial waters. The initiative was funded from a government-led crowdfunding campaign called 'Stand with Palau', which raised US$53,000 from more than 400 small donations. The funds were used to purchase boats and drones for monitoring, mooring buoys and staffing.[7]

### 3.3.5.3. Lotteries

Some jurisdictions have also raised funding for scientific research by establishing national, state and provincial lotteries. Such facilities may be administered by government agencies or by private sector operators licensed by the government.

In the UK, the National Lottery Community Fund is responsible for distributing 40% of all the money raised for good causes by the National Lottery. In 2018, for example, it provided grants to the Cetacean Research and Rescue Unit to deliver marine stewardship workshops to schools and youth groups.[8]

The Dutch National Postcode Lottery provides 60% of its annual gross earnings to local and international NGOs for public causes, including nature conservation. Until 2002, for example, the lottery had approved grants to the WWF totalling US$128 million for biodiversity conservation activities that included marine research projects in the Gulf of California area of Mexico (Spergel and Moye, 2004).

As a final example, Oregon, a state on the west coast of the USA, launched a unique lottery. The Oregon Lottery amended in 1998 the state constitution that mandates the allocation of 15% of the revenues for state parks, restoration and protection of salmon, watersheds and habitat to be '...divided evenly between state parks and statewide restoration and protection of salmon, watersheds, and habitat' (Spergel and Moye, 2004).

### 3.3.5.4. Levies

Levies are legislated special taxes, and represent another type of instrument that has been successfully applied in some countries to generate funding for a variety of purposes, including marine and coastal research programmes. One example is the Green Fund Levy, implemented by the Government of Trinidad

6 See: https://fathom.fund/news/2018/12/5/fathom-fund-launches-pilot-crowdfunding-campaign.

7 See: https://www.scientificamerican.com/article/island-nation-sets-up-worlds-first-crowdfunded-marine-protected-area; https://grist.org/living/this-is-what-happens-when-you-crowdfund-an-awesome-marine-park; https://news.nationalgeographic.com/news/2014/06/140617-pacific-marine-reserves-ocean-environment.

8 See Foundation Maps Platform website. Available at: https://fundingtheocean.org/funding-map.

and Tobago in the Caribbean. The facility was established by an Act of Parliament in 2000 and currently represents a tax of 0.3% on the gross sales of businesses operating in the country. It raised an estimated US$9 million in 2018. The levy is used to fund environmental projects, especially those which seek to mitigate the environmental impacts of terrestrial and marine pollution.

## 3.4. Selected case studies on funding streams

This section provides some selected case studies with information on funding streams and mechanisms, featuring Norway, USA and the Caribbean.

### *3.4.1. Norway*

The Research Council of Norway (RCN) invests in research and innovation that builds knowledge for a sustainable future and meets major societal challenges. The RCN is financed by 15 ministries. In 2019, the RCN allocated NOK 11 billion (approximately US$1.07 billion) to research and innovation initiatives across all possible thematic areas. The RCN is a key player in Norwegian research and development, advising the government, providing research funding (e.g. supporting basic and applied research, implementing national thematic priorities, investing in all science and technology fields, and supporting private R&D), supporting networking, dissemination and internationalization (Horizon 2020 is the main area of international research collaboration, and Norway is fully integrated in the EU research funding). The RCN's Ocean Secretariat is responsible for coordinating and pursuing Norwegian efforts related to the Ocean Decade.

Approximately NOK 1 billion (around US$98 million) of the RCN budget was used to finance ocean science in 2019. This is roughly 30% of the financial support to ocean science in Norway. Industry is financing 36% of this amount, and direct funding provided to universities and research institutes represents 23% of it.

The objective of the research is to develop knowledge and solutions to maintain clean, rich seas for future generations, and to build a strong basis for sustainable ocean management and ocean-based industries, now and for the future. Research and innovation related to petroleum and maritime activities are not included in this definition of marine research. The approximate NOK 1 billion for marine research and innovation is used on a variety of activities detailed below. The two most important programmes include marine resources and the environment, and aquaculture; other programmes focus on biotechnology, polar research and climate activities.

- The research programme Marine Resources and the Environment provides funding for research on the marine environment and seeks to generate knowledge about ecosystems in ocean and coastal areas and the impact of pressures from human activity. Research activities aim to strengthen the basis for sustainable management and value creation, based on marine resources and other ecosystem services. The programme encompasses the entire value chain for wild organisms, from harvesting to processing to markets.
- The Aquaculture programme provides funding for research and innovation to generate knowledge and solutions for socially, economically and environmentally sustainable growth and development in the Norwegian aquaculture industry. Programme activities are intended to maintain and further develop Norway's leading position in aquaculture research. The programme encompasses the entire value chain for the production of fish and other marine species, from selective breeding and genetics to production and markets.
- The programme Biotechnology for Innovation provides funding for research and innovation to promote the development and application of biotechnology in a responsible manner. The programme focuses on the agricultural, marine, industrial and health sectors in particular.

Norway also supports some independent projects such as The Nansen legacy,[9] with a total budget of NOK 740 million over six years. The Nansen Legacy is a novel and holistic Arctic research project that aims to provide integrated scientific knowledge on the rapidly changing marine climate and ecosystem. It is envisaged that the project will result in a new knowledge base, required to facilitate a sustainable management of the northern Barents Sea and adjacent Arctic Basin through the twenty-first century.

In addition to the thematic programmes, there are a number of initiatives that contribute to the wider ocean research and innovation ecosystem:

- The National Financing Initiative for Research Infrastructure seeks to build relevant, up-to-date infrastructure that is accessible to the Norwegian research community and trade and industry. New infrastructure contributes to research

[9] The Nansen Legacy https://arvenetternansen.com/project-description.

and innovation at the international forefront of areas of importance for Norwegian society, such as environmentally friendly energy, technology for future Norwegian industrial products and improved health.

- The Centres for Research-based Innovation develop expertise in fields of importance for innovation and value creation. Through long-term research, conducted in close collaboration between research-performing companies and prominent research groups, the Research-Based Innovation (SFI) centres aim to enhance technology transfer, internationalization and researcher training. The scientific merit of the research must be of high international calibre.
- And finally, the SkatteFUNN R&D tax incentive scheme is a government programme designed to stimulate research and development in Norwegian trade and industry. The incentive is a tax credit and comes in the form of a possible deduction from a company's payable corporate tax. RCN is responsible for the application process and approval.

### *3.4.2. USA*

Research, funding and application of ocean science in the USA derives support from many federal agencies.

This diversity of stakeholders is illustrated by the membership of the federal interagency Subcommittee on Ocean Science and Technology, under the National Science and Technology Council (Executive Office of the President), which includes nine departments and six independent agencies. The subcommittee is co-chaired by the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation (NSF), representing two of the major supporters of ocean science in the US Government. For support of academic scientific research, NASA and the Office of Naval Research, Department of the Navy are also major sponsors (National Research Council, 2015). The remaining departments and agencies all have dedicated programmes that rely on ocean science and technology but represent a smaller fraction of the overall federal investment in ocean research.

In addition to federal investments, ocean science receives support from the states, directly from state natural resource departments and in partnership with federal and regional programmes, such as the National Sea Grant College Program and the regional associations of the US Integrated Ocean Observing System. Outside of government, ocean science in the USA also receives support from private industry, foundations and other NGOs.

Most academic scientists receive support through competitive awards, typically grants or contracts. NSF funds most of the investigator-initiated research, with the emphasis on basic research to advance fundamental knowledge. Other agencies may support both investigator-initiated and targeted research that addresses the science required for that agency's mission. In addition to these extramural programmes, many agencies directly employ scientists to conduct research on critical issues for their agencies, such as NOAA's programmes on ocean acidification, sea level change and stock assessment for fisheries.

In 2018, the Subcommittee on Ocean Science and Technology produced *Science and Technology for America's Oceans: A Decadal Vision*.[10] The report lays out priorities for the federal ocean research portfolio through identification of five goals: (1) Understand the ocean in the earth system; (2) Promote economic prosperity; (3) Ensure maritime security; (4) Safeguard human health; and (5) Develop resilient coastal communities (US Subcommittee on Ocean Science and Technology, 2018). Within these broad themes, objectives and near-term opportunities are identified. For example, the document describes how advancing data collection and analysis could be used to support earth system prediction models and decision-support tools. To advance these goals, the report calls for partnerships across the US federal government departments and agencies, states and territories, industries and NGOs, as well as international partnerships, to enhance collaboration and coordination in ocean science programmes, including support for research and research infrastructure.

In November 2019, the theme of partnerships was advanced through the White House Summit on Partnerships in Ocean Science and Technology, which assembled a large group of experts and stakeholders from various sectors to promote partnerships for ocean science and technology (US Ocean Policy Committee, 2019). Although the USA supports a robust ocean science community, the demand still exceeds the available resources. Hence, addressing the full spectrum of societal needs would benefit from the development of effective and efficient partnerships across sectors and governments.

10 See https://www.noaa.gov/sites/default/files/atoms/files/Science%20and%20Technology%20for%20Americas%20Oceans%20A%20Decadal%20Vision.pdf.

### 3.4.3. The Caribbean

The Caribbean, with its 13 countries and 17 dependent territories, is host to beautiful marine landscapes and rich biodiversity, which have drawn tourists from across the globe for decades. The region, however, is extremely vulnerable to climate change and natural disasters (World Bank, 2020*b*). The importance of developing sustainable development strategies, building on marine resources, has grown in most countries, particularly the SIDS (UN General Assembly, 2018).

In that context, the Caribbean Community Climate Change Centre (CCCCC) plays an important role in leveraging funds for ocean science research. It was established by agreement between the heads of government of the Caribbean Community (CARICOM) in February 2002. Its mandate is to coordinate the region's response to the risks posed by global climate change, by providing scientific, financial and policy support to CARICOM member states as they seek to implement effective adaptation and mitigation strategies. Given the vital importance of marine and coastal resources to the economic and social development of the Caribbean, the centre has been focusing on strengthening regional capacity to manage these assets in a sustainable manner, as a component of its strategy to build resilience to global climate change.

Since 2013, the centre has been able to secure funding from the EU and USAID for the purchase and deployment of critical monitoring and detection equipment, including Coral Reef Early Warning Stations (CREWS). These provide continuous, real-time oceanographic and atmospheric data required for predicting the likelihood of coral bleaching events, and for developing effective, evidence-based strategies for managing a suite of other marine and coastal assets. Table 3.5 gives a breakdown of costs of deployment of ten CREWS stations in the Caribbean, coordinated by the CCCCC.

Coastal reefs protect the coasts from severe impacts by storms and wave erosion in many of the Caribbean countries and territories. They provide key ecosystems services contributing to sustainable fisheries and tourism (Manfrino and Dell, 2019). Given the concerns regarding the effects of increasing sea temperatures on coral reefs, reducing human pressure is the most urgent action that the different Caribbean communities can undertake to protect theirs reefs, while pursuing capacity building to further ocean research.

In that context, the Association of Marine Laboratories of the Caribbean (AMLC)[11] promoted joint marine research projects and knowledge transfer in the Caribbean. It is a confederation of 40 marine research, education and resource management institutions, with an annual AMLC meeting, hosted by member laboratories and offering grants for young researchers.

**Table 3.5.** Cost of CREWS deployed by the CCCCC, 2013–2018.

| Country | No. of stations | Cost (US$) | Shipping, installation and commissioning (US$) | Total cost per country (US$) |
|---|---|---|---|---|
| Antigua and Barbuda | 1 | 62 250 | 8 000 | 70 250 |
| Barbados | 1 | 123 600 | 26 858 | 150 458 |
| Belize | 1 | 123 600 | 26 858 | 150 458 |
| Dominican Republic | 2 | 247 200 | 53 716 | 300 916 |
| Grenada | 1 | 62 250 | 8 000 | 70 250 |
| St. Kitts and Nevis | 1 | 62 250 | 8 000 | 70 250 |
| St. Lucia | 1 | 62 250 | 8 000 | 70 250 |
| St. Vincent and the Grenadines | 1 | 62 250 | 8 000 | 70 250 |
| Trinidad and Tobago | 1 | 123 600 | 26 858 | 150 458 |
| | | **Total cost of CREWS programme (US$)** | | **1 103 540** |

*Source:* CCCCC, Belize

[11] See http://www.amlc-carib.org/index.html.

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# 4

# Research capacity and infrastructure

# 4. Research capacity and infrastructure

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## 4.1. Introduction

In light of the upcoming UN Decade of Ocean Science for Sustainable Development (2021–2030) (the 'Ocean Decade'), the transformation of ocean science capabilities, enhanced management tools to cope with threats to ecosystems goods and services, and the growing challenges related to the Sustainable Development Goals (SDGs) in the 2030 Agenda for Sustainable Development, will require countries around the world to accelerate the development of human and technical capacities through individual commitments and partnerships at local, national, regional and global levels.

The quality of ocean science outcomes depends heavily on human resources and technical infrastructure supported by appropriate financial means. Distributing funds that match national needs and demands requires an assessment of existing capacities. Therefore, this chapter examines existing global ocean science capacities in terms of human resources, including gender and age distribution, ocean science institutions, observation platforms and tools used for sustained ocean observations. The chapter further presents ocean science capacity development strategies and inspiring examples of transfer of marine technology, including some regional pilot activities.

One important source of data used in the current assessment is the GOSR2020 questionnaire. The questionnaire from the first edition of the GOSR was also used as an additional data source and for comparison purposes whenever possible (see Chapter 2 for further information). Consequently, the analysis, which is based on the data submitted by Member States only, is not always complete and comparisons are not always possible. In this regard, it should be noted that the information available for Asia is very limited. Further, this chapter does not address the significant role played in ocean science by the private sector; the GOSR2020 questionnaire did not specifically refer to the private sector, and thus the information provided by Member States is insufficient to assess its specific role in its own right.

Complete information submitted by Member States is available via the GOSR2020 portal.[1]

[1] See GOSR2020 portal https://gosr.ioc-unesco.org.

## 4.2. Human resources

A core objective of the Ocean Decade (IOC-UNESCO, 2018) is to improve the scientific knowledge base through capacity development for the regions and groups that are presently limited in capacity and capability. Human capacity development in ocean science feeds into a complex web where education, innovation, growth and employment are closely interlinked. This implies that education and training systems in ocean science are much more than a science support mechanism. The human resources capacity necessary for ocean science is determined by different criteria, mainly related to the qualification, knowledge and experience to work in research. This section of the chapter examines available data and information on the number of ocean science personnel, with particular emphasis on gender and age distribution.

There is growing awareness of the urgent need to manage the ocean environment in a sustainable manner to secure the ecosystem services that the ocean provides. If we are to make rational and sustainable use of the resources available in the sea, we need skilled and trained personnel who can provide science-based knowledge as a basis for decision-making, as well as personnel able to develop *inter alia* new technologies, methodologies and products through research and innovation. Ocean science requires human resources with high motivation, knowledge, experience and curiosity who can help to improve our understanding of the ocean and related processes. The people who make up the workforce within the field of marine science vary in number, gender, age, education level, etc. between countries and over time.

For the GOSR2020, the total number of ocean science personnel in a number of countries, where data are available for comparison, and its change (percentage variance), was examined based on the data compiled for 2013 and 2017 (Figure 4.1). Between 2013 and 2017, there was an increase in the number of personnel in 17 of the 27 countries. However, total numbers are most probably an underestimation, as in some cases national submissions were from certain agencies or institutions only, due to insufficient or non-availability of the required data and information for the whole country (see Table 4.1 for further information about subsets of data utilized in Figure 4.1 for 2017).

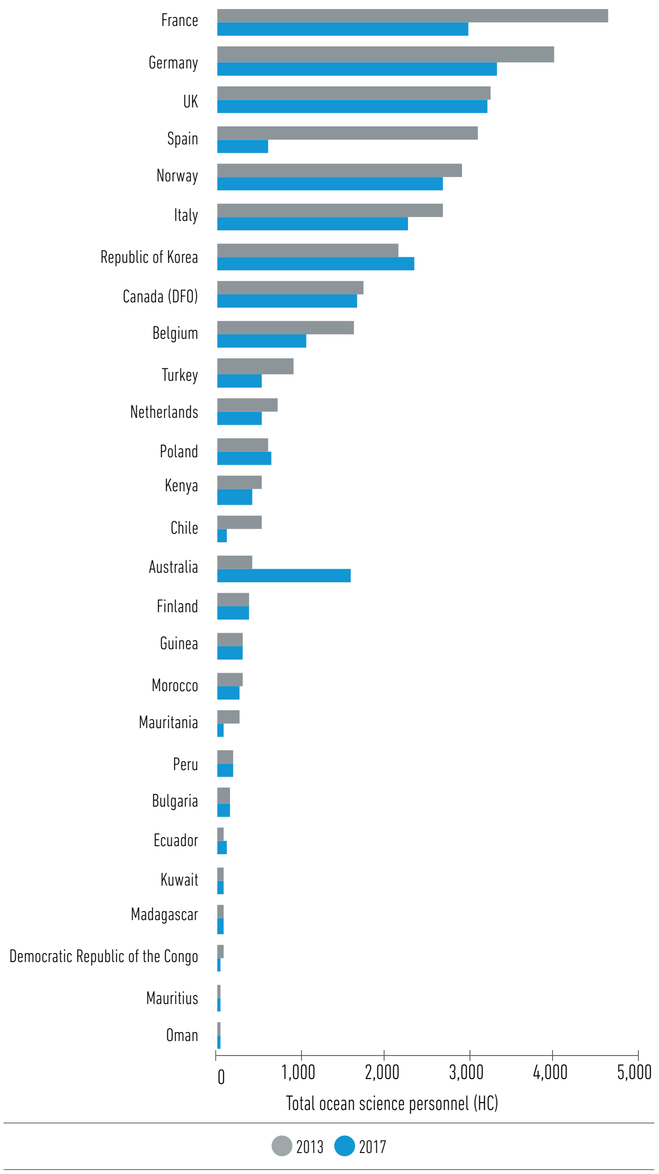


**Figure 4.1.** Total ocean science personnel (headcount) for 26 countries that provided information for 2013 and 2017.[2,3]
*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires.

The total number of ocean science personnel (researchers and technical staff) in 45 countries ranges from 12 in El Salvador to 13,434 in the USA (Table 4.1). Based on available data, on average, 53% of ocean science personnel are researchers (the average ratio of scientists to technical support staff is 1:0.89). However, it should also be noted that some of the data presented here are only rough estimates (e.g. Germany, Kenya, Morocco, Peru, Portugal, South Africa and USA) or are from a subset of the national ocean research institutions (e.g. Australia, Canada, Chile, Denmark, Japan, Netherlands, Mauritania, Mauritius, Mozambique and Poland). In Norway's response to the GOSR2020 questionnaire, for example, it was specified that personnel from the private sector were not included in the data and, although not specified, it seems to be the case for many other countries. Also, some data were provided as total ocean science personnel with no breakdown for any categories, or the only number of researchers was disaggregated from the total. Some countries only provided numbers for full-time equivalents (FTEs) and not headcount (HC).

2 'Country' acronyms: DFO - Fisheries and Ocean Canada.

3 Subsets of institutions for Australia and Spain are very different for 2013 and 2017. In 2017, Australia provided data for a subset of institutions; in 2013, Spain provided data for the Spanish Institute of Oceanography (IEO) only.

4 'Country' acronyms: DFO - Fisheries and Ocean Canada; OSJ - Oceanographic Society of Japan; WMR - Wageningen Marine Research; NIOZ - Royal Netherlands Institute for Sea Research; SHOA - Servicio Hidrográfico y Oceanográfico de la Armada; PUC - Pontifical Catholic University of Chile; UCSC - Catholic University of the Most Holy Conception; IMROP - Mauritanian Institute of Oceanographic and Fisheries Research; MOI - Mauritius Oceanography Institute; UoM - University of Mauritius; MMS - Mauritius Meteorological Services (ocean science personnel: researchers and technicians only); CSMZAE - Department for Continental Shelf, Maritime Zones Administration & Exploration.

5 'Country' subsets of institutions: Australia: The Integrated Marine Observing System, Institute for Marine and Antarctic Studies, Australian Antarctic Division, Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine National Facility; Great Barrier Reef Marine Park Authority. Colombia: Not specified. Denmark: Aalborg University; Aarhus University (Department of Bioscience and Department of Geoscience); Danish Coastal Authority; Danish Environmental Protection Agency; Defence Centre for Operational Oceanography; Danish Meteorological Institute; University of the Faroe Islands; NIVA Danmark; Ramboll; Roskilde University, Department of Science and Environment; GEUS; Fiskaaling; Technical University of Denmark (National Food Institute, National Institute of Aquatic Resources, National Space Institute); The Faroe Marine Research Institute; University of Copenhagen (Department of Biology, Department of Food and Resource Economics, Department of Geosciences and Natural Resource Management, Globe Institute, Natural History Museum, Niels Bohr Institute); University of Southern Denmark. Mozambique (for researchers only): National Institute for Hydrography and Navigation (INAHINA), Universidade Eduardo Mondlane; National Marine Institute (INAMAR); National Institute of Fisheries Research (IIP). Poland: Institute of Oceanology - Polish Academy of Sciences; Institute of Meteorology and Water Management National Research Institute; National Marine Fisheries Research Institute; Pomeranian University in Slupsk; Institute of Oceanography University of Gdańsk; Institute for Marine and Coastal Sciences University of Szczecin.

**Table 4.1.** Total ocean science personnel, total ocean science researchers, relative proportion (%) of researchers to total ocean science personnel by headcount (HC).[4,5] Figures provided are for the latest year for which data is available. In the absence of HC, full-time equivalents (FTEs) are provided (indicated in brackets). Cases where appropriate data were not available are marked with '–'.

| Country | Total ocean science personnel (HC) | Total ocean science researchers (HC) | % of ocean science personnel who are researchers |
|---|---|---|---|
| USA (2013) | 13 434 | 5 874 | 43.7 |
| Iran, Islamic Republic of (2015, FTE) | 5 890 | 879 | 14.9 |
| South Africa (2017) | 5 000 | 2 000 | 40.0 |
| France (2017) | 4 637 | 3 298 | 71.1 |
| Portugal (2016) | 4 022 | 3 326 | 82.7 |
| Germany (2013) | 3 328 | 2 385 | 71.7 |
| UK (2017) | 3 275 | 1 394 | 42.6 |
| Spain (2017) | 3 101 | 1 704 | 55.0 |
| Norway (2017) | 2 907 | 1 955 | 67.3 |
| Italy (2017) | 2 708 | 1 657 | 61.2 |
| Republic of Korea (2017) | 2 159 | 537 | 24.9 |
| Canada (2017, DFO) | 1 760 | 186 | 10.6 |
| Belgium (2018) | 1 617 | 1 179 | 72.9 |
| Japan (2017, OSJ) | – | 1 591 | – |
| Sweden (2017) | – | 1 200 | – |
| India (2013) | 971 | 452 | 46.5 |
| Denmark (2017–2018, subset of institutions) | 968 | 561 | 58.0 |
| Turkey (2017) | 933 | 710 | 76.1 |
| Mozambique (2017, subset of institutions for researchers) | 800 | 50 | 6.3 |
| Netherlands (2017, WMR, NIOZ, Deltares) | 731 | – | – |
| Ireland (2017) | 687 | 561 | 81.7 |
| Poland (2017, subset of institutions) | 625 | 204 | 32.6 |
| Brazil (2014) | – | 606 | – |
| Kenya (2017) | 530 | 150 | 28.3 |
| Chile (2017, SHOA, PUC, UCSC) | 526 | 230 | 43.7 |
| Australia (2017, subset of institutions) | 426 | 110 | 25.8 |
| Finland (2017) | 370 | 201 | 54.3 |
| Guinea (2017) | 313 | 156 | 49.8 |
| Morocco (2017) | 300 | 200 | 66.7 |
| Mauritania (2017, IMROP) | 259 | 68 | 26.3 |
| Peru (2017) | 190 | 60 | 31.6 |
| Bulgaria (2017) | 156 | 51 | 32.7 |
| Croatia (2013) | 150 | 110 | 73.3 |
| Ecuador (2017) | 101 | 46 | 45.5 |
| Dominican Republic (2013) | 94 | 29 | 30.9 |
| Kuwait (2017) | 90 | 45 | 50.0 |
| Benin (2013) | 89 | 67 | 75.3 |
| Madagascar (2017) | 88 | 50 | 56.8 |
| Suriname (2013) | 75 | 5 | 6.7 |
| Democratic Republic of the Congo (2017) | 67 | 12 | 17.9 |
| Angola (2013) | 55 | 31 | 56.4 |
| Colombia (2017, FTE, subset of institutions) | 48 | 28 | 58.3 |
| Mauritius (2017, MOI, UoM, MMS and CSMZAE) | 42 | 24 | 57.1 |
| Oman (2017) | 28 | 15 | 53.6 |
| El Salvador (2017) | 12 | 4 | 33.3 |

*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires.

4

Figure 4.2 illustrates in more detail the HC of national ocean science researchers employed per million inhabitants, based on the subset of countries presented in Table 4.1, and for the latest year for which data were available. Based on the information gathered, European countries, such as Norway and Portugal, have the highest ratio of researchers as against the total population, with more than 300 researchers employed per million inhabitants.

When comparing the number of ocean science researchers to the approximated length of national coastline,[6] no direct relationship between the length of coastline and the number of ocean science researchers is evident (Figure 4.3).

Finally, based on the data provided in Table 4.1, the number of ocean science researchers in relation to the gross domestic product (GDP, purchasing power parity (PPP), current million US$), is displayed in Figure 4.4. As in the number of researchers employed per million inhabitants (Figure 4.2), Portugal and Norway lead the way.

Unlike the results presented in Figure 4.2, some developing countries (e.g. Guinea, Mauritania, Benin and South Africa) showed comparable, or even higher, levels of national ocean science researchers (headcount) in relation to the GDP than some developed countries (e.g. Sweden, Belgium, Denmark) (Figure 4.4).

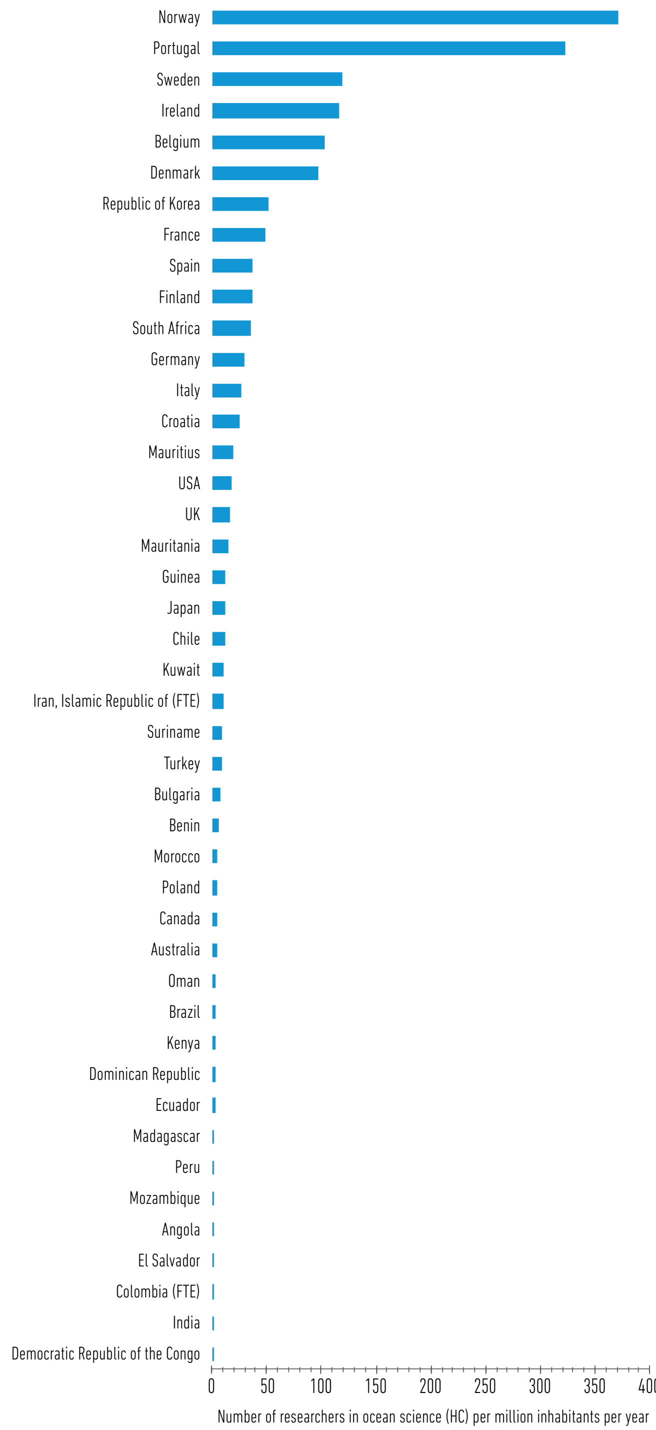


**Figure 4.2.** Number of national ocean science researchers (HC) employed per million inhabitants. Based on the subset of data presented in Table 4.1., researchers employed in ocean science per million inhabitants were extracted for the year indicated for each country.
*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaire (researchers) and World Bank DataBank (inhabitants).[7]

[6] *Source:* CIA World Factbook (km of coastline), available at https://www.cia.gov/library/publications/resources/the-world-factbook.

[7] See https://databank.worldbank.org/source/world-development-indicators (accessed 17 December 2019).

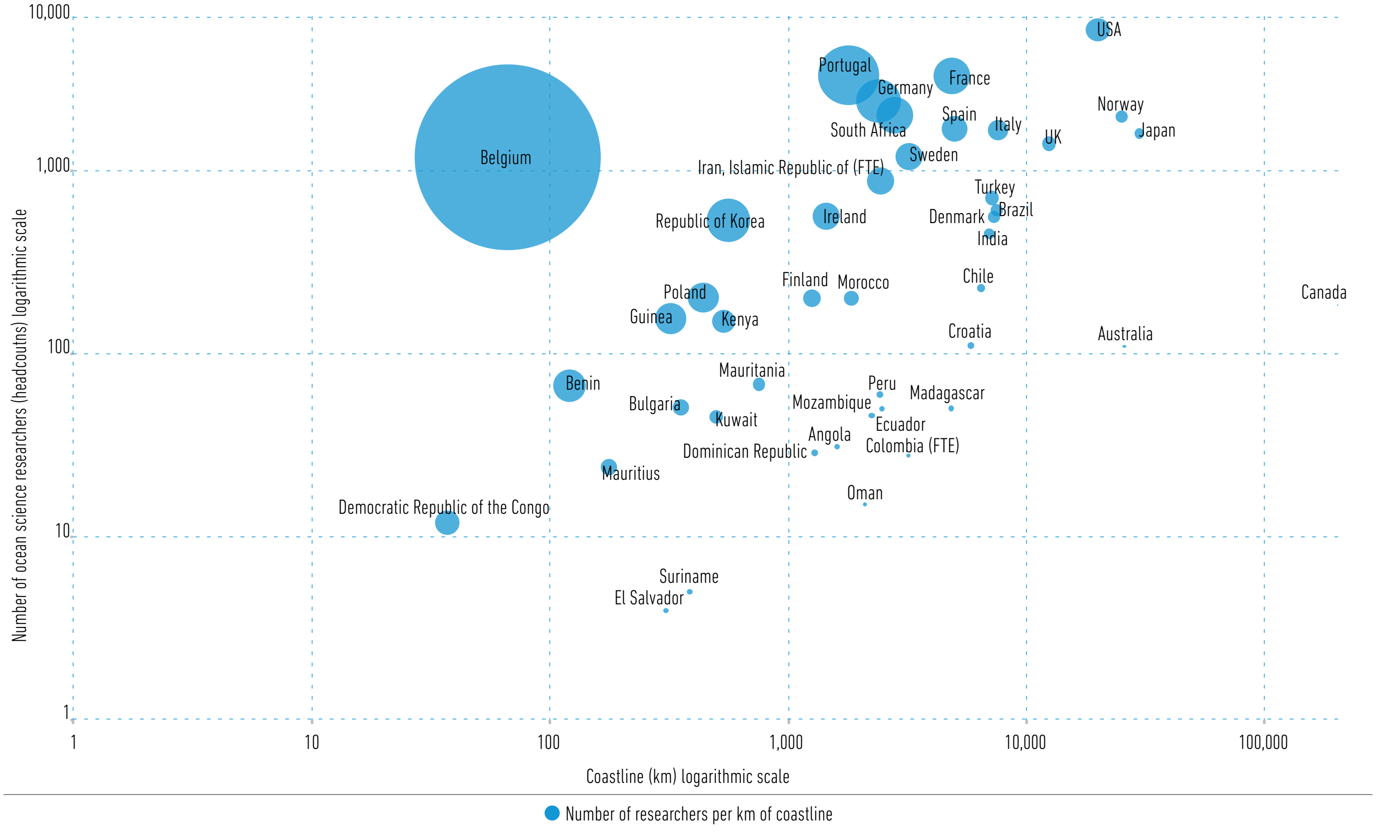


**Figure 4.3.** Number of national ocean science researchers (HC) per km of coastline. The size of the bubble is proportional to the number of researchers per km of coastline for each country (Belgium reported 18 ocean science researchers per km). Based on the subset of data presented in Table 4.1, researchers employed in ocean science.
*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires (researchers) and the CIA World Factbook.[8]

8. CIA World Factbook (km of coastline), available at https://www.cia.gov/library/publications/resources/the-world-factbook/ (accessed 13 February 2020).

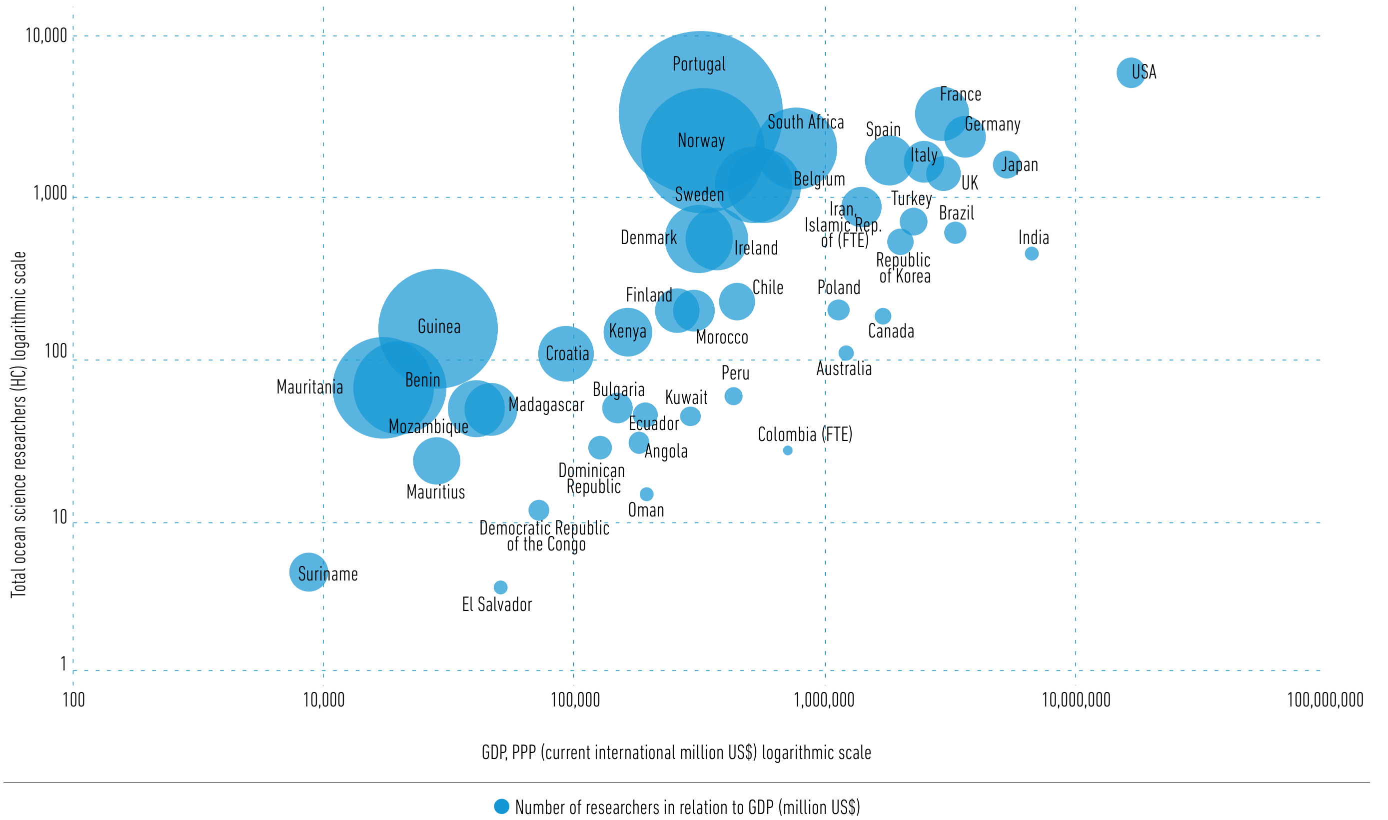


**Figure 4.4.** Number of national ocean science researchers (headcount) in relation to the gross domestic product (GDP, purchasing power parity (PPP), current million US$) extracted for each country and year. The size of the bubble is proportional to the number of researchers per GDP for each country.
*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires (researchers); the Global Economic Monitor (GDP, current US$, millions, seasonal adjustment), available at the World Bank Databank.[9]

Unlike the results presented in Figure 4.2, some developing countries (e.g. Guinea, Mauritania, Benin and South Africa) showed comparable, or even higher, levels of national ocean science researchers (headcount) in relation to the GDP than some developed countries (e.g. Sweden, Belgium, Denmark) (Figure 4.4).

### 4.2.1. Ocean science personnel by gender

It was not long ago that the maritime community was described in the masculine form. Twentieth-century science was dominated by men (UNESCO, 2015) and, although 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. Conversely, men and women publish at a comparable annual rate in science, technology, engineering and mathematics, and have an equivalent career impact for the same total number of publications. Gender differences in productivity and impact are explained by a shorter publishing career duration for female scientists and higher dropout rates (defined as the yearly fraction of authors in the population who have just published their last paper), which persist throughout their scientific careers (Huang et al., 2020). UNESCO (2015) identified the existence of obstacles specific to women when accessing relevant positions in academia, industry and administration. 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. Women still account for a minority of the world's researchers, despite the growing demand for cross-nationally comparable statistics on women in science; national data and their use in policymaking often remain limited (UNESCO,

[9] See https://databank.worldbank.org/home.aspx (accessed 12 February 2020).

2017). There is a need for more systematic collection and use of sex-disaggregated information regarding ocean management (Michalena et al., 2020).

Some insights on the proportion of female ocean science personnel are gained by analysing the data submitted via the GOSR2020 questionnaire and complemented with data submitted via the GOSR2017 questionnaire (Table 4.2). On average, 38.6% of total ocean science researchers are female — a similar level to that reported in the GOSR2017 (38%) — and one which remains 10% higher than the global share of female researchers in natural sciences (IOC-UNESCO, 2017*a*; UNESCO, 2015). It shows that in ocean science, important work has been done in reducing the gender gap; however, the number of women among disciplines varies at the regional and national level. In the subset of countries surveyed, several countries do not have gender specific information with respect to ocean science personnel (e.g. Australia, Comoros, Kuwait, Mexico and Poland). Female ocean science personnel range from about 7% (Democratic Republic of the Congo) to 72% (Ireland). The percentage of female ocean science personnel is equal to or higher than 50 in countries such as Angola, Bulgaria, Croatia, El Salvador, Ireland, Poland and Turkey (Table 4.2, Figure 4.5). Yet, female participation within ocean science researchers ranges from about 12% (Japan) to more than 63% (Croatia) for the subset of countries examined in this report. In Angola, Brazil, Bulgaria, Croatia, Dominican Republic, El Salvador, Mauritius, Poland and Suriname, 50% or more of ocean science researchers are women.

However, due to the fact that some countries do not have updated information or have information from some institutions only, the results presented here can only provide an indication of the current gender distribution among ocean science personnel.

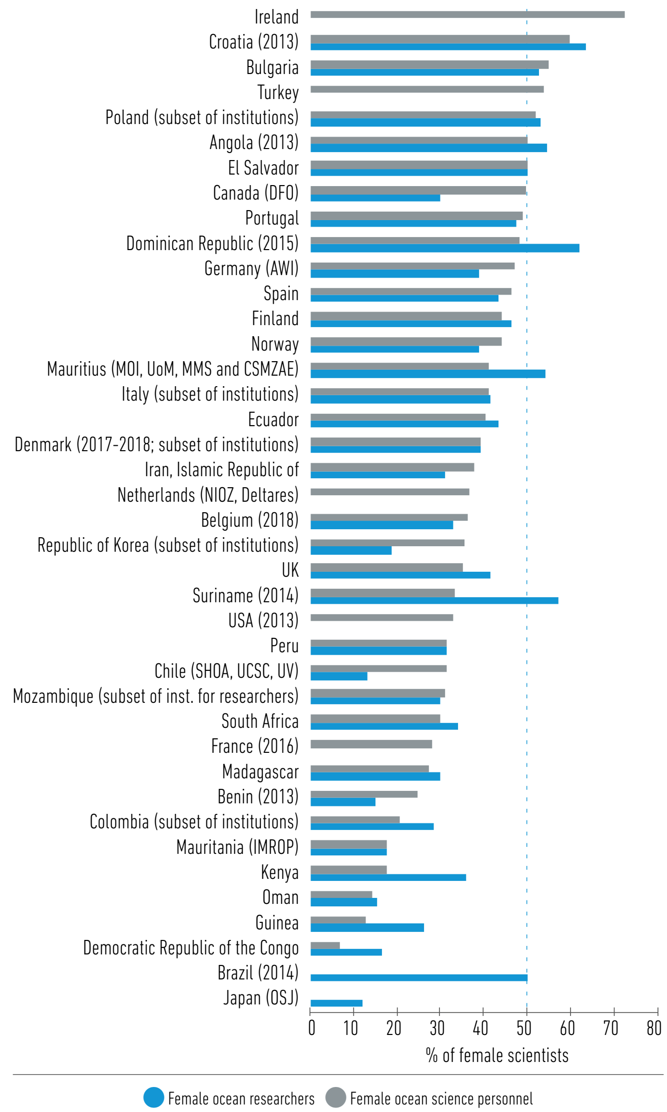


**Figure 4.5.** Proportion (% of total HC) of female ocean science personnel and female ocean researchers in 2017.[10,11] In the absence of data for 2017, the latest available year is shown in brackets.
*Sources*: Data based on the GOSR2017 and GOSR2020 questionnaires.

[10] Figure 'country' acronyms are the same as in Table 4.2.

[11] Subset of institutions are the same as in Table 4.2.

**Table 4.2.** Proportion (% of total headcount)[12,13] of female ocean science personnel and female researchers in 2017, sorted from highest value to lowest value of female ocean science personnel. In the absence of data for 2017, the latest available year is shown in brackets. Cases where appropriate data were not available are marked with '–'.

| Country | Year | % female of total ocean science personnel | % female of total ocean science researchers | SDG regional groupings |
|---|---|---|---|---|
| Ireland | 2017 | 72.42 | – | Europe and Northern America |
| Croatia (2013) | 2013 | 60.00 | 63.64 | Europe and Northern America |
| Bulgaria | 2017 | 55.13 | 52.94 | Europe and Northern America |
| Turkey | 2017 | 54.02 | – | Northern Africa and Western Asia |
| Poland (subset of institutions) | 2017 | 52.16 | 52.99 | Europe and Northern America |
| El Salvador | 2017 | 50.00 | 50.00 | Latin America and the Caribbean |
| Angola (2013) | 2013 | 50.00 | 54.55 | Sub-Saharan Africa |
| Canada (DFO) | 2017 | 49.62 | 30.11 | Europe and Northern America |
| Portugal | 2016 | 48.91 | 47.59 | Europe and Northern America |
| Dominican Republic (2015) | 2015 | 48.35 | 61.90 | Latin America and the Caribbean |
| Germany (AWI) | 2017 | 46.98 | 39.05 | Europe and Northern America |
| Spain | 2017 | 46.37 | 43.60 | Europe and Northern America |
| Finland | 2017 | 44.05 | 46.27 | Europe and Northern America |
| Norway | 2017 | 44.03 | 38.87 | Europe and Northern America |
| Mauritius (MOI, UoM, MMS and CSMZAE) | 2017 | 41.38 | 54.17 | Sub-Saharan Africa |
| Italy (subset of institutions) | 2017 | 41.08 | 41.73 | Europe and Northern America |
| Ecuador | 2017 | 40.59 | 43.48 | Latin America and the Caribbean |
| Denmark (2017–2018; subset of institutions) | 2017 | 39.28 | 39.15 | Europe and Northern America |
| Iran, Islamic Republic of | 2015 | 38.00 | 31.29 | Central and Southern Asia |
| Netherlands (NIOZ, Deltares) | 2017 | 36.90 | – | Europe and Northern America |
| Belgium (2018) | 2017 | 36.18 | 32.82 | Europe and Northern America |
| Republic of Korea (subset of institutions) | 2017 | 35.60 | 18.75 | Eastern and South-Eastern Asia |
| UK | 2017 | 35.33 | 41.68 | Europe and Northern America |
| Suriname (2014) | 2014 | 33.33 | 57.14 | Latin America and the Caribbean |
| USA (2013) | 2013 | 33.17 | – | Europe and Northern America |
| Peru | 2017 | 31.58 | 31.67 | Latin America and the Caribbean |
| Chile (SHOA, UCSC, UV) | 2017 | 31.50 | 13.16 | Latin America and the Caribbean |
| Mozambique (subset of institutions for researchers) | 2017 | 31.25 | 30.00 | Sub-Saharan Africa |
| South Africa | 2017 | 30.00 | 34.29 | Sub-Saharan Africa |
| France (2016) | 2016 | 28.01 | – | Europe and Northern America |
| Madagascar | 2017 | 27.27 | 30.00 | Sub-Saharan Africa |
| Benin (2013) | 2013 | 24.72 | 14.93 | Sub-Saharan Africa |
| Colombia (subset of institutions) | 2017 | 20.83 | 28.57 | Latin America and the Caribbean |
| Mauritania (IMROP) | 2017 | 17.79 | 17.86 | Sub-Saharan Africa |
| Kenya | 2017 | 17.55 | 36.00 | Sub-Saharan Africa |
| Oman | 2017 | 14.29 | 15.38 | Northern Africa and Western Asia |
| Guinea | 2017 | 12.69 | 26.28 | Sub-Saharan Africa |
| Democratic Republic of the Congo | 2017 | 6.90 | 16.67 | Sub-Saharan Africa |
| Brazil (2014) | 2014 | – | 50.17 | Latin America and the Caribbean |
| Japan (OSJ) | 2017 | – | 12.01 | Eastern and South-Eastern Asia |

*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires.

12 Table 4.2 'Country' acronyms: AWI - Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research; CSMZAE - Department for Continental Shelf, Maritime Zones Administration & Exploration; DFO - Fisheries and Ocean Canada; IMROP - Mauritanian Institute of Oceanographic and Fisheries Research; MOI - Mauritius Oceanography Institute; NIOZ - Royal Netherlands Institute for Sea Research; OSJ - Oceanographic Society of Japan; SHOA - Servicio Hidrográfico y Oceanográfico de la Armada; UCSC - Catholic University of the Most Holy Conception; UoM - University of Mauritius; MMS - Mauritius Meteorological Services (ocean science personnel: researchers and technicians only); UV - University of Valparaiso.

13 Table 4.2 'Country' subsets of institutions: Colombia: Not specified. Denmark: Aalborg University; Aarhus University (Department of Bioscience and Department of Geoscience); Danish Coastal Authority; Danish Environmental Protection Agency; Defence Centre for Operational Oceanography; Danish Meteorological Institute; University of the Faroe Islands; NIVA Danmark; Ramboll; Roskilde University, Department of Science and Environment; GEUS; Fiskaaling; Technical University of Denmark (National Food Institute, National Institute of Aquatic Resources, National Space Institute); The Faroe Marine Research Institute; University of Copenhagen (Department of Biology, Department of Food and Resource Economics, Department of Geosciences and Natural Resource Management, Globe Institute, Natural History Museum, Niels Bohr Institute); University of Southern Denmark. Italy: Consiglio Nazionale delle Ricerche (CNR); Agenzia Nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA); Stazione Zoologica Anton Dohrn Napoli (SZN); National Institute of Oceanography and Applied Geophysics (OGS), Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA); Consorzio Nazionale Interuniversitario per le Scienze del Mare (CONISMA). Mozambique (for researchers only): National Institute for Hydrography and Navigation (INAHINA), Universidade Eduardo Mondlane; National Marine Institute (INAMAR); National Institute of Fisheries Research (IIP). Poland: Institute of Oceanology - Polish Academy of Sciences; Institute of Meteorology and Water Management National Research Institute; National Marine Fisheries Research Institute; Pomeranian University in Slupsk; Institute of Oceanography University of Gdańsk; Institute for Marine and Coastal Sciences University of Szczecin. Republic of Korea: National Institute of Fisheries Science (NIFS); Korea Meteorological Administration (KMA); Korea Institute of Ocean Science and Technology (KIOST).

The information presented in Table 4.2 can be better expressed as in Figure 4.5, which shows the proportion (% of total HC) in 2017 for each country with reported information. This information is key, because it shows that in some countries, considerable efforts are being made by women to become ocean researchers, instead of just ocean science personnel. It is necessary, however, to sustain the efforts being made to reduce the gender gap.

Sex-disaggregated data was also gathered from the list of participants of selected international conferences/symposia. Country and gender information was identified for 27,501[14] participants attending 57 international conferences/symposia held from 2009 to 2018 (Supplementary material 4.1). In that 10-year period, less than 20% of the conferences included in this analysis were organized in the southern hemisphere.

The first part of the assessment presented refers to the proportion of female and male participants (16,400 participants in total) attending the most recent 37 international conferences/symposia, held from 2015 to 2018 (Figure 4.6 and Figure 4.7). Data were extracted from the lists of participants of conferences focusing on ocean science in general, and conferences within seven of the eight categories of ocean science introduced in Chapter 2: Ocean and climate, Marine ecosystem functions and processes, Human health and well-being, Blue growth, Ocean observations and marine data, Ocean health, and Ocean crust and marine geo-hazards. The assessment addresses five regions: the North Atlantic Ocean (data provided by the International Council for the Exploration of the Sea — ICES); the Pacific Ocean (data provided by the North Pacific Marine Science Organization — PICES); the Mediterranean Sea (data provided by the Mediterranean Science Commission — CIESM); the Polar regions (data provided by, among others, the Scientific Committee on Antarctic Research — SCAR and the International Arctic Science Committee — IASC); and the Indian Ocean (data provided by the Western Indian Ocean Marine Science Association — WIOMSA).

Women constitute 43% of the total number of participants attending international conferences/symposia considered in Figure 4.6. However, the gender distribution varies considerably according to the subject of the conference, as well as the region. Female participants account for 29% and 53% of the participants in all ocean science categories and regions respectively. Women represent 48% of the participants in conferences on ocean science in general (not specific to any of the ocean science categories introduced in Chapter 2). Although close to parity, there is a stronger representation of women in two of the ocean science categories (Human health and well-being and Ocean health). For Marine ecosystem functions and processes, the gender representation of participants is roughly equal. In terms of regions, parity is only achieved in the Mediterranean area (51% female participants). This contrasts with the assessment provided in the GOSR2017 (IOC-UNESCO, 2017*a*) for the period 2009–2015, in which there was either parity or a stronger representation of men in all the ocean categories and regions under consideration. Indeed, the proportion of female participants per ocean category and per region is always higher in the current assessment, when compared with the assessment provided for the same categories and regions in the GOSR2017.

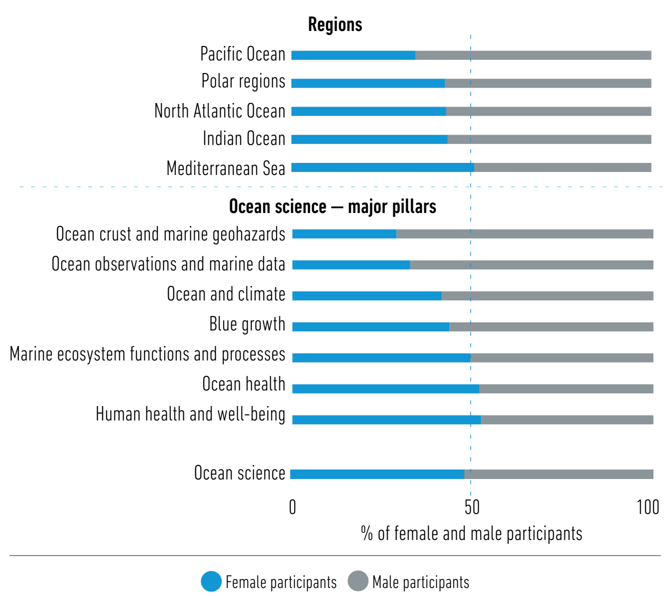


**Figure 4.6.** Proportion (%) of female and male participants at international scientific conferences/symposia held from 2015 to 2018. Upper section focuses on regional conferences/symposia; lower section on topic-specific conferences/symposia.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2015 to 2018.

The proportion of females among the participants for the time-period 2012–2018 at international conferences for which sex-disaggregated data was provided is illustrated in Figure 4.8. The figure shows that the number of women participants did not vary significantly over the indicated time period.

[14] The total number of participants in a conference may include participants from a nation for which gender was not identified, or participants for which the country of affiliation was not identified. The proportion of female and male participants are calculated from the total number of participants for which both country of affiliation and gender were identified.

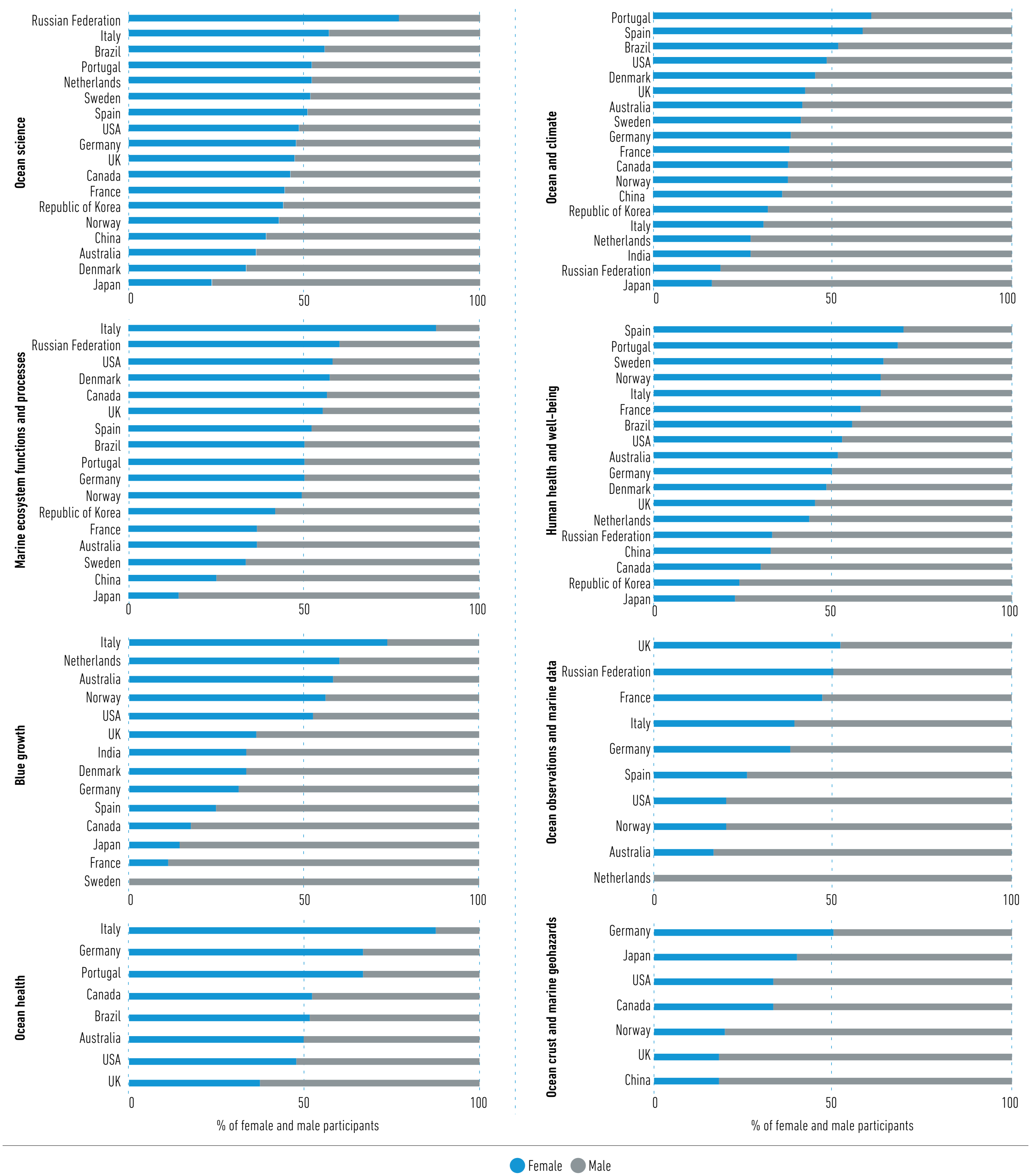


**Figure 4.7.** Proportion (%) of female and male experts attending international scientific conferences/symposia held between 2015–2018 with different foci (ocean science, ocean and climate, marine ecosystem functions and processes, human health and well-being, blue growth, ocean observations and marine data, ocean health, ocean crust and marine geo-hazards) for the top 20 publishing countries of ocean science (Chapter 5; Supplementary material 4.1).

*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2015 to 2018.

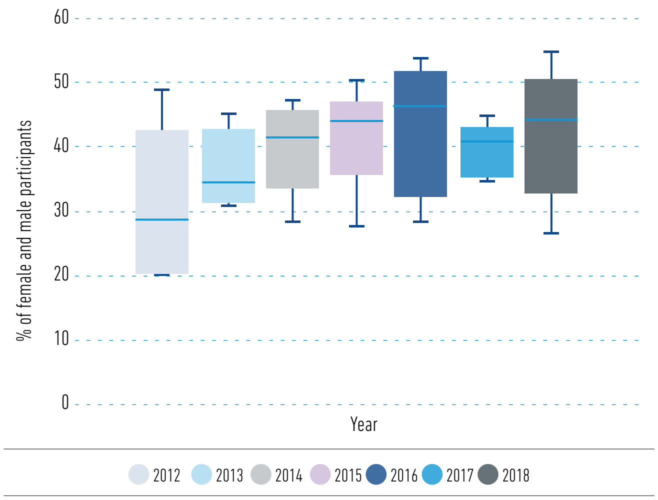


**Figure 4.8.** Proportion (%) of female participants from total number of participants in international conferences for which sex-disaggregated data was provided for the time period 2012–2018, as per table in supplementary material 4.1. (Box plots show the five-number summary of a set of data: including the minimum score, first (lower) quartile, median, third (upper) quartile, and maximum score).
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2012 to 2018.

One determining factor in participation in international conferences/symposia seems to be the childcare-conference conundrum faced by parent-researchers. Mothers are generally at a disadvantage because of biological, prejudicial and socially driven childcare demands — in particular pregnancy, breastfeeding and childminding. Therefore, it is necessary to mainstream strategies to enforce gender equality in the organization of such conferences. Removing barriers to participation, including making conferences family-friendly — for example, providing childcare in the form of childcare grants or on-site childcare, assisting with travel and accommodation, or developing mandatory codes of conduct for all conferences, including anti-harassment policies to support women who wish to breastfeed their babies in the conference space and during talks — would be a first step (Calisi and a Working group of Mothers in Science, 2018; Sardelis and Drew, 2016).

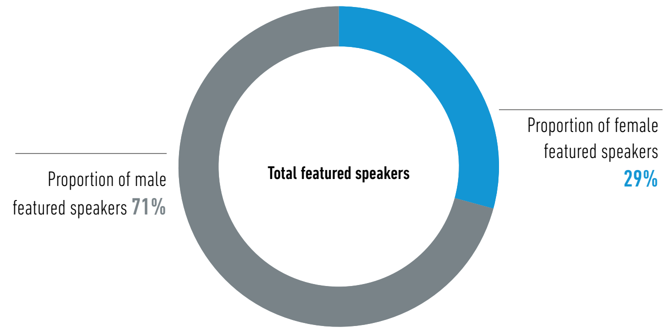


**Figure 4.9.** Proportion (%) of female and male featured speakers at international conferences, as per data presented in supplementary material 4.2.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2011 to 2018.

One way of illustrating the 'glass ceiling' — a barrier to advancement in a profession particularly affecting women — is through the participation of female scientists as featured speakers in international conferences and symposia. The gender of invited and other speakers in plenary sessions was identified for a total of 414 speakers participating in 12 international conferences (Supplementary material 4.2). Figure 4.9 shows that only 29% of the total featured speakers were women.

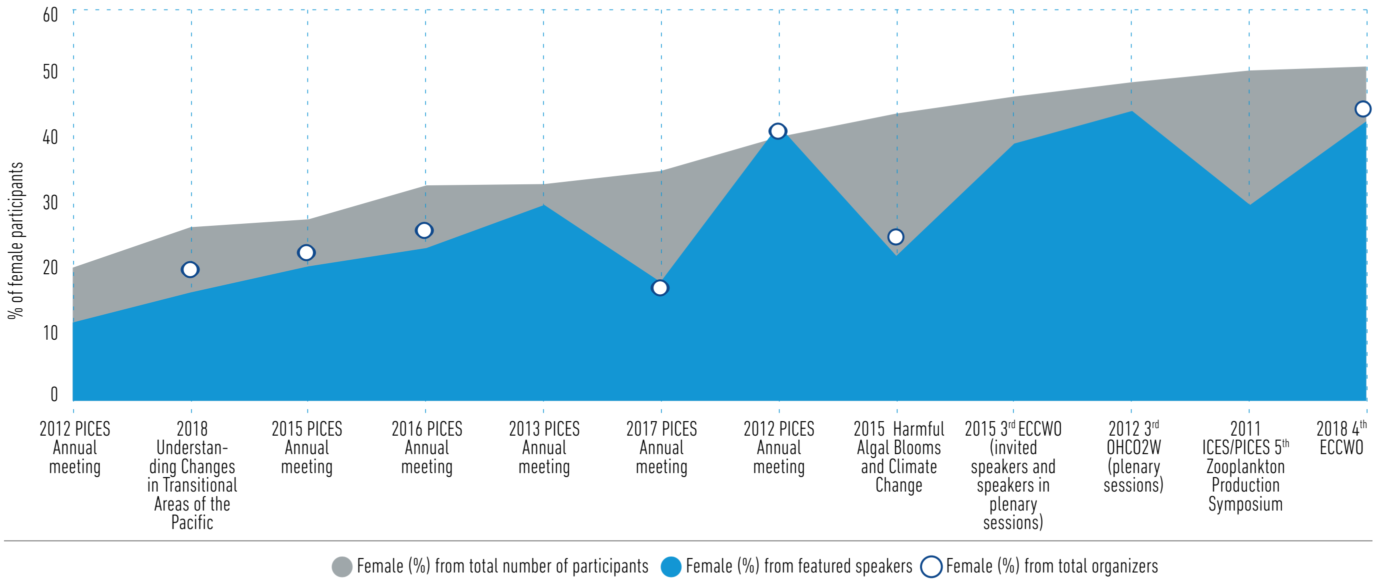


**Figure 4.10.** Proportion (%) of female participants, female invited speakers and female organizers of international conferences as per data gathered in supplementary material 4.2.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2011 to 2018.

There is a positive relationship between the relative proportion of women organizing international conferences/symposia and the proportion of women participating as invited speakers and speakers in plenary sessions (Figure 4.10). These results are consistent with the analysis provided by Sardelis and Drew (2016) for conservation symposia. Further, when the percentage of female invited speakers is compared to the percentage of female participants, the former is always smaller than the latter, meaning that women are broadly underrepresented as featured speakers.

For international conferences with a focus on the Pacific Ocean, the proportion of female invited speakers was 20% (Figure 4.11), which is lower than the global average of 29% (see Figure 4.9).

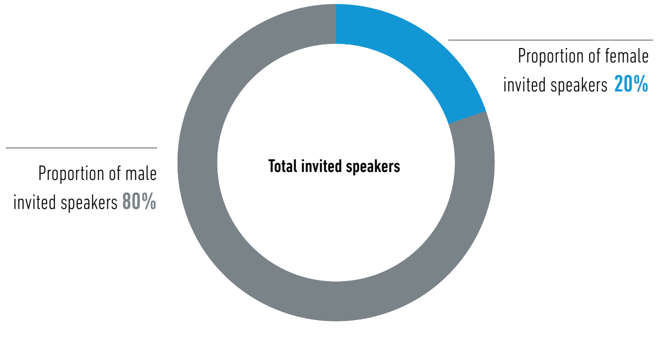


**Figure 4.11.** Proportion (%) of female and male invited speakers at international conferences that focus on the Pacific Ocean Region (Supplementary material 4.2).
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2012 to 2018.

### 4.2.2. Age distribution and gender of ocean science researchers

A subset of 15 countries also provided information regarding both age distribution and gender of ocean science researchers (Table 4.3).

**Table 4.3.** Age distribution and gender of researchers engaged in ocean science (HC, 2017).[15,16]

| Country | Age class under 25 years | | Age class 25–34 years | | Age class 35–44 years | | Age class 45–54 years | | Age class 55–64 years | | Age class 65 years and over | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male |
| Ecuador (total ocean science personnel) | 2 | 1 | 12 | 25 | 6 | 14 | 14 | 24 | 1 | 2 | 0 | 0 |
| El Salvador (total ocean science personnel) | 0 | 0 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 0 |
| Madagascar | 6 | 8 | 6 | 10 | 4 | 6 | 2 | 3 | 2 | 3 | 0 | 0 |
| Peru | 1 | 3 | 3 | 10 | 5 | 10 | 5 | 10 | 3 | 5 | 2 | 3 |
| UK | 7 | 7 | 228 | 138 | 207 | 241 | 173 | 186 | 41 | 145 | 7 | 14 |
| **Information provided for a subset of institutions** | | | | | | | | | | | | |
| **Country** | **Age class under 25 years** | | **Age class 25–34 years** | | **Age class 35–44 years** | | **Age class 45–54 years** | | **Age class 55–64 years** | | **Age class 65 years and over** | |
| | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male |
| Canada (DFO) | 0 | 0 | 2 | 4 | 18 | 19 | 22 | 39 | 11 | 23 | 3 | 45 |
| Denmark (2017–2018, subset of institutions) | 27 | 36 | 74 | 71 | 41 | 56 | 29 | 57 | 19 | 38 | 1 | 16 |
| Finland (subset of institutions) | 1 | 0 | 21 | 9 | 34 | 22 | 12 | 27 | 11 | 38 | 3 | 3 |
| Italy (subset of institutions) | 0 | 0 | 65 | 66 | 180 | 212 | 217 | 323 | 170 | 242 | 61 | 104 |
| Japan (OSJ) | 21 | 64 | 80 | 242 | 52 | 310 | 28 | 391 | 7 | 234 | 3 | 159 |
| Mauritius (subset of institutions) | | | 3 | 1 | 3 | 10 | 5 | 3 | | | | |
| Oman (SQU) | | | 1 | 1 | 2 | 2 | | 6 | | 2 | | 1 |
| Poland (subset of institutions) | 0 | 0 | 35 | 24 | 73 | 37 | 35 | 25 | 35 | 34 | 9 | 24 |
| Republic of Korea (subset of institutions) | 3 | 1 | 36 | 84 | 39 | 159 | 20 | 161 | 1 | 24 | | |
| Spain (subset of institutions) | 44 | 34 | 191 | 173 | 209 | 223 | 171 | 263 | 83 | 175 | 9 | 25 |

*Source:* Data based on the GOSR2020 questionnaire.

15 'Country' acronyms: DFO - Fisheries and Ocean Canada; OSJ - Oceanographic Society of Japan; SQU - Sultan Qaboos University.

16 'Country' subsets of institutions: Denmark: Aarhus University (Department of Bioscience and Department of Geoscience); Defence Centre for Operational Oceanography; Danish Meteorological Institute; Ramboll; GEUS; Fiskaaling; Technical University of Denmark (National Food Institute, National Institute of Aquatic Resources, National Space Institute); The Faroe Marine Research Institute; University of Copenhagen (Department of Biology, Department of Food and Resource Economics, Department of Geosciences and Natural Resource Management); University of Southern Denmark; NIVA Denmark; Ramboll; ORBICON; DHI. Finland: Not specified. Italy: Consiglio Nazionale delle Ricerche (CNR); Agenzia Nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA); Stazione Zoologica Anton Dohrn Napoli (SZN); National Institute of Oceanography and Applied Geophysics (OGS), Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA); Consorzio Nazionale Interuniversitario per le Scienze del Mare (CONISMA). Mauritius: MOI- Mauritius Oceanography Institute; UoM - University of Mauritius; MMS - Mauritius Meteorological Services; CSMZAE - Department for Continental Shelf, Maritime Zones Administration & Exploration. Poland: Institute of Oceanology - Polish Academy of Sciences; Institute of Meteorology and Water Management National Research Institute; Pomeranian University in Slupsk; Institute of Oceanography University of Gdańsk; Institute for Marine and Coastal Sciences University of Szczecin. Republic of Korea: National Institute of Fisheries Science (NIFS); Korea Meteorological Administration (KMA); Korea Institute of Ocean Science and Technology (KIOST). Spain: Not specified.

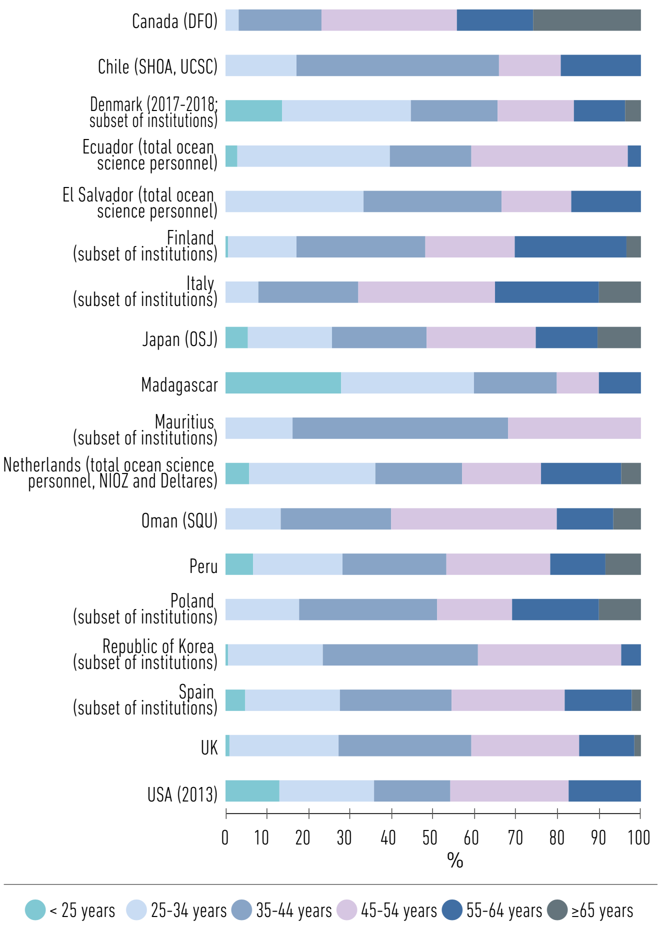


**Figure 4.12.** Proportion (%) of age classes of ocean science researchers in 2017.[17,18] In the absence of data for 2017, the latest available year is shown in brackets.
*Source:* Data based on the GOSR2020 questionnaire.

Figure 4.12 shows the age-class percentages of employed ocean science researchers in 18 countries, for the year 2017 (or the latest year for which data was available). For some countries, data was provided for slightly different age classes (e.g. for the USA, data was provided for the following groupings: <30 years, 30–39 years, 40–49 years, 50–59 years and ≥60 years; for Canada the groupings were 55–59 years and ≥60 years). Also, some of the records include extrapolations (e.g. USA, Spain) and/or a subset of the national ocean research institutions (e.g. Canada, Chile, Denmark, Finland, Italy, Japan, Mauritius, Netherlands, Oman, Poland, Republic of Korea and Spain) and others are given as total ocean science personnel, with no category breakdown (e.g. Netherlands, El Salvador, Ecuador).

Of the 18 countries in Figure 4.12, 6.6% of ocean science researchers are younger than 25; 21.3% are between 25 and 34 years old; 23.9% are between 35 and 44 years old; 27.5% are between 45 and 54; 16.9% are between 55 and 64 years old; and the remaining 3.8% are older than 65 years.

Some countries, developing countries in particular, reported a relatively young community of researchers, with more than 50% of ocean researchers aged under 34 years in Madagascar. A number of the other countries reported that more than 50% of their ocean science researchers are aged over 45 years (Canada, Finland, Italy, Japan, Oman).

### 4.2.3. Level of qualification of ocean science researchers

The level of qualification of ocean science researchers varies among countries. Some countries that answered related questions in the GOSR2020 questionnaire reported that all ocean science researchers have a PhD (i.e. Brazil, Canada, Germany, Sweden), while in others staff with a level of qualification equal to or higher than a master's, are the most engaged in research activities (i.e. Democratic Republic of the Congo, Guinea, Mauritania, Spain). This is explained by the fact that in several countries, holding a PhD is a required qualification to apply to researcher positions in national institutions. In others, master's and PhD students might be also counted as ocean science researchers, as they are carrying out research work. In certain countries (i.e. Chile, Italy, Kenya, Madagascar, Mauritius, Mozambique, Oman, Republic of Korea), the majority of ocean researchers have a level of qualification which is at least equal to a bachelor's degree (Figure 4.13).

[17] Figure 'country' acronyms are the same as in Table 4.3. Not included in Table 4.3: SHOA - Servicio Hidrográfico y Oceanográfico de la Armada; UCSC - Catholic University of the Most Holy Conception.

[18] Subset of institutions are the same as in Table 4.3. Not included in Table 4.3: NIOZ - Royal Netherlands Institute for Sea Research.

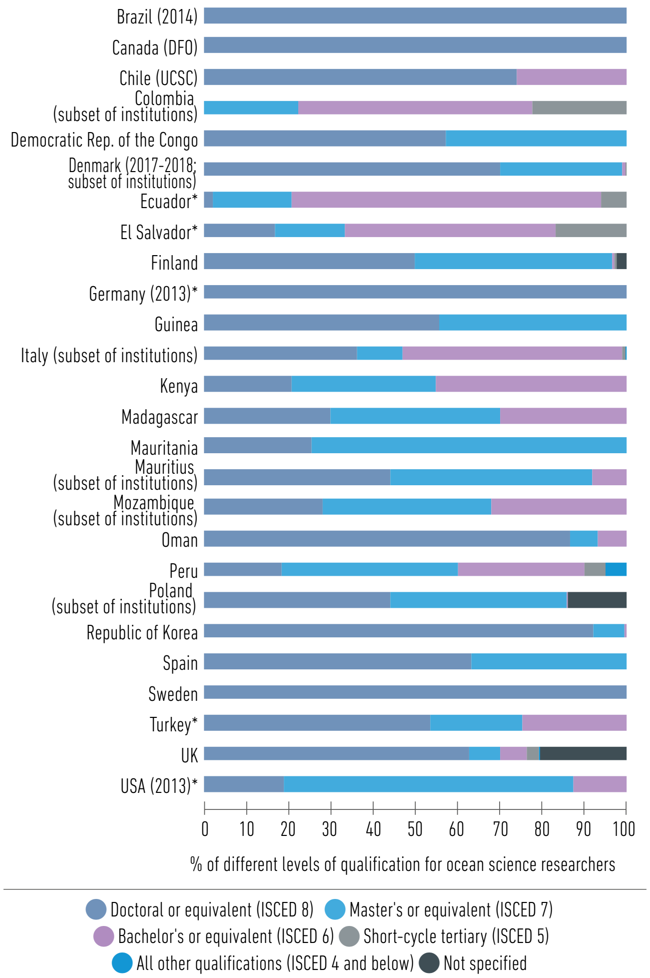


**Figure 4.13.** Proportion (%) of ocean science researchers with different levels of qualification in 2017 (or the latest available year).[19]
*Source:* Data based on the GOSR2020 questionnaire.

## 4.3. Ocean science institutions

Information about ocean science institutions was provided at the national level. However, the type of data submitted varied greatly in detail between the different respondents. While some countries summarized the information by major organization, others differentiated between the various departments, centres, etc. which are part of a larger institution/organization.

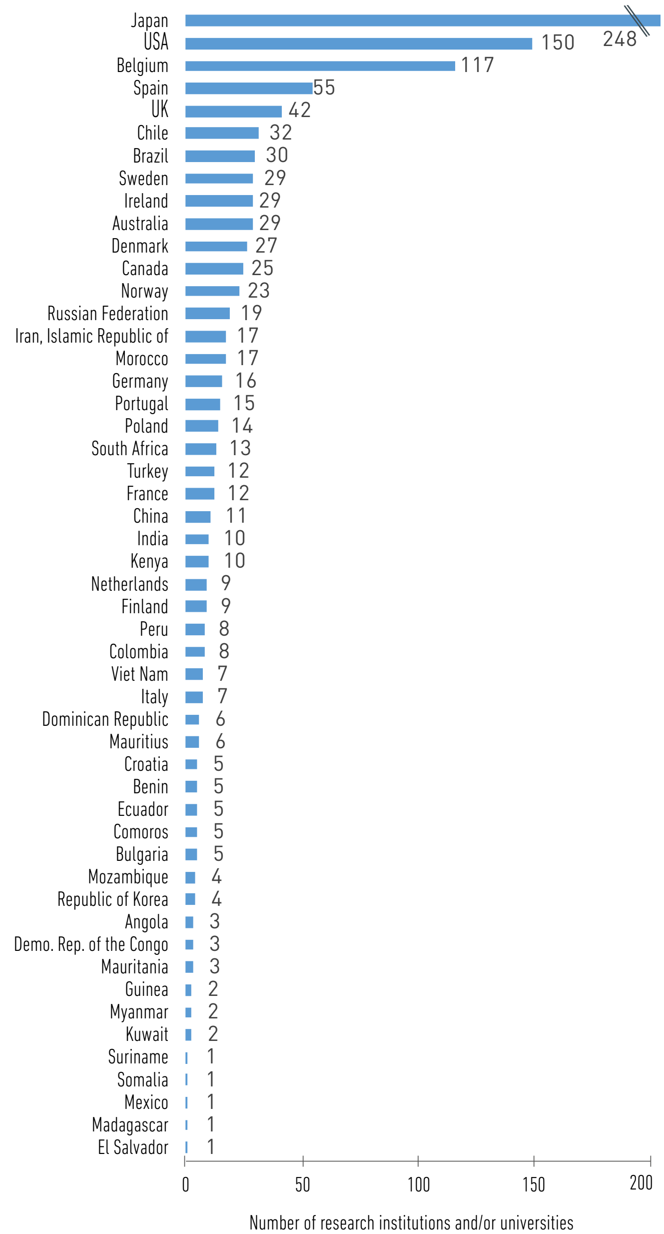


**Figure 4.14.** Number of ocean science institutions, marine laboratories and field stations, by country.
*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires.

Countries that invest and publish in ocean science usually display a complex science infrastructure attributed to various ministries. Often, several centres at different locations in the country constitute one organization, and national and federal universities have faculties, departments, groups, institutes and laboratories focusing on different fields of ocean science. In the analysis presented here, countries which have at least one ocean science-related centre/organization are considered (Figure 4.14).

[19] Figure 4.13 shows the employed ocean science researchers in 26 countries for year 2017 or the latest available year — for those exceptions, the year is indicated together with 'Country'. Some of the records include extrapolations (e.g. Germany, Kenya, Spain, USA), rough numbers (e.g. Mozambique) and/or a subset of the national ocean research institutions (e.g. Brazil, Canada, Chile, Denmark, Italy, Mauritius, Mozambique, Poland, Republic of Korea, Spain). Finally, some data are given as total ocean science personnel (e.g. Ecuador, El Salvador, Germany, Turkey, USA) — those exceptions are marked with '*'.

From the data obtained via the GOSR2020 questionnaire, the top five countries with regard to the number of ocean science institutions are Japan, USA, Belgium, Spain and UK.

## 4.4. Observation platforms and tools for sustained ocean observation

The GOSR2017 (IOC-UNESCO, 2017*a*) compiled information on research vessels and other research infrastructure/equipment for the time period 2012–2015. Updated information, based on installed capacity, was gathered though the GOSR2020 questionnaire for the period 2013–2017.

### *4.4.1. Research vessels and ships partly used for ocean science*

Information about research vessels (RVs) was provided by 30 countries for the GOSR2017; this number increased to 36 for the GODR2020 questionnaire. For the analysis presented here, the data were combined with some from the GOSR2017, resulting in data from 42 countries overall. A total number of 1,081 vessels were reported as being used in ocean science-related activities — 924 RVs mainly used for ocean science and 157 ships of opportunity (Figure 4.15). A comparison of the results for the GOSR2017 and GOSR2020 questionnaires shows a three-fold increase in the number of oceanographic RVs, especially those used in coastal areas. Of the countries that maintain more than 20 RVs nationally, the top 8 are: USA (441), Japan (50,) Sweden (42), Canada (40), Republic of Korea (26), UK (26), Germany (25) and Turkey (24). The total number of vessels maintained by countries with more than 20 vessels each (674) is higher than for all other countries with a combined total count of 250 vessels (Figure 4.15). Besides the data gathered through the GOSR2020 questionnaire, some data were obtained from the OCEANIC,[20] MarineTraffic[21] and Eurofleets[22] international databases, which contain compiled information about maintained RVs (Figure 4.16).

In general, the RV categorization applied in this report uses the following five classes of ship, based on vessel length (Figure 4.17):

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

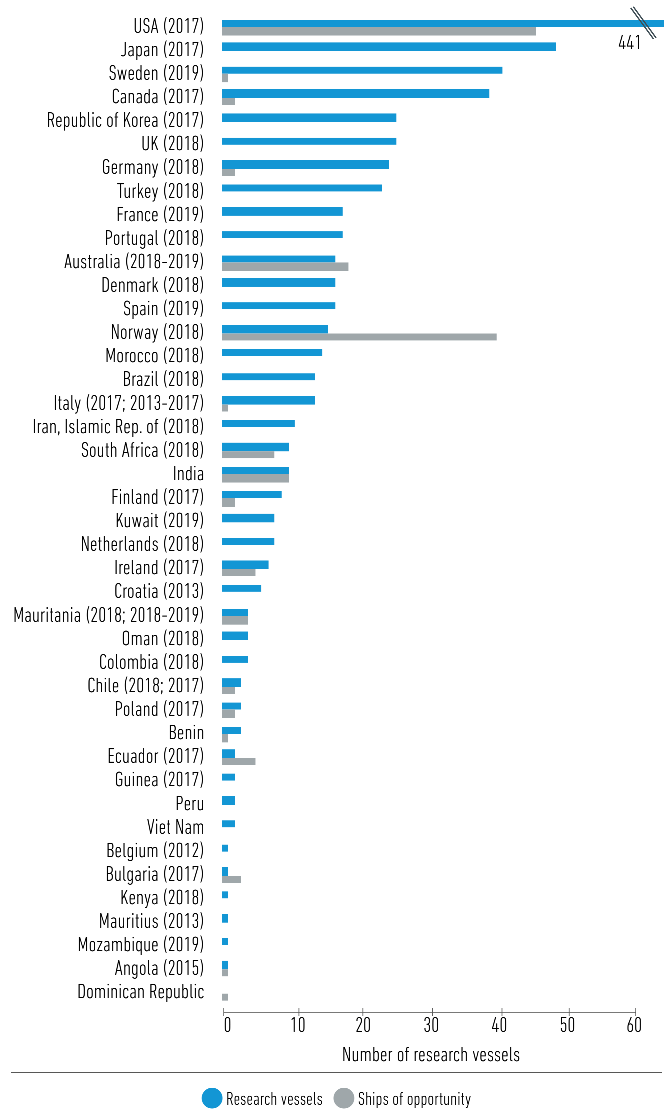


**Figure 4.15.** Number of nationally maintained vessels for ocean science.
*Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires.

[20] See https://www.researchvessels.org.

[21] See https://www.marinetraffic.com.

[22] See https://www.eurofleets.eu.

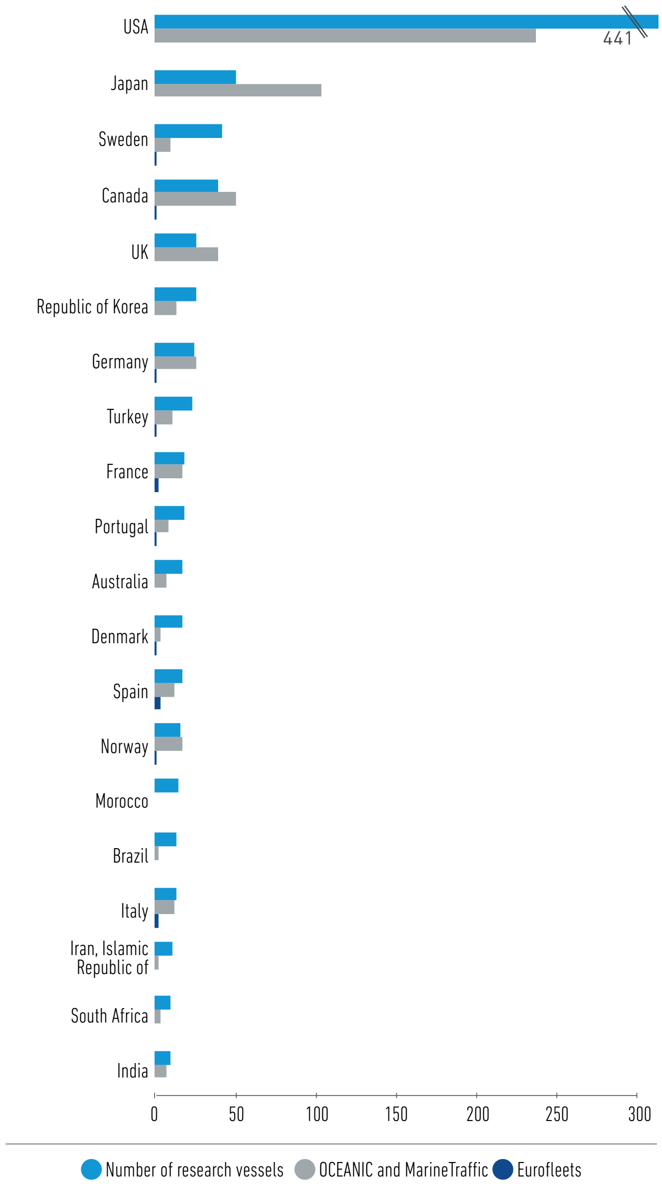


**Figure 4.16.** Number of RVs maintained by top 20 countries. *Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires, OCEANIC, MarineTraffic and Eurofleets databases.

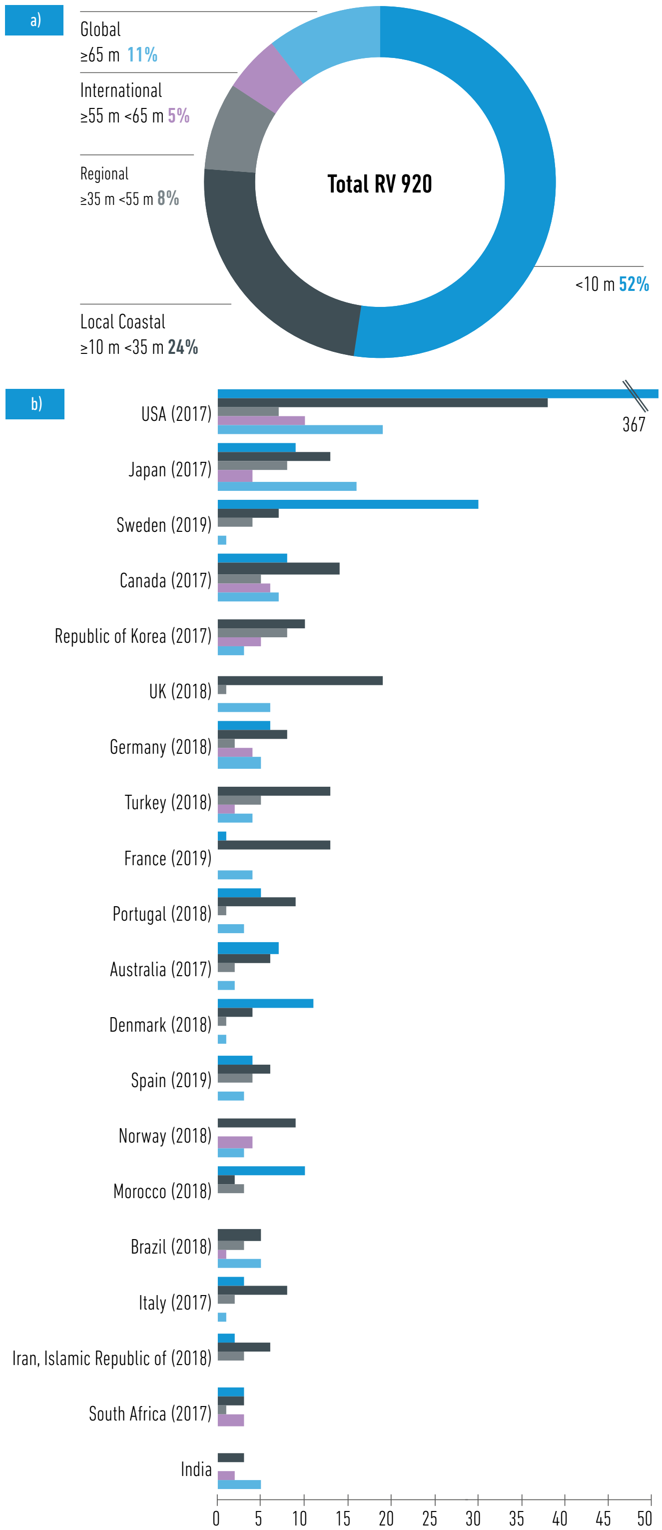


**Figure 4.17.** Number of nationally maintained RVs, classified by ship size. Detailed information is provided for the top 20 countries only. *Sources:* Data based on the GOSR2017 and GOSR2020 questionnaires.

4

Local and coastal research is the primary purpose of 24% of the RVs in 35 countries, while 8% of the vessels operate at regional, 5% at international and 11% at global scales. Vessels used at the global scale are maintained by 23 countries (Figure 4.17).

Another indicator that provides useful information about the fleet of vessels supporting ocean science is the age of the ships. The comparative distribution of ships owned by the top 20 countries is illustrated in Figure 4.18. On average, these vessels were built more than 30 years ago, while just less than 4% were put into operation during the last 10 years.

The ship time allocated for conducting research in territorial waters, the Exclusive Economic Zone and high seas was reported by 26 countries (Figure 4.19). The top three countries in terms of days at sea are the UK, Japan and USA.

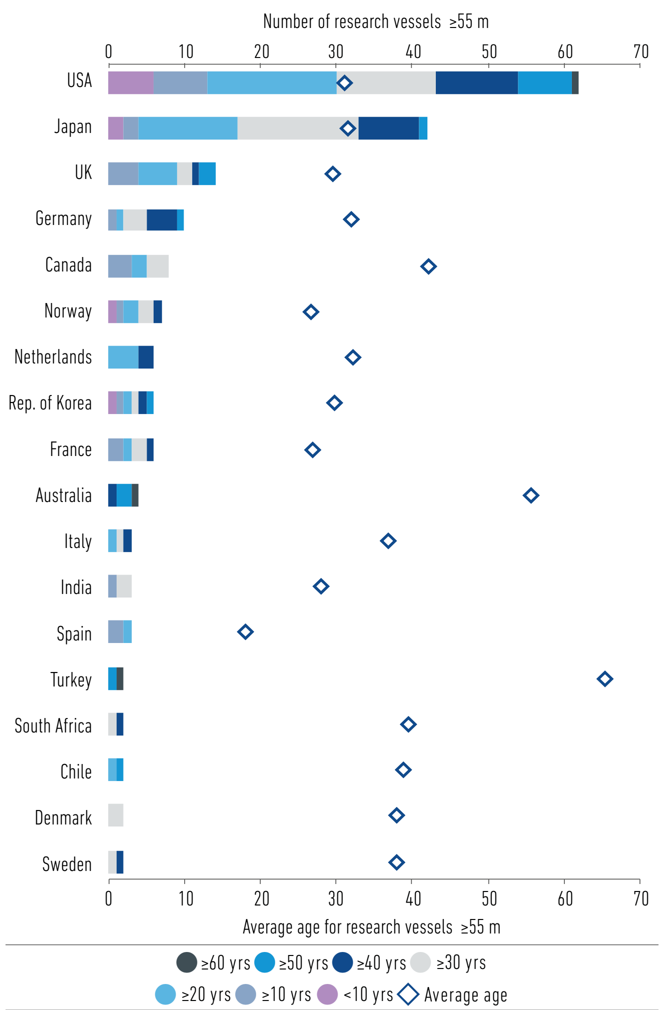


**Figure 4.18.** Number and age of RVs equal to or larger than 55 m in 2019.
*Sources:* Data based on the OCEANIC and MarineTraffic databases.

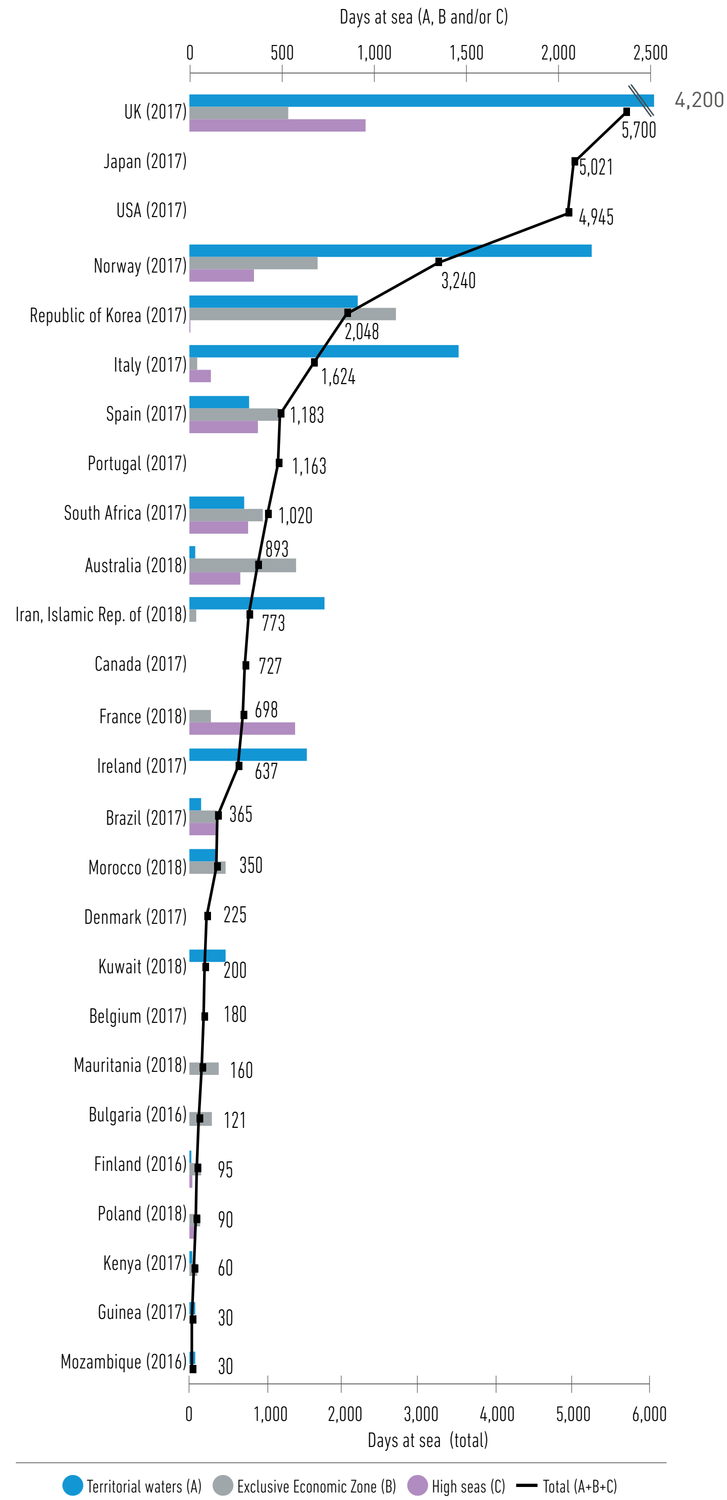


**Figure 4.19.** Number of days per year of research conducted from RVs for territorial waters (A), Exclusive Economic Zone (B) and high seas (C) and/or total days at sea (A+B+C) by country. Latest year for which data available in brackets. In the absence of disaggregated data, only total number of days are provided.
*Source:* Data based on the GOSR2020 questionnaire.

### 4.4.2. Other research infrastructure/equipment

Information about specific technical equipment used for ocean science was provided by 42 countries via the GOSR2020 questionnaire. Although the numbers of infrastructure/equipment were not provided, the top five countries that reported access to all categories of equipment are USA, Germany, Norway, Japan and Canada. In addition, Canada does not have access to human operated vessels (submersible), remotely operated drilling equipment or X-ray tomography. Almost all countries had access to multiple kinds of equipment, except three countries (Comoros, Myanmar and Mexico), which did not specify if they have access to any of the listed equipment. Detailed information can be accessed via the GOSR2020 Portal. Some results are listed in Table 4.4, referring to countries which have access to research infrastructure, other than RVs (human-operated vessels (submersible), unmanned surface vessels (USVs), moorings/buoys, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), underwater gliders, wave gliders, flying drones).

Oceanographic moorings and buoys are important to gather data on the state of the global ocean by providing continuous measurements of physical and chemical parameters. Often, moorings are a collection of sensors and measuring devices (such as acoustic doppler current profilers (ADDCP), single point current meters, CTD sensors, sediment traps or surface meteorological and sea surface sensors) connected to a wire and anchored on the sea floor. Countries maintaining moorings/buoys are shown in Table 4.4. More than 85% (36 countries) own buoys. The Data Buoy Cooperation Panel (DBCP)[23] only accounts for 21 countries maintaining 498 buoys at the global level, while more than half of them are operated by the USA (256). As many of the countries that submitted information to the GOSR2020 questionnaire are not listed in the DBCP database and some listed countries (Greece, India, New Zealand, Thailand) did not submit information to the GOSR2020, it can be assumed that at least 40 countries maintain oceanographic moorings/buoys. Other types of ocean science technologies include ROVs, which are unoccupied, highly manoeuvrable underwater robots that can be used to explore ocean depths while being operated by someone at the water surface. An AUV is a self-propelled, unmanned, untethered underwater vehicle capable of carrying out simple activities with little or no human supervision, such as gliders. Underwater and wave gliders serve different purposes. Underwater gliders employ variable buoyancy that allows them to glide forward while descending or ascending through the water, while measuring temperature, conductivity (to calculate salinity), currents, chlorophyll fluorescence, optical backscatter, bottom depth and (occasionally) acoustic backscatter. A wave glider is a wave- and solar-powered AUV. With this energy, source wave gliders can spend many months at a time at sea, collecting and transmitting ocean data. The vehicles can host sensors such as atmospheric and oceanographic sensors applicable to ocean and climate science, seismic sensors for earthquake and tsunami detection, and video cameras and acoustic sensors for security and marine environment protection purposes. Emerging technologies used more and more in ocean science include flying drones, which are unmanned aerial vehicles. In summary, according to the information submitted in the GOSR2020 questionnaire (42 responses), 15 respondents (36%) own or have access to human-operated submersible vessels, 18 (43%) to USVs, 36 (86%) to moorings/buoys, 29 (69%) to ROVs, 23 (55%) to AUVs, 23 (55%) to underwater gliders, 14 (33%) to wave gliders and 17 (40%) to flying drones (Table 4.4).

[23] The Data Buoy Cooperation Panel (DBCP) is an official joint body of the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC). Source: http://www.jcommops.org/dbcp as of March 2020.

**Table 4.4.** Access by country to new ocean science technologies.

| Country | Human operated vessel (submersible) | Unmanned surface vessel (USV) | Mooring buoy | Remotely operated vehicle (ROV) | Autonomous underwater vehicle (AUV) | Under-water glider | Wave glider | Flying drone |
|---|---|---|---|---|---|---|---|---|
| Australia | | x | x | x | x | x | | |
| Belgium | | x | x | x | x | | | |
| Brazil | x | x | x | x | x | x | x | x |
| Bulgaria | x | | x | x | | | | |
| Canada | | x | x | x | x | x | x | x |
| Chile | | | x | x | | x | | x |
| China | x | | x | | x | x | x | |
| Colombia | | | x | x | | | | |
| Democratic Republic of the Congo | | x | x | x | x | | | |
| Denmark | | | | x | | | | x |
| Ecuador | | | x | | | x | | |
| El Salvador | | | x | | | | | x |
| Finland | | | x | x | | x | | |
| France | x | | x | | x | x | | x |
| Germany | x | x | x | x | x | x | x | x |
| Ireland | | | x | x | | x | | |
| Italy | | x | x | x | x | x | x | |
| Japan | x | x | x | x | x | x | x | x |
| Kenya | | | x | x | | | | |
| Kuwait | | | x | | | | | |
| Madagascar | | | x | | | | | |
| Mauritius | | | x | | | | | |
| Morocco | | | x | x | | | | |
| Mozambique | | | x | | | | | |
| Netherlands | x | x | x | x | x | | | x |
| Norway | x | x | x | x | x | x | x | x |
| Oman | | | x | | | | x | |
| Peru | x | x | x | x | x | x | x | |
| Poland | | | x | x | x | x | | |
| Portugal | x | x | x | x | x | x | | x |
| Republic of Korea | | x | x | x | x | x | x | x |
| Russian Federation | x | | | x | x | | | |
| Somalia | | | | | | | | x |
| South Africa | x | x | x | x | x | x | x | |
| Spain | x | | x | x | x | x | | |
| Sweden | | x | x | x | x | x | x | x |
| Turkey | x | x | x | x | x | x | | x |
| UK | | x | x | x | x | x | x | x |
| USA | x | x | x | x | x | x | x | x |
| **Total** | **15** | **18** | **36** | **29** | **23** | **23** | **14** | **17** |

*Source:* Data based on the GOSR2020 questionnaire.

In addition to the research infrastructure/equipment listed in Table 4.4, there are also high frequency radar (HF radar) systems used to monitor specific variables and conditions from the seas, e.g. the speed and direction of ocean surface currents, in near real time. Although HF radar systems were not included in the questionnaire sent to Member States, given their potential to provide relevant data to inform policies for a well-functioning ocean in light of the Ocean Decade, a brief review is provided.

**Box 4.1.** High frequency radars (HFRs)

One of the benefits of HFRs is that they can measure current conditions over large regions of the coastal ocean, from a few kilometres offshore up to about 200 km, and can operate under relatively bad weather conditions. HFRs are the only sensors that can measure certain ocean variables in large areas at once with the level of detail required for several important applications, such as coastal ocean current measurements. Satellites are unable to carry out this function, as they lack the necessary temporal and spatial resolution.[24]

HFRs are well suited to many applications, such as coastal guard, search and rescue, marine safety and navigation, response to oil and chemical spills, tsunami warning, coastal zone ecosystem management, water quality assessment, and weather, climate and seasonal forecasting.

Since 2012, worldwide consortia of academic, governmental and private organizations with HFR networks at national or regional levels have established partnerships to coordinate and collaborate on a single Global HF Radar Network.[25] This is part of the Group on Earth Observations (GEO), promoting HFR technology and enhancing data sharing among operators and users. In 2017, the Global HFR Network (Figure 4.20) was recognized by the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) as an observing network of the Global Ocean Observing System (GOOS). Nine countries — Australia, Canada, Croatia, Germany, Italy, Malta, Mexico, Spain and USA — provide data to the Global HF Radar Network. The network covers over 35 countries, and it is expected that more countries will establish their networks and join the global network in the near future. Growth has remained steady, with about 350 radars already in operation and 9 countries sharing data via the global network. There were approximately 281 sites reporting to the GEO list as of 2018 (Roarty et al., 2019).



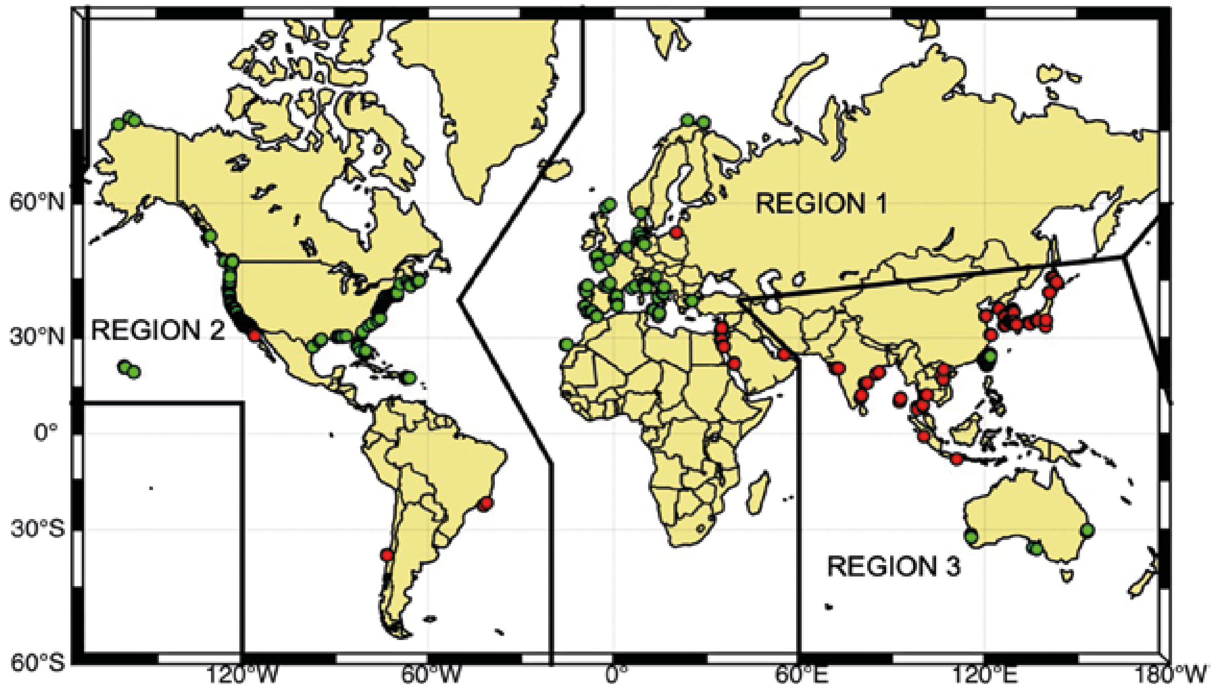


**Figure 4.20.** Global distribution of HFR stations. The green dots indicate stations that are sharing their data through the global network and red dots indicate stations that are currently not sharing their data.
*Source:* Roarty et al., 2019.

[24] See https://ioos.noaa.gov/project/hf-radar.

[25] See http://global-hfradar.org.

## 4.5. Capacity development

Capacity development — a process by which individuals and organizations obtain, strengthen and maintain the capabilities to set and achieve their own development objectives over time — is a fundamental tenet of IOC-UNESCO and of the Ocean Decade. It enables all Member States to participate in, and benefit from, ocean research and services that are vital to sustainable development and human welfare on the planet (IOC-UNESCO, 2016).

According to the IOC-UNESCO Capacity Development Strategy (2015–2021), two of its six outputs are: (i) human resources developed by way of academic (higher) education, continuous professional development, sharing of knowledge and gender balance; and (ii) visibility and increased awareness through public information and ocean literacy (IOC-UNESCO, 2016).

These outputs are illustrated in sections 4.5.1–4.5.6, through: (i) transfer of marine technology; (ii) attendance of ocean science students at international conferences and symposia; (iii) WIOMSA, JPI Oceans and SPREP as examples of organizations supporting international science; (iv) academic (higher) education; (v) the Ocean Teacher Global Academy (OTGA) model for continuous professional development; and (vi) the relevance of ocean literacy. These examples may serve as inspiration for the upcoming Ocean Decade.

Quantitative data and information about capacity development are limited, as demonstrated by the data provided by Member States through the GOSR2020 questionnaire. Only a few countries provided answers to all the questions and the biggest gaps were found in Asia. In order to illustrate current developments and to provide at least some examples, information gathered from regional initiatives coordinated by IOC-UNESCO was analysed for Latin America and Western Africa regions, paving the ground for wider assessments within future editions of the GOSR.

### *4.5.1. Transfer of marine technology*

Transfer of marine technology, as a tool to implement capacity development, encourages states and international organizations to cooperate in promoting the development and transfer of marine technology (i.e. human resources, infrastructure research, processes and methodologies to produce and use ocean and coastal knowledge) on fair and reasonable terms and conditions. This enables countries to access the benefits of the oceans by improving the study and understanding of the nature and resources of oceans and coasts.

The types of marine technology used in the context of research are:

a. User-friendly information and data on marine sciences and related marine operations and services;
b. Manuals, guidelines, criteria, standards, reference materials;
c. Sampling and methodology equipment (e.g. for water, geological, biological, chemical samples);
d. Observation facilities and equipment (e.g. remote sensing equipment, buoys, tide gauges, shipboard and other means of ocean observation);
e. Equipment for *in situ* and laboratory observations, analysis and experimentation;
f. Computer and computer software, including models and modelling techniques; and
g. Expertise, knowledge, skills, technical/scientific/legal know-how and analytical methods related to marine scientific research and observation (IOC-UNESCO, 2005).

IOC-UNESCO is starting to develop a clearing house mechanism for the transfer of marine technology (CHM/TMT) (Figure 4.21). Capacity development must be needs-driven and acknowledge regional diversity, and the system must match offers with demands (IOC-UNESCO, 2019). In this sense, within the framework of the IODE-IOC project, the CHM/TMT for Latin America and the Caribbean is a prototype developed as a flexible architecture information tool, which includes seven thematic modules that collect specific data for the region: (i) access to information from ocean science experts; (ii) documents; (iii) education and training opportunities; (iv) laboratories; (v) institutions; (vi) RVs; (vii) geospatial data and information, including the base scheme developed for the Caribbean Marine Atlas (CMA). The CHM/TMT for the Latin America and Caribbean portal is based on web services for interoperability with multiple sources of data and information, in particular using the different platforms created by IOC's initiative on International Data and Information Exchange (IODE), such as OceanExpert, OceanDocs, Ocean Biogeographic Information System (OBIS) and Ocean Data and Information System (ODIS). CHM-LAC uses the following technologies as a method of data extraction: (i) web scraping for websites, (ii) Catalogue Service - Web (CSW) for geographic information and (iii) data imports from files.

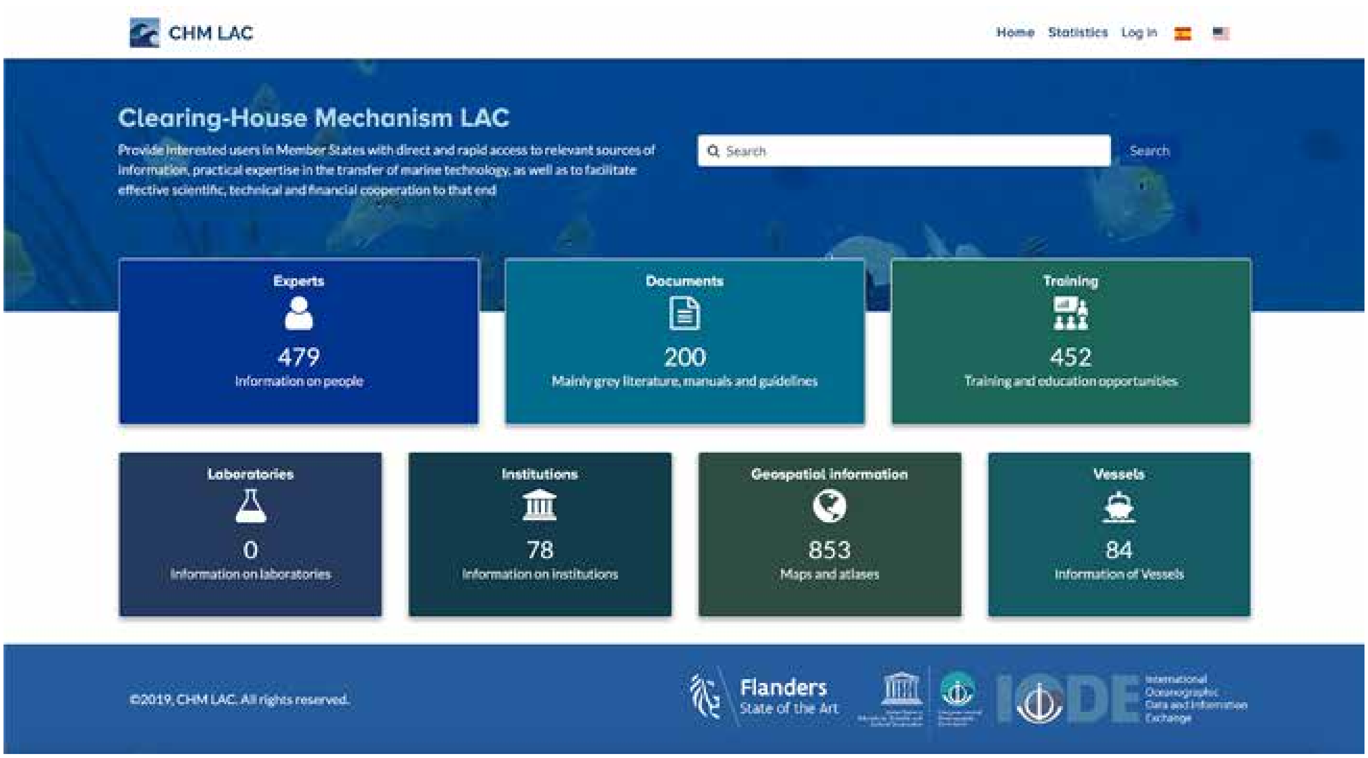


Figure 4.21. CHM LAC prototype home page.
*Source:* See http://portete.invemar.org.co/chm.

### 4.5.2. Attendance of ocean science students at international conferences and symposia

One important capacity development factor for early career scientists is their attendance at ocean science conferences and symposia.

An analysis of ocean science students' (bachelor, master and PhD) attendance at international conferences and symposia held during the 10-year period 2009–2018 (student information available from 2011 on) is presented in supplementary material 4.3.

Gender information was extracted for a total of 1,851 students participating in 15 international conferences[26] held between 2011 and 2018. Females accounted for 56% of the total number of participants (Supplementary material 4.22). Of these 15 conferences, 6 took place in the area of the Pacific Ocean. The female proportion of total students participating was lower than the global average, only accounting for 47% (Figure 4.23).

When the percentage of females among the student participants is compared to that of the other female participants in the conferences (Figure 4.24), it is obvious that the former is higher than the latter. Additional studies will be required to determine if this is an indication of a generational change, or of the difficulties faced by women in pursuing their scientific careers in later years.

[26] For two of the conferences, students and early career scientists were counted within the same category: Second WCRP/CLIVAR Open Science Conference (early career scientists include students and researchers within five years of their most recent degree); the 10th International Conference on Marine Bioinvasions (ICMB-X).

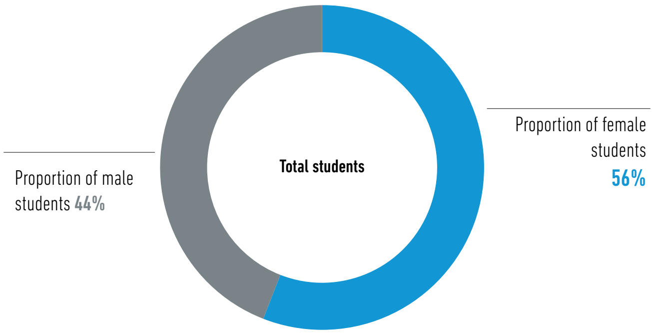


**Figure 4.22.** Proportion (%) of female and male students attending international conferences as per data gathered in supplementary material 4.3.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2011 to 2018.

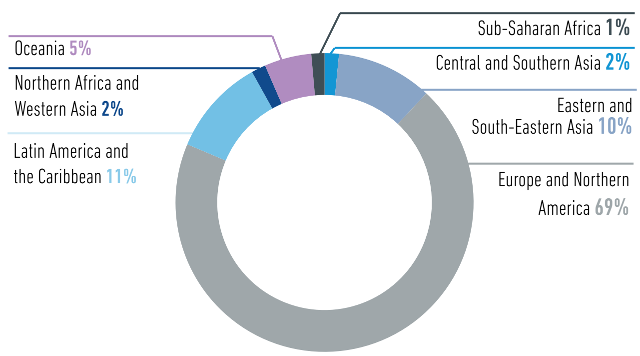


**Figure 4.23.** Proportion (%) of female and male students at international conferences with a focus on the Pacific Ocean region.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2012 to 2018.

Further, based on the information for 1,541 students participating in 9 international conferences, the region of affiliation was identified. Conferences with a focus on a region (e.g. Pacific Ocean) were excluded from this analysis (Supplementary material 4.3). This analysis shows that students from Europe and Northern America account for 69% of total students globally attending ocean science conferences (Figure 4.25).

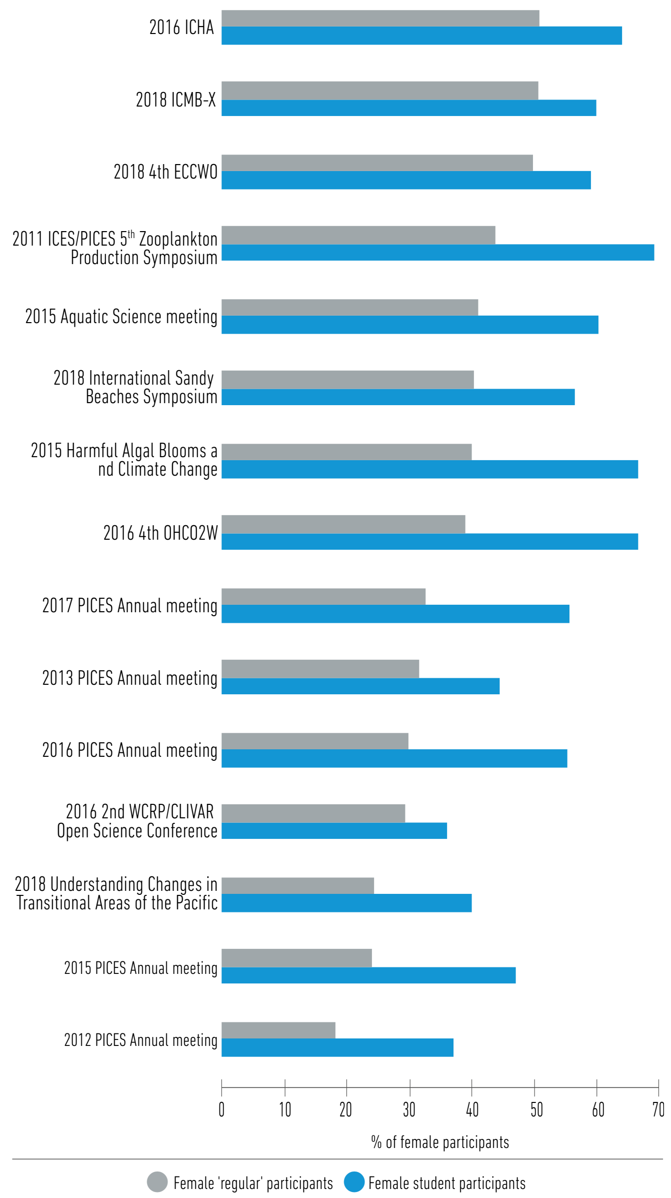


**Figure 4.24.** Proportion (%) of female student and female 'regular' participants participating in international conferences, as per data gathered in supplementary material 4.3.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2011 to 2018.

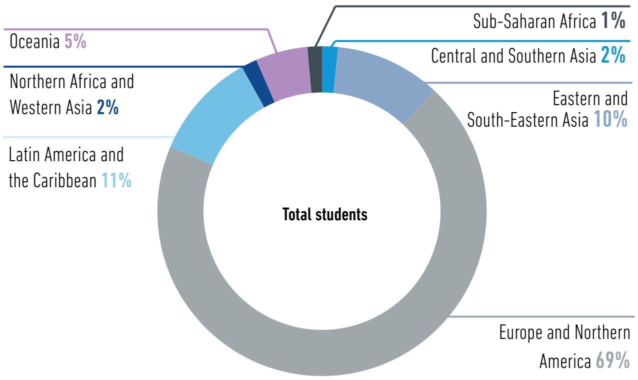


**Figure 4.25.** Proportion (%) of students per region attending international conferences/symposia, excluding regional conferences from the Pacific Ocean.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2011 to 2018.

However, student participation varies if the place where the conference is held is also considered. Figure 4.26 reveals the relationship between students' region of affiliation and the region where the conference is held. This information was available only for conferences held in Eastern and South-Eastern Asia, Europe and Northern America, Latin America and the Caribbean, and Oceania.

Clearly, student access to conferences varies depending on the region where the conferences take place. Students from each of the regions Eastern and South-Eastern Asia, Latin America and the Caribbean and Oceania account for less than 10% of participants when conferences are organized in a region different from their own. However, their representation increases when conferences are held in their own region, where they account for more than 40% of student participants. In contrast, participation by students from Europe and Northern America seem to be less affected by the place where the meeting takes place. They represent a minimum of 30% of total participants independently of the region, reaching more than 80% of students participating in conferences held in Europe and Northern America.

Further analysis will be required to see if these distribution patterns also occur for conferences held in Central and Southern Asia, Northern Africa and Western Asia and Sub-Saharan Africa.

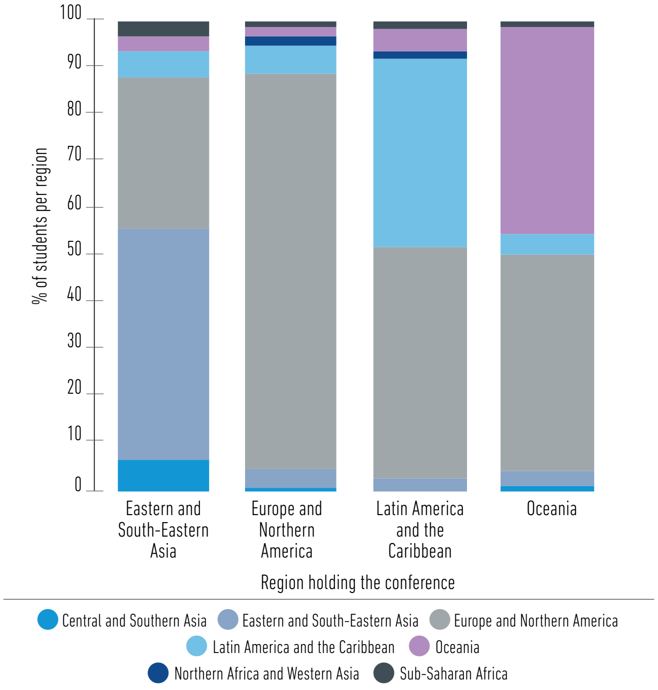


**Figure 4.26.** Proportion (%) of students per region participating in international conferences, excluding regional conferences (Pacific Ocean), in relation to the region where the conferences are held, as per data gathered in supplementary material 4.3.
*Source:* Selected lists of participants in international scientific ocean science conferences/symposia held from 2011 to 2018.

### *4.5.3. International science support organizations — Sharing of knowledge and community building*

The following descriptions of international science support organizations are examples from different parts of the world. This short selection of model organizations allows the identification of good practice for capacity development in ocean science. The list is not comprehensive, as there exist many more organizations supporting the sharing of knowledge and building of communities.

#### 4.5.3.1. The Western Indian Ocean Marine Science Association (WIOMSA)

The Western Indian Ocean Marine Science Association (WIOMSA) is a regional non-profit, non-governmental organization registered in Tanzania in 1993. WIOMSA's activities include domains such as education, sciences and technological development in marine sciences. The association supports research on the marine and coastal ecosystems of the eastern coast of Africa. Science action in ten countries (Comoros, Kenya, Madagascar, Mauritius, Mozambique, Réunion (France), Seychelles, Somalia, South Africa and Tanzania,) can benefit from WIOMSA's programmes. WIOMSA receives financial support from many actors, including several countries such as Kenya, South Africa and Sweden. In 2018, other donors included the State Department of the USA, UNEP and the Nairobi Convention, the World Bank, the European Union and the Indian Ocean Commission.[27] More generally, WIOMSA cites the Government of Sweden, USAID and the MacArthur Foundation as its main donors.[28]

In 2019, WIOMSA had two general research programmes:[29] MASMA (Marine and Coastal Science for Management); and the Marine Research Grant Programme (MARG), which aims to enhance research capacity and understanding of marine sciences.[30] Finally, WIOMSA established two programmes supporting research with specific scientific foci: The Cities and Coasts project; and the Ocean Acidification Monitoring project for the countries in the Western Indian Ocean region.

The Women in Marine Science Network (WiMS) and the Western Indian Ocean Early Career Scientists Network (WIO-ECSN) are two initiatives launched at the 10th WIOMSA Scientific Symposium held in Dar es Salaam, Tanzania, in 2017.

While WiMS was launched to address the gender equality issues that are facing women marine scientists — its mission is to provide women in marine sciences with a platform to share experiences, challenges and solutions, celebrate their achievements and promote their visibility within and outside the WIO region[31] — WIO-ECSN promotes scientific research through fostering strong regional ties among early career scientists and representing their collective scientific interests at an international level.[32]

WIO-ECSN comprises scientists from eight Western Indian Ocean (WIO) countries, namely: Comoros, France (Mayotte and La Réunion), Kenya, Madagascar, Mozambique, Seychelles, South Africa and Tanzania. The core objective of the network is to give a voice to early career scientists by facilitating and communicating research priorities for the development of marine sciences in the WIO region. The network's mission is to strengthen capacity of early career scientists in the WIO region through partnership with relevant stakeholders.

In 2018, the network nominated some of its members to participate in several research cruises on board the RV *Dr Fridtjof Nansen*, which operates within the EAF-Nansen Programme of the Food and Agriculture Organization of the UN (FAO). In the same year, 32 network members participated in the second South African research cruise under the second International Indian Ocean Expedition (IIOE-2) programme, on board the RV *SA Agulhas II*. The EAF-Nansen Programme, IOC-UNESCO and the Department of Environmental Affairs of South Africa provided financial support for members and students to participate in the cruises. The WIO early career scientists view these research cruises as successful capacity development events because the members directly benefited from training in the handling of scientific equipment, data analyses and the presentation of scientific findings. The opportunity to work and interact with other young marine scientists across different oceanographic disciplines enabled an environment of transdisciplinary research in the region.

#### 4.5.3.2. The Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans)

The Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans) was launched in 2011 as an intergovernmental platform open to all European Union member states. The organization strives to increase the impact of national investments in marine and maritime research and innovation. Following a wide consultation conducted by JPI Oceans, the Strategic Research and Innovation Agenda 2015–2020 (SRIA) was published in 2015.[33] The SRIA identified ten strategic areas for action: 'deep sea resources', 'technology and sensor developments', 'science support to coastal and maritime planning and management', 'linking oceans, human health and well-being', 'interdisciplinary research for good environmental status', 'observing, modelling and predicting oceans state and processes', 'climate change impact on physical and biological ocean processes', 'effects of ocean acidification on marine ecosystems', 'food security and safety' and 'biotechnology'. The organization also supports science activities addressing cross-cutting issues like 'science-policy interface' and 'human capacity building'.

Each member state participates financially with an annual membership fee corresponding to a proportion of the planned JPI Oceans annual budget; the proportion varies according to the

27 See WIOMSA, 2019.

28 See https://www.wiomsa.org/about-wiomsa/donors (Accessed 9 December, 2019).

29 See https://www.wiomsa.org/our-work (Accessed 9 December, 2019).

30 See WIOMSA, 2019.

31 See https://wims.wiomsa.org.

32 See https://www.wiomsa.org/wio-ecsn.

33 See JPI Oceans, 2015.

GDP of each country.[34] In the GOSR2020 questionnaire, Belgium, Bulgaria, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Russian Federation and the UK declared funding JPI Oceans over the years 2013–2017. Some individual actions led by countries or some contracted projects are not covered financially by the annual membership fees. Netherlands, Norway, the UK and Portugal also declared receiving financial support for their ocean scientists through the GOSR2020 questionnaire.

#### 4.5.3.3. The Secretariat of the Pacific Regional Environment Programme (SPREP)

The Secretariat of the Pacific Regional Environment Programme (SPREP) was established in the 1970s[35] as a joint initiative of the South Pacific Commission (SPC, now Pacific Community), the South Pacific Bureau for Economic Cooperation (SPEC), the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) and the UN Environment. It was functioning as a part of UNEP's Regional Seas Programme. In 1993, it was established as an independent intergovernmental organization. In the agreement establishing SPREP, the objectives of the programme are outlined as follows: 'Promote cooperation in the South Pacific Region and to provide assistance in order to protect and improve the environment and to ensure sustainable development for present and future generations'.[36] In 1993, SPREP stood for 'South Pacific Regional Environment Programme', however it was changed to 'Secretariat' as countries from the northern hemisphere were added to the member states. Nowadays, there are 19 Parties to the agreement, including 14 Pacific island countries and 5 metropolitan countries with direct interests in the region.[37] The SPREP secretariat is now a key player for environment and sustainable development in the region, as it is the secretariat for the Noumea Convention, the Waigani Convention and the Apia Convention, and it is part of the Council of Regional Organizations in the Pacific (CROP).

Nowadays, SPREP concentrates its activities in four main areas: (i) environmental monitoring and governance; (ii) waste management and pollution control; (iii) island and ocean ecosystem services; and (iv) climate change resilience. The projects supported by SPREP are all part of one of the priorities. For instance, SPREP supports the 'New Zealand-Pacific Partnership on Ocean Acidification' (PPOA), as part of the climate change resilience priority. Other projects, such as 'Pacific Ecosystem-Based Adaptation to Climate Change' (PEBACC) or 'Biodiversity and Protected Areas Management Project' (BIOPAMA), are part of the island and ocean ecosystem services priority.[38]

### *4.5.4. Academic (higher) education in two developing regions*

Technical ocean science capacities can be developed through a series of formal educational activities organized at different levels of qualification and through specialized technical training. Access to tertiary education is unequal around the world, as is the availability of university programmes on ocean science in different countries. Examples of two regional assessments — for Latin America and the Caribbean, and Western Africa, which are largely composed of developing countries — are provided in Sections 4.5.4.1 and 4.5.4.2.

#### 4.5.4.1. Latin American and the Caribbean region (LAC)

For the Latin American and Caribbean region (LAC), there are reports for 23 countries, offering a total of 577 ocean science programmes at bachelor, master and doctorate levels during the academic year 2018–2019. As per subregions, Latin America (including Spanish- and Portuguese-speaking countries in the region) has the greatest proportion of academic programmes (76%) followed by Northern America (English programmes) (18%) and the Caribbean (English and French programmes) (6%). As America is the continent with the most Hispanic speakers, it is normal to expect that the majority of programmes are offered in Spanish (318), followed by Portuguese (144), English (111) and French (4). However, results show that Brazil is the leading nation in the region, with more ocean science graduates than any other country on the continent (Figure 4.27).

[34] The fee is calculated as a proportion of the annual budget based on weighted GDP from the last five calendar years. The weighted GDP is a percentage calculated by using a 50:50 ratio of GDP and GDP per capita in the last five years (meaning that the 2019 financial plan is based on GDP data from the period 2012–2017) (JPI Oceans, 2018).

[35] See https://www.sprep.org/governance.

[36] See SPREP, 1993.

[37] Australia, Cook Islands, Papua New Guinea (PNG), Federated States of Micronesia (FSM), Fiji, France, Kiribati, Marshall Islands, Nauru, New Zealand, Niue, Palau, Samoa, Salomon Islands, Tonga, Tuvalu, UK, USA, Vanuatu.

[38] See https://www.sprep.org/projects.

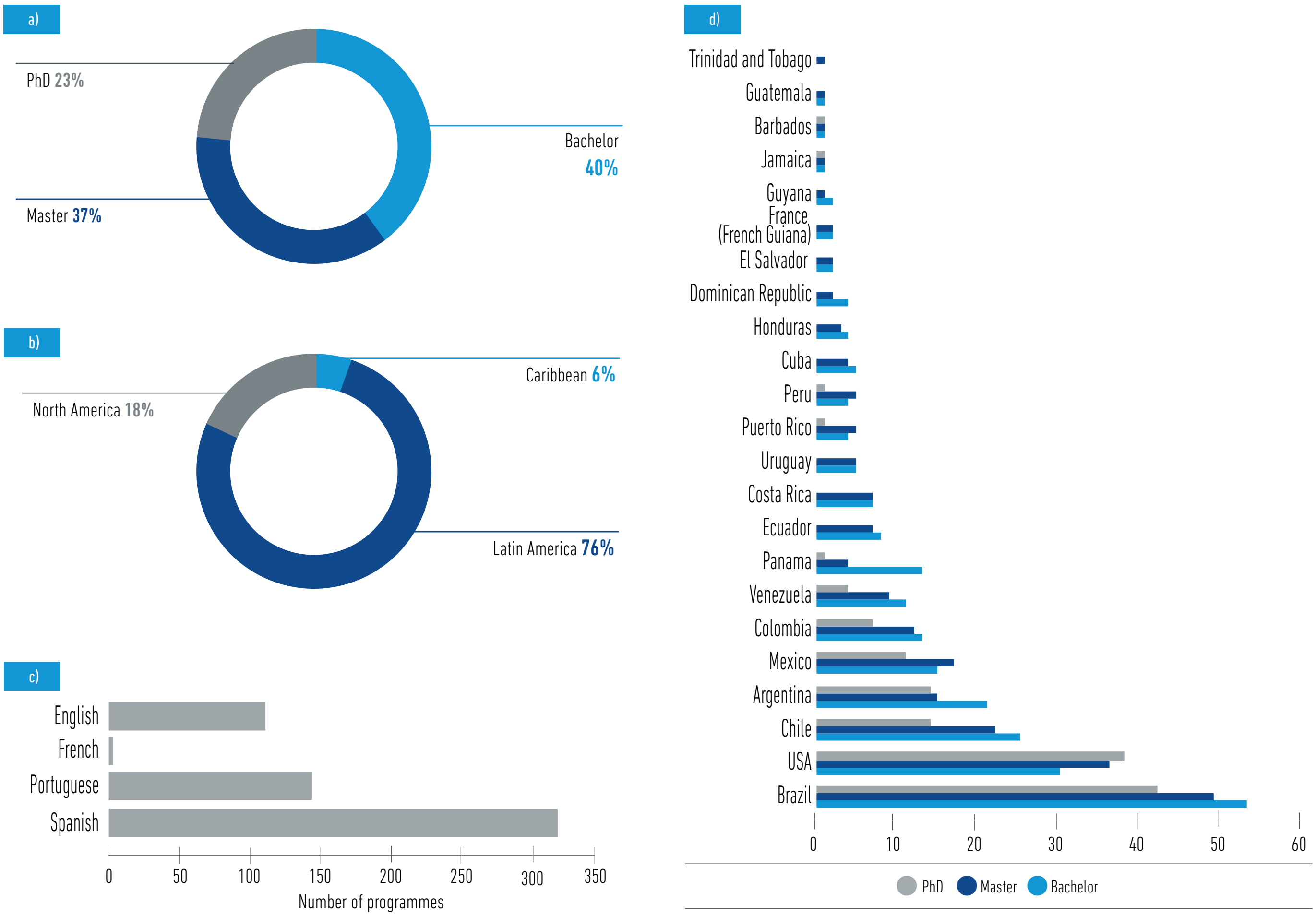


**Figure 4.27.** Training and education opportunities in LAC and Northern America: a) by type; b) by region; c) by language; and d) by country and type. *Sources:* IOCARIBE (https://bit.ly/3aFtpZ1) and (http://portete.invemar.org.co/chm).

### 4.5.4.2. Western Africa countries

Within the framework of the IOC-UNESCO project 'Enhancing Oceanography Capacities in the Canary Current Large Marine Ecosystem (CCLME) Western Africa Countries', supported by the Spanish Agency for International Development Cooperation and executed by IOC, information was gathered about university programmes on ocean science and related matters in North-West Africa coastal countries for the academic year 2019–2020. Areas/countries covered in this assessment are Cabo Verde, Gambia, Guinea, Guinea-Bissau, Mauritania, Morocco, Senegal and Spain (Canary Islands region only). A total of 49 graduate and postgraduate programmes were identified in 5 countries, although they are unequally distributed in the region (Figure 4.28), with up to 20 programmes identified in Senegal and none in other countries. These programmes cover different fields of ocean science, including oceanography/marine science and the ocean-atmosphere-climate relationship; coastal science and management; management, valorization and exploitation of marine resources with a focus on fisheries and aquaculture; and naval sciences. All the trainings are offered in one official language of the country, the majority being delivered in French (38), followed by Spanish (8), Portuguese (2) and English (1) (Figure 4.28).

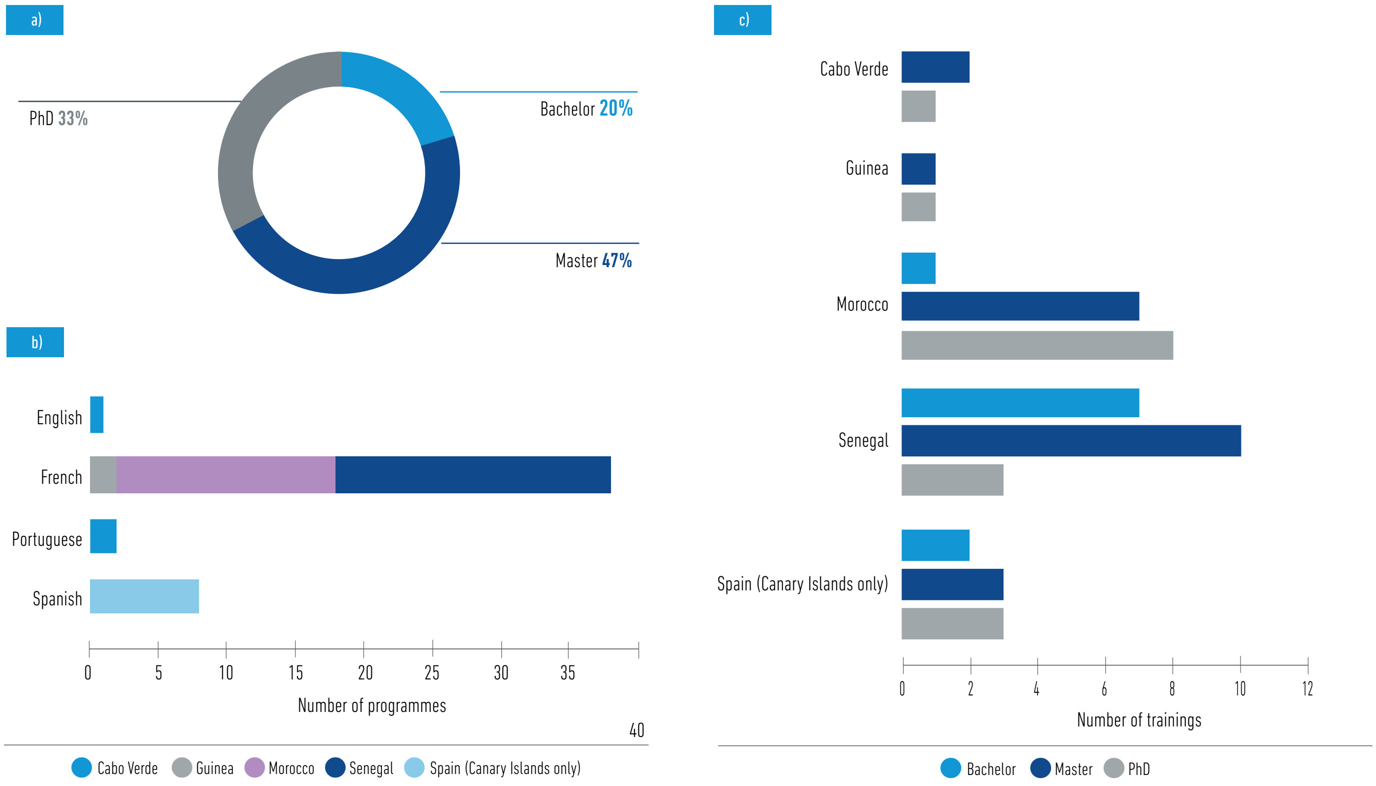


**Figure 4.28.** Number of training programmes identified in the CCLME Western Africa region: a) by type; b) by language;[39] c) by country.
*Source:* unpublished data IOC-UNESCO, 2020.

### 4.5.5. Continuous professional development — the OceanTeacher Global Academy model

The achievement of a university degree is not the end of education. The rapid evolution in science and technology requires continuous professional development. Short-term (one–two weeks) training courses are essential tools to ensure continuous professional development, i.e. updating or extending the expertise and knowledge of scientific or technical personnel (IOC-UNESCO, 2016).

IOC's International Oceanographic Data and Information Exchange (IODE) programme has built a comprehensive learning management system (OceanTeacher) which, in combination with classroom instruction, has trained nearly 3,000 students from 134 countries since 2005 and has more than 4,000 registered users. The OceanTeacher programme is supported by the Government of Flanders, Belgium (FUST funding) and benefits all IOC-UNESCO Member States, with special emphasis on developing regions. Over the past 15 years, the programme has extended from Belgium all over the world through regional training centres (RTCs) and specialized training centers (STCs) (Figure 4.29) associated with universities and marine research institutions. It now operates as the OceanTeacher Global Academy (OTGA).

The OTGA validates the expertise available in developing regions and promotes their self-reliance in terms of specialized technical training and higher education related to ocean science, observation and data/information management. It also promotes the use of local languages and local experts as lecturers and training assistants at OTGA-RTCs, further developing the OceanTeacher Learning Management System to cover multiple IOC-UNESCO (and associate) programmes. As a result of the quality management framework in place for organizing training activities delivered through the OTGA, the IODE project office obtained its ISO 29990 Certification for Learning Services Providers in April 2018.

[39] Two training programmes, offered mainly in Spanish, include some lectures in English.

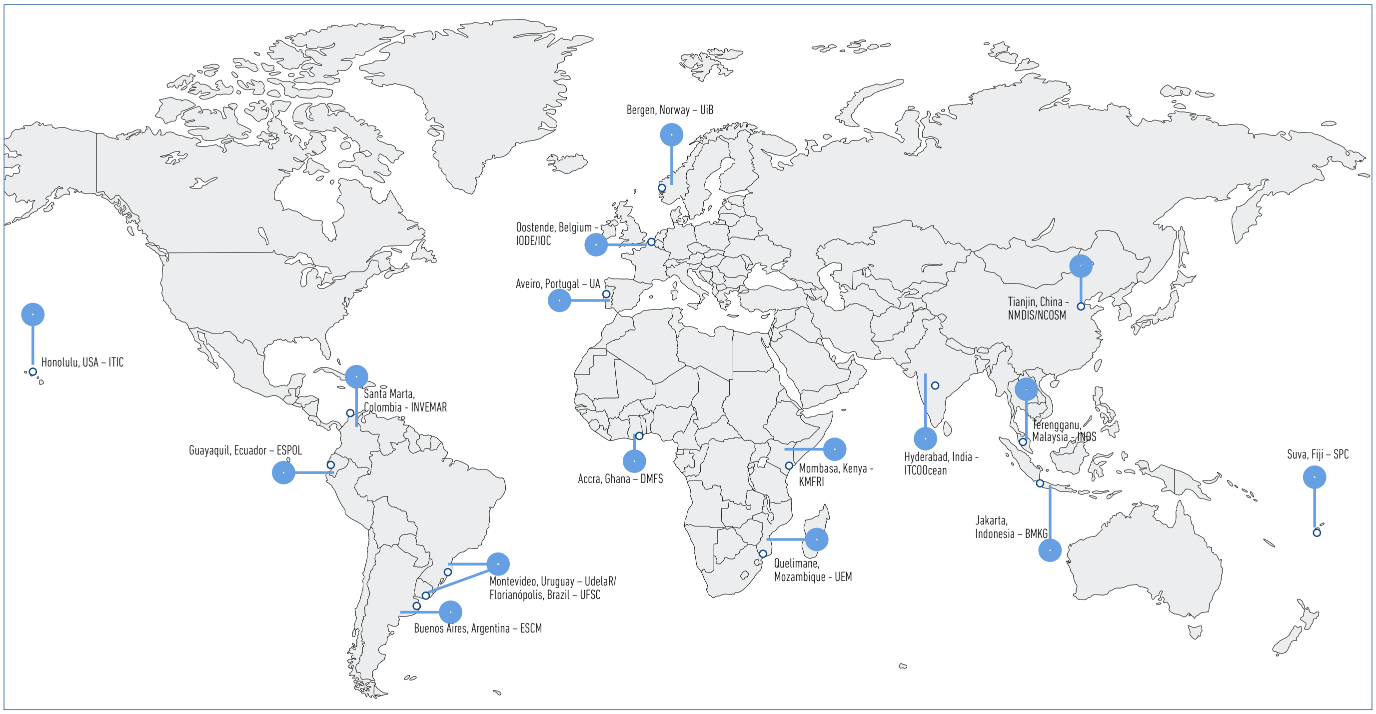


**Figure 4.29.** Location of OTGA regional training centres and specialized training centres (November 2020). *Source:* IODE.

Between 2017–2019, no less than twenty new training courses were uploaded on the OceanTeacher e-Learning Platform (OT e-LP), available in up to four languages (English, French, Portuguese and Spanish). A change in business model for the new OTGA phase 2020–2022, in alignment with the Ocean Decade, will focus on developing 'packaged courses' that can be delivered on demand. Courses will be delivered either fully online, by blended learning and/or face-to-face (classroom), depending on the topic.

It is important to recognize that the OTGA-RTCs have been designing courses in accordance with the needs identified by member states in each region. One example is the INVEMAR RTC-Latin American and Caribbean (LAC), which was recognized as a designated RTC in 2015. INVEMAR contributes to the RTC by providing facilitating infrastructure, logistical support and co-funding scholarships for local and national participants, adding to the funds for international alumni. From 2015 to 2019, 550 scientists from 22 countries attended 29 courses organized by RTC-LAC, covering 11 different topics. Half of the participants were female, due to the implementation of INVEMAR's and UNESCO's gender policies (Figure 4.30). There can be no doubt that courses held at the RTC-LAC enable countries in the region to increase their skills and knowledge in ocean science.

Other important training centres and initiatives are those of are POGO-SCOR, the UN-Nippon Foundation, the World Maritime University of IMO, the International Ocean Institute and regional centres of excellence, such as those in the Partnerships in Environmental Management for the Seas of East Asia (PEMSEA).

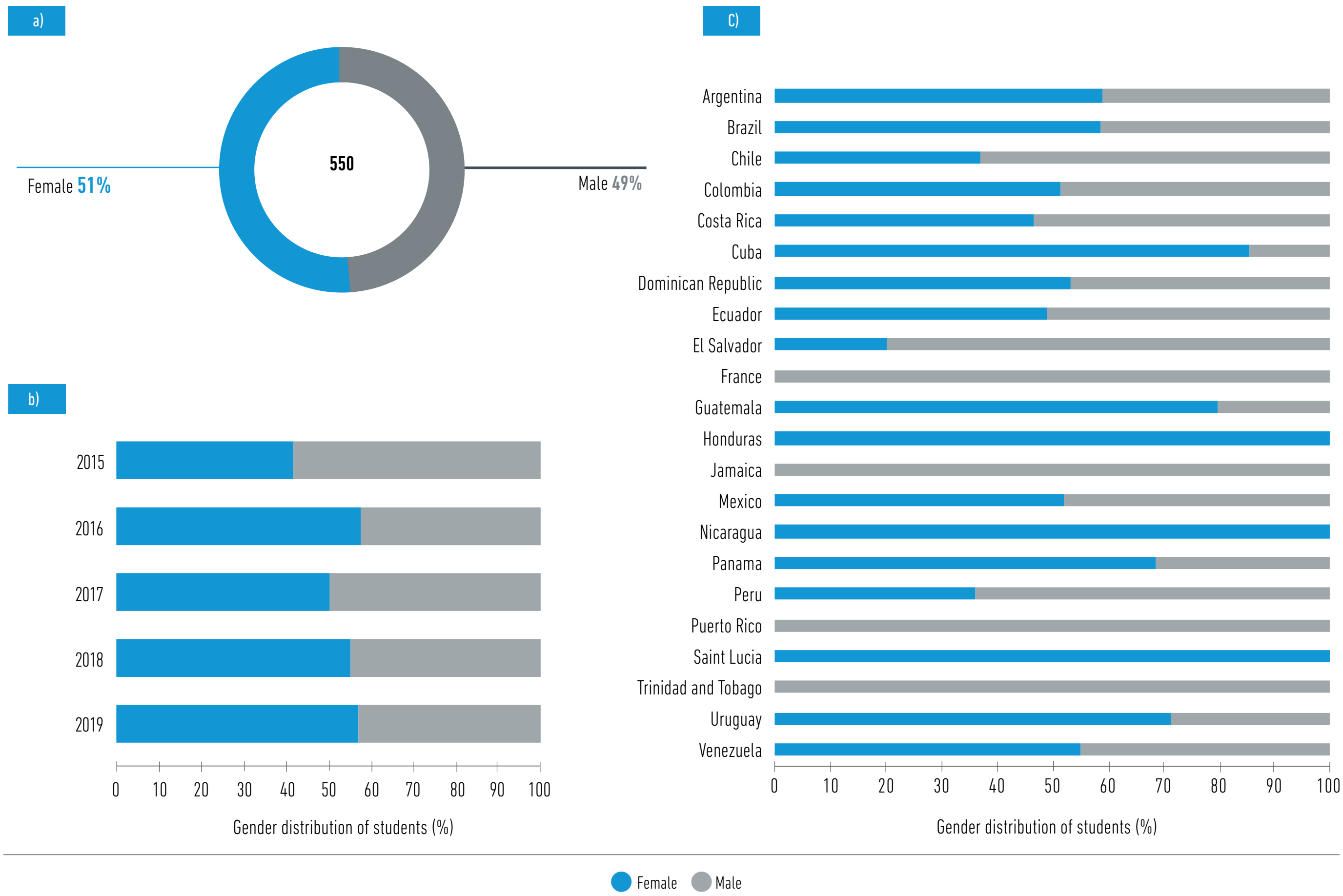


**Figure 4.30.** Gender balance of students participating in courses (taught in Spanish) at the RTC-LAC: a) total; b) per year; c) per country.
*Source:* Based on data provided by INVEMAR at: https://bit.ly/2Ix38QH.

### *4.5.6. Ocean literacy as ocean visibility and awareness — Non-technical capacity development*

Addressing ocean issues through conceptual ties to science and global societal issues has captured the attention of the international community. However, sometimes there is a disconnect between what scientists know about the ocean and what the public understands. Although standards for science teaching and literacy are well-established, the fundamental role of the ocean is not emphasized in formal education. Moreover, there is greater interest in the ocean space due to the development of the ocean economy, commitment to the implementation of the 2030 Agenda (with particular reference to SDG 14 and its targets), the negotiation of new legal instruments and the need to provide scientifically sound solutions to emerging threats to the ocean (Santoro et al., 2016). For this reason, a variety of actors and stakeholders need to have a better understanding of ocean characteristics and processes, as well as of the importance of ocean science, observation and data for managing ocean activities and research. Ocean literacy is defined as the understanding of human influence on the ocean and the ocean's influence on humans (NMEA, 2010). Ocean literacy is not only about increasing awareness of the state of the ocean, it is also about providing tools and approaches to transform ocean knowledge into actions to promote ocean sustainability (Borja et al., 2020).

The success of ocean literacy will depend partly on capacity to enhance the science-society-policy interface and partly on empowering a wide range of stakeholders, i.e. communities and networks of business, universities, research centres and civic groups, to share responsibility in addressing urgent threats that are causing a decline in ocean health. Furthermore, increasing ocean literacy at the national level, and at all educational levels, is a fundamental element in enabling capacity development in the national marine science sector. While national and regional organizations and associations are critical to promote ocean literacy nationally and regionally, IOC-UNESCO is committed to ensuring international collaboration, the application of quality standards and the exchange of good practices. Since 2017, IOC-UNESCO has developed several tools to support activities on ocean literacy. In particular, *Ocean Literacy for All: A Toolkit* (IOC-UNESCO, 2017*b*), with English, French, Spanish, Portuguese and Italian versions, and the IOC-UNESCO Ocean Literacy Portal.[40] *Ocean Literacy for All: A Toolkit*, is intended to provide educators and learners with innovative tools, methods and resources to understand ocean processes and functions, to alert them to the most urgent ocean issues and to provide ready-to-use activities to be implemented in formal and non-formal educational contexts. The manual presents the essential ocean literacy principles and the information needed to understand the cause-and-effect relationship between individual and collective behaviour, and the impacts that threaten ocean health. It aims to inspire citizens, scientists, educators and learners to take greater personal responsibility for the ocean, as well as to work through partnerships and networks, sharing ideas and experiences and developing new approaches and initiatives in support of ocean literacy.

The IOC-UNESCO Ocean Literacy Portal aims to be a repository for quality education and information tools, resources, good practices and local or international success stories. It also aims to become the reference point for enabling coordination and exchange with other ocean literacy practitioners, by creating collaborative workspaces and networks and thus contributing to community building. Community members are encouraged to share their resources through the Ocean Literacy Collaborative Workspace, where the global ocean literacy community can work directly with fellow members by thematic forum discussions, working on shared documents, and by creating databases. This unique forum for ocean literacy enables knowledge sharing and, in doing so, strengthens and widens each member's radius of action. The portal was designed to be user-friendly and to facilitate navigation by using sectoral information based on stakeholder background (students, educators, scientists, media, policymakers, private sector), and filtering the vast store of information by resource- and subject-type search engines.

[40] See http://oceanliteracy.unesco.org.

## 4.6. Emerging issues and concluding remarks

The enormous demand for ocean data and information in all sectors (environmental, scientific, academic, private and public), requires a major commitment from all countries to generate and maintain research capacities and infrastructure at all levels. New information technologies, social media and the digital revolution are transforming approaches in ocean sciences. Today, more than ever, open access to ocean data and information, increased interaction between the sectors and society, transfer of marine technology (TMT) and ocean literacy for all should be prioritized, to bring about more responsible and informed behaviour towards marine and coastal resources and services. Innovative South–South and North–South partnership arrangements for capacity development and TMT, as well as training opportunities on ocean science data, should provide evidence to raise awareness of the ocean and help break down current socio-economic and political barriers, to enable creative and transformative approaches that generate far-reaching solutions.

The information and examples presented in this chapter are the first steps to providing a global overview of research capacities and infrastructure. However, they only provide an approximation of the present capabilities based on national reporting mechanisms currently in place.

Technical capacity to prepare national inventories on ocean science requires a multidisciplinary approach, as well as the capacity of countries for timely consultation with the institutions working on ocean science and related topics. Future progress in this area depends heavily on adequate and effective capacity at the national level for collecting, updating and publishing the necessary information, as well as systems that provide mapping of technical and human capacities in ocean science. Access to the databases of international cooperation agencies would further contribute to the development of ocean science capacities. Relevant actors would include local, national and international organizations (both governmental and non-governmental), industry and the private sector, and the insurance and law sectors. Industry and the private sector in particular are major actors in offshore activity that impacts the global ocean through fishing, energy extraction, commerce, leisure and tourism, coastal engineering, dredging and aggregate extraction, among others. Many of the companies involved employ significant numbers of scientists, engineers, educators and policy specialists.

South-South and North-South cooperation are important in the promotion of partnerships to improve marine research capacities and optimize research infrastructure, in order to explore, monitor and conserve strategic marine and coastal ecosystems such as coral reefs, salt marshes, mangroves and sea grass beds, among others. TMT and innovation both play a major role in exploiting the huge wealth that can be derived from the ocean and associated resources, as well as sustainable sea-related activities.

Ocean science capacities (human resources, institutions, marine laboratories, field stations, observation platforms and tools for sustained ocean observation) require an improved and increased mobilization of financial resources during the Ocean Decade. This is essential for maintaining scientific infrastructure — not only laboratories, vessels, instruments and the main buildings of organizations, but also infrastructure for information dissemination and open data availability, for the implementation of education programmes in data collection and management and for interdisciplinary approaches, as well as training courses in new topics using new technologies to reach the Ocean Decade's six societal outcomes (a clean, healthy and resilient, predicted ocean, a safe ocean, sustainably harvested and productive ocean as well as a transparent and accessible ocean).[41]

It should be noted that further professional development for ocean scientists is also provided by learned marine societies and professional bodies, such as the Institute for Marine Engineering Science and Technology, and licensed by the Marine Technology Society (MTS) and the Society for Underwater Technology (SUT). These capacity development activities lead to qualifications such as 'Chartered Marine Scientist' and others that are widely adopted in industry, government laboratories, armed services and the research sector. Such qualifications are necessary if researchers wish to take part in industry-funded research as a quality control standard.

Capacity development and TMT are complementary in understanding the key attributes of Biodiversity Beyond National Jurisdiction (BBNJ), SDGs and nationally determined contributions (NDCs) to the Paris Agreement.

Without doubt, the participation of women in all ocean science categories, on equal terms, is critical to sustaining ocean-based livelihoods. This chapter has highlighted the increased participation of women in conferences and in regional training courses, compared to GOSR2017. However, the need to abide by national and international commitments to improve the participation of women in ocean science, particularly in innovative areas such as information technologies, TMT, ocean literacy and other thematic areas (e.g. deep-sea scientific research that requires participation in surveys aboard RVs, blue carbon and innovative financial solutions such as blue bonds for voluntary carbon markets or payment for environmental services), still remains.

It is also important to promote early career scientists' networks in the field of ocean science, to facilitate the involvement of young scientists in determining research priorities and strengthening the capacity of members through partnerships with relevant stakeholders.

Capacity development must concentrate on generating guidelines and proper global schemes that work, taking into account specificities at the national and regional levels, large marine ecosystems and the jurisdiction of UN Member States. Priorities should include:

I. Improving the academic level of human resources (scientists and technicians);

II. Promoting collaboration between different postgraduate programmes around the world;

III. Increasing training courses and facilities, as well as accessibility to them, including through workshops and seminars;

IV. Establishing an ocean info hub and methodologies for accessing specialized data from different disciplines (natural, socio-economic, political, among others);

V. Strengthening institutional capacities at regional and local levels for country-driven activities and being responsive to periodically assessed needs and priorities;

VI. Sharing of knowledge and expertise through collaboration across a wide range of research, disciplines, institutions and sectors; and

VII. Developing capacities for the dissemination and communication of science results in different languages for different audiences, including social awareness.

Last but not least, the development of capabilities on traditional knowledge documentation is emerging as a new and important opportunity. This would enhance the benefits of data collected by local communities and improve scientific analysis for decision making, not only for citizen science but also for ancestral knowledge.

In summary, research (human and infrastructure) and TMT capacities lie at the heart of ocean science. Facilitating access to data, information and exchange networks (know-how, lesson

[41] See https://en.unesco.org/ocean-decade.

learning, protocols, etc.) and driving progress on research will be key to achieve the seven societal outcomes of the Ocean Decade, in particular number six: 'A transparent and accessible ocean, whereby all nations, stakeholders and citizens have access to ocean data and information technologies and have the capacities to inform their decisions' (Ryabinin et al., 2019). Similarly, new human capacities should be developed in an innovative way to combine natural and socio-economic ocean data through data science (data mining and big data analysis) to enforce interdisciplinary teamwork and digital communication, addressing new and emerging challenges, in particular human health dependence on ocean goods and services (i.e. food security, climate and weather regulation, maritime transportation, alternative energies, etc.).

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4

**Supplementary material 4.1.** List of international conferences 2009–2018 by major focus, showing the number of female and male participants from the total number of participants whose gender and country of affiliation were identified.

| Year | Host country | Conference name | Female participants | Male participants | Number of participants | Number of countries |
|---|---|---|---|---|---|---|
| **Environmental science conferences** | | | | | | |
| 2012 | UK | Planet under Pressure | 1 212 | 1 784 | 2 996 | 104 |
| **Ocean science** | | | | | | |
| 2014 | Spain | 2nd International Ocean Research Conference | 249 | 311 | 560 | 69 |
| 2015 | Spain | Aquatic Sciences Meeting | 1 182 | 1 286 | 2 468 | 61 |
| **Ocean and climate** | | | | | | |
| 2012 | Republic of Korea | 2nd International Symposium on the Effects of Climate Change on the World's Oceans (2nd ECCWO) | 89 | 272 | 361 | 38 |
| 2012 | USA | 3rd International Symposium on the Ocean in a High-CO2 World (3rd OHCO2W) | 263 | 275 | 538 | 36 |
| 2015 | Brazil | 3rd International Symposium on the Effects of Climate Change on the World's Oceans (3rd ECCWO) | 124 | 142 | 266 | 36 |
| 2016 | Australia | 4th International Symposium on the Ocean in a High-CO2 World (4th OHCO2W) | 163 | 189 | 352 | 35 |
| 2016 | China | 2nd WCRP/CLIVAR Open Science Conference: Charting the Course for Climate and Ocean Research | 187 | 397 | 584 | 45 |
| 2017 | USA | WCRP/IOC Sea Level Conference | 134 | 251 | 385 | 42 |
| 2018 | Ecuador | The IV International Conference on El Niño Southern Oscillation: ENSO in a Warmer Climate | 63 | 96 | 159 | 26 |
| 2018 | USA | 4th International Symposium on the Effects of Climate Change on the World's Oceans (4th ECCWO) | 304 | 290 | 594 | 48 |
| **Marine ecosystems functions and processes** | | | | | | |
| 2009 | Canada | 3rd GLOBEC OSM | 88 | 223 | 311 | 34 |
| 2010 | Argentina | 3rd Jellyfish Blooms Symposium | 46 | 49 | 95 | 27 |
| 2011 | Chile | ICES/PICES 5th Zooplankton Production Symposium | 150 | 147 | 297 | 35 |
| 2013 | Japan | 4th Jellyfish Blooms Symposium | 42 | 94 | 136 | 29 |
| 2014 | Norway | IMBER Open Science Conference - Future Ocean | 183 | 282 | 465 | 44 |
| 2016 | Norway | ICES/PICES 6th Zooplankton Production Symposium | 196 | 176 | 372 | 32 |
| 2017 | UK | 3rd International Krill Symposium | 26 | 45 | 71 | 15 |
| 2018 | Greece | 2018 International Sandy Beaches Symposium | 32 | 38 | 70 | 20 |
| **Human health and well-being** | | | | | | |
| 2013 | France | Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) | 23 | 28 | 51 | 21 |
| 2014 | New Zealand | 16th International Conference on Harmful Algae (ICHA 2014) | 186 | 208 | 394 | 35 |
| 2015 | Sweden | Scientific Symposium on Harmful Algal Blooms and Climate Change | 26 | 33 | 59 | 23 |
| 2015 | Estonia | Oceans Past V Conference | 22 | 28 | 50 | 15 |
| 2016 | Brazil | 17th International Conference on Harmful Algae (ICHA 2016) | 183 | 157 | 340 | 34 |
| 2018 | France | 18th International Conference on Harmful Algae (ICHA 2018) | 378 | 332 | 710 | 62 |
| **Blue growth** | | | | | | |
| 2015 | Greece | ICES symposium on Targets and Limits for Long-Term Fisheries Management | 20 | 45 | 65 | 18 |
| 2015 | Italy | IMBer IMBIZO IV | 52 | 51 | 103 | 27 |
| 2017 | USA | IMBer IMBIZO V | 48 | 59 | 107 | 26 |

Supplementary material 4.1. Continued

| Year | Host country | Conference name | Female participants | Male participants | Number of participants | Number of countries |
|---|---|---|---|---|---|---|
| **Ocean observations and marine data** | | | | | | |
| 2009 | Italy | OceanObs'09 | 133 | 507 | 640 | 35 |
| 2016 | Poland | International Conference on Marine Data and Information Systems | 28 | 71 | 99 | 24 |
| 2018 | Spain | International Conference on Marine Data and Information Systems | 65 | 119 | 184 | 33 |
| **Ocean health** | | | | | | |
| 2016 | Australia | 9th International Conference on Marine Bioinvasions (ICMB-IX) | 79 | 81 | 160 | 19 |
| 2018 | Argentina | 10th International Conference on Marine Bioinvasions (ICMB-X) | 81 | 67 | 148 | 23 |
| **Ocean crust and marine geohazards** | | | | | | |
| 2018 | Canada | 8th International Symposium on Submarine Mass Movements and their Consequences | 24 | 59 | 83 | 17 |
| **Ocean technology** | | | | | | |
| 2011 | Spain | Oceans'11 | 70 | 328 | 398 | 30 |
| 2012 | Spain | IC Coastal Engineering | 158 | 636 | 794 | 43 |
| **North Atlantic Ocean** | | | | | | |
| 2012 | Norway | ICES Annual Science Conference | 213 | 434 | 647 | 29 |
| 2013 | Iceland | ICES Annual Science Conference | 232 | 415 | 647 | 33 |
| 2014 | Spain | ICES Annual Science Conference | 236 | 333 | 569 | 31 |
| 2015 | Denmark | ICES Annual Science Conference | 299 | 429 | 728 | 34 |
| 2016 | Latvia | ICES Annual Science Conference | 255 | 351 | 606 | 33 |
| 2017 | USA | ICES Annual Science Conference | 214 | 310 | 524 | 31 |
| 2018 | Germany | ICES Annual Science Conference | 289 | 306 | 595 | 33 |
| **Mediterranean Sea** | | | | | | |
| 2016 | Germany | 41st CIESM Congress | 238 | 229 | 467 | 37 |
| **Pacific Ocean** | | | | | | |
| 2012 | Japan | PICES Annual Meeting | 95 | 371 | 466 | 22 |
| 2013 | Canada | PICES Annual Meeting | 121 | 244 | 365 | 11 |
| 2014 | Republic of Korea | PICES Annual Meeting | 103 | 262 | 365 | 19 |
| 2015 | China | PICES Annual Meeting | 141 | 367 | 508 | 13 |
| 2016 | USA | PICES Annual Meeting | 181 | 369 | 550 | 16 |
| 2017 | Russian Federation | PICES Annual Meeting | 116 | 214 | 330 | 11 |
| 2018 | Republic of Korea | PICES Annual Meeting | 175 | 375 | 550 | 14 |
| 2018 | Mexico | International Symposium: Understanding Changes in Transitional Areas of the Pacific | 39 | 108 | 147 | 14 |
| 2018 | Philippines | 4th Asia-Pacific Coral Reef Symposium | 238 | 271 | 509 | 32 |
| **Polar regions** | | | | | | |
| 2017 | Norway | Svalbard Science Conference 2017 | 147 | 212 | 359 | 29 |
| 2018 | Switzerland | SCAR/IASC Open Science Conference 2018 | 893 | 1 190 | 2 083 | 43 |
| **Indian Ocean** | | | | | | |
| 2015 | South Africa | 9th WIOMSA Scientific Symposium | 217 | 275 | 492 | 22 |
| 2017 | United Republic of Tanzania | 10th WIOMSA Scientific Symposium | 228 | 301 | 529 | 27 |

**Supplementary material 4.2.** List of international conferences 2009–2018 by major focus, for which sex-disaggregated information was provided on invited speakers and organizers,[42] showing total number of invited speakers and participants whose gender was identified. In cases where information was provided about the number of speakers presenting in plenary sessions, this is indicated in brackets after the conference name. Conferences where some convenors were also invited speakers are marked with '*'.

| Year | Host country | Conference name | Number of female invited speakers | Number of male invited speakers | Total invited speakers | Number of female organizers | Number of male organizers | Total organizers |
|---|---|---|---|---|---|---|---|---|
| **Environmental science conferences** | | | | | | | | |
| 2012 | UK | Planet under pressure | 30 | 41 | 71 | 7 | 10 | 17 |
| **Ocean and climate** | | | | | | | | |
| 2012 | USA | 3rd International Symposium on the Ocean in a High-CO2 World (3rd OHCO2W) (plenary sessions) | 4 | 5 | 9 | | | |
| 2015 | Brazil | 3rd International Symposium on the Effects of Climate Change on the World's Oceans (3rd ECCWO) (invited speakers and speakers in plenary sessions) | 15 | 23 | 38 | | | |
| 2018 | USA | 4th International Symposium on the Effects of Climate Change on the World's Oceans (4th ECCWO) | 21 | 28 | 49 | 33 | 41 | 74 |
| **Marine ecosystems functions and processes** | | | | | | | | |
| 2011 | Chile | ICES/PICES 5th Zooplankton Production Symposium | 6 | 14 | 20 | | | |
| **Human health and well-being** | | | | | | | | |
| 2015 | Sweden | Scientific Symposium on Harmful Algal Blooms and Climate Change | 2 | 7 | 9 | 1 | 3 | 4 |
| **Pacific Ocean** | | | | | | | | |
| 2012 | Japan | PICES Annual meeting | 6 | 44 | 50 | | | |
| 2013 | Canada | PICES Annual meeting | 9 | 21 | 30 | | | |
| 2015 | China | PICES Annual meeting* | 8 | 31 | 39 | 11 | 38 | 49 |
| 2016 | USA | PICES Annual meeting* | 11 | 36 | 47 | 16 | 46 | 62 |
| 2017 | Russian Federation | PICES Annual meeting* | 4 | 18 | 22 | 6 | 29 | 35 |
| 2018 | Mexico | International Symposium: Understanding Changes in Transitional Areas of the Pacific* | 5 | 25 | 30 | 3 | 12 | 15 |

[42] Information available about organizers varies for each conference. Planet under Pressure: members of the committee and conference chairs; 4th ECCWO: convenors of the symposium, convenors of sessions/workshops and symposium coordinators; Scientific Symposium on Harmful Algal Blooms and Climate Change: convenors of the symposium; International Symposium: Understanding Changes in transitional Areas of the Pacific, PICES Annual meetings 2015, 2016, 2017: convenors of sessions/workshops.

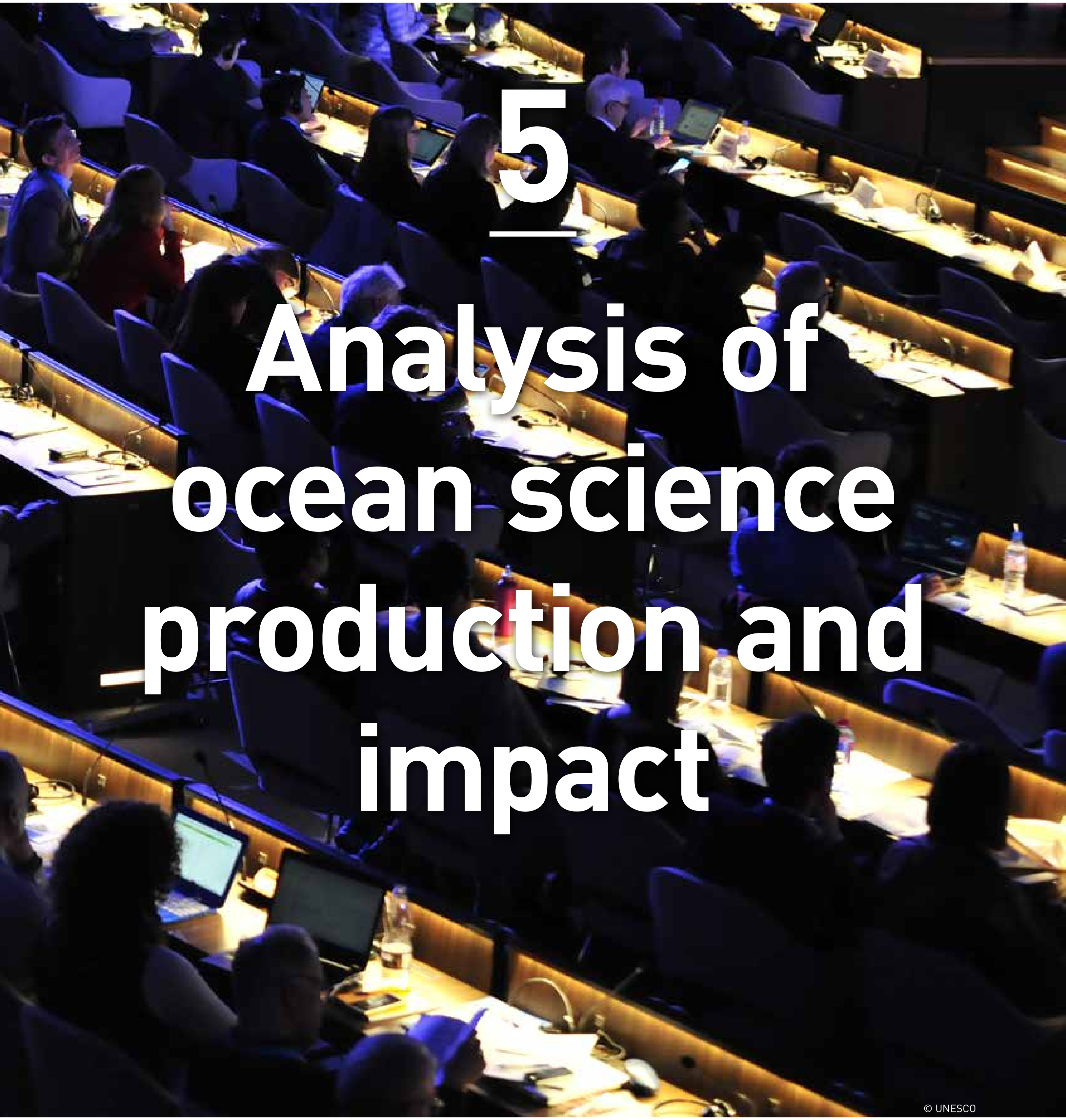
**Supplementary material 4.3.** List of conferences 2011–2018 for which sex-disaggregated information on students was provided. Conferences where students and early career scientists were counted within the same category are marked with '*'

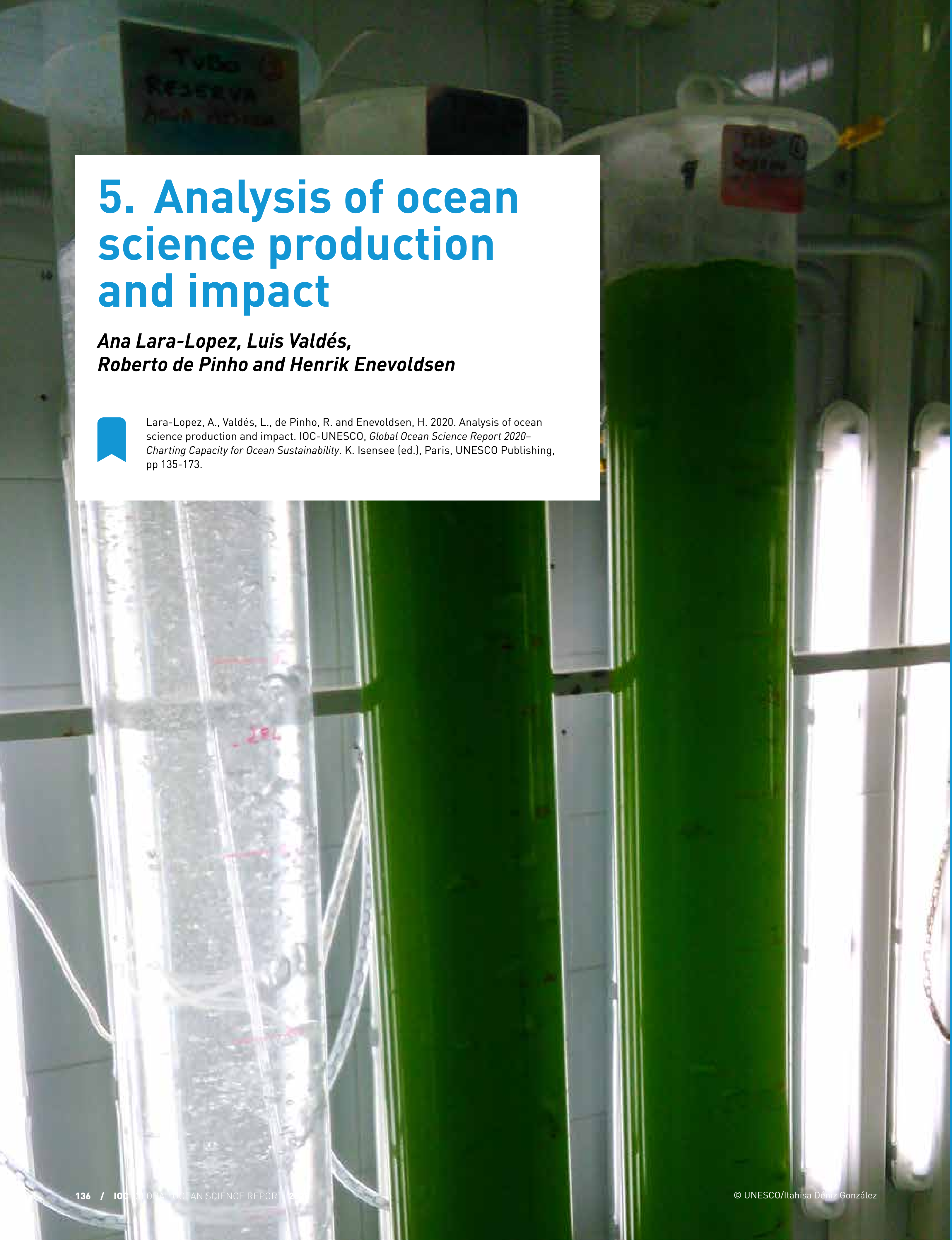
| Year | Host country | Conference name | Number of female students | Number of male students | Total number of students | Number of 'regular' female participants (excluding students) | Number of 'regular' male participants (excluding students) | Number of 'regular' participants (excluding students) |
|---|---|---|---|---|---|---|---|---|
| **Ocean science** | | | | | | | | |
| 2015 | Spain | Aquatic Science Meeting | 533 | 352 | 885 | 649 | 934 | 1 583 |
| **Ocean and climate** | | | | | | | | |
| 2016 | Australia | 4th International Symposium on the Ocean in a High-CO2 World (4th OHCO2W) | 62 | 31 | 93 | 101 | 158 | 259 |
| 2016 | China | Second WCRP/CLIVAR Open Science Conference: Charting the Course for Climate and Ocean Research* | 82 | 145 | 227 | 105 | 252 | 357 |
| 2018 | USA | 4th International Symposium on the Effects of Climate Change on the World's Oceans (4th ECCWO) | 52 | 36 | 88 | 252 | 254 | 506 |
| **Marine ecosystems functions and processes** | | | | | | | | |
| 2011 | Chile | ICES/PICES 5th Zooplankton Production Symposium | 54 | 24 | 78 | 96 | 123 | 219 |
| 2018 | Greece | 2018 International Sandy Beaches Symposium | 13 | 10 | 23 | 19 | 28 | 47 |
| **Human health and well-being** | | | | | | | | |
| 2015 | Sweden | Scientific Symposium on Harmful Algal Blooms and Climate Change | 6 | 3 | 9 | 20 | 30 | 50 |
| 2016 | Brazil | 17th International Conference on Harmful Algae (ICHA 2016) | 50 | 28 | 78 | 133 | 129 | 262 |
| 2018 | Argentina | 10th International Conference on Marine Bioinvasions (ICMB-X)* | 39 | 26 | 65 | 42 | 41 | 83 |
| **Pacific Ocean** | | | | | | | | |
| 2012 | Japan | 2012 PICES Annual Meeting | 20 | 34 | 54 | 75 | 337 | 412 |
| 2013 | Canada | 2013 PICES Annual Meeting | 20 | 25 | 45 | 101 | 219 | 320 |
| 2015 | China | 2015 PICES Annual Meeting | 39 | 44 | 83 | 102 | 323 | 425 |
| 2016 | USA | 2016 PICES Annual Meeting | 37 | 30 | 67 | 144 | 339 | 483 |
| 2017 | Russian Federation | 2017 PICES Annual Meeting | 20 | 16 | 36 | 96 | 198 | 294 |
| 2018 | Mexico | (2018) International Symposium: Understanding Changes in Transitional Areas of the Pacific | 8 | 12 | 20 | 31 | 96 | 127 |

The authors of this chapter are very grateful to the IOCARIBE Secretariat and the Director of INVEMAR for the data and information provided for the Latin American and Caribbean regional graphs. Thanks go also to the experts participating in the IOC project 'Enhancing oceanography capacities in CCLME Western Africa countries Phase III' (2018-2020), supported by the Spanish Agency for International Development Cooperation for contributing data related to the example of the Canary Current region presented in the chapter.

# 5

# Analysis of ocean science production and impact





# 5. Analysis of ocean science production and impact

*Ana Lara-Lopez, Luis Valdés, Roberto de Pinho and Henrik Enevoldsen*

Lara-Lopez, A., Valdés, L., de Pinho, R. and Enevoldsen, H. 2020. Analysis of ocean science production and impact. IOC-UNESCO, *Global Ocean Science Report 2020–Charting Capacity for Ocean Sustainability*. K. Isensee (ed.), Paris, UNESCO Publishing, pp 135-173.

# 5.1. Measuring global ocean science through publications

The publication of scientific articles in peer-reviewed journals is the cornerstone of research dissemination in ocean science, and is a necessary process to evaluate the quality of scientific research and assess its performance and the impact of research. This evaluation is undertaken mainly through two different methods: (i) the peer-review system, where the research is rated by other scientists with expertise in the field ('peers'), and is typically qualitative; and (ii) bibliometric analyses, which offer a quantitative tool to assess science performance (Moed, 2009; Van Raan, 2003). The bibliometric analysis uses a series of metrics that give us an overview of the productivity, visibility, relative impact, specialization and level of collaboration of science. These indicators are obtained from analysing and quantifying the published literature (journal articles, books and other documents) by applying mathematical or statistical methods to develop metrics or indices that can be compared (Pritchard, 1969).

This chapter examines the ocean science output (total number of publications) and productivity (a measure of output per unit of input) globally and how these have changed over the past 18 years. This is done through bibliometric analyses of published scientific literature, similar to the previous report GOSR2017 (IOC-UNESCO, 2017), with details of the methodologies used included in Chapter 2 of this report. However, a few changes have been made for the GOSR2020:

- The main source of data for the bibliometric analysis by Science-Metrix/Relx Canada[1] changed from Web of Science by Thomson Reuters to Scopus by Elsevier[2] from GOSR2017 to GOSR2020. It should be noted that figures are not directly comparable, although they both present stability of coverage that supports consistent analysis within their respective frames (Harzing and Alakangas, 2016). All figures presented here are based on the new assessment.
- The timeframe included in this analysis has been expanded to 18 years, covering 2000 to 2017.
- Revised keywords for ocean science and each subfield, avoiding double counting of publications, are used for the bibliometric analyses.
- New patent analysis is included using data from PATSTAT for technometric analysis and taking citations in patent families to ocean science publications as an additional measure of science impact. The time frame included is 2000 to 2018.

[1] See https://www.science-metrix.com.
[2] See https://www.scopus.com.

### *5.1.1. Total scientific publication output*

Overall, the number of ocean science peer-reviewed articles has grown over the past 18 years, from 41,614 publications in 2000 to 116,253 in 2017, representing a 179% increase in output. This growth in output is mirrored by an increase in the number of journals with ocean science content, where a constant growth over the years is shown (Figure 5.1). It is not clear if the increase in the number of papers is causing an increase in the number of journals or vice versa. It is possible that the increasing number of published papers is causing an increase in the number of journals, which in turn enables the publication of even more papers, driving the creation of more journals and so on.

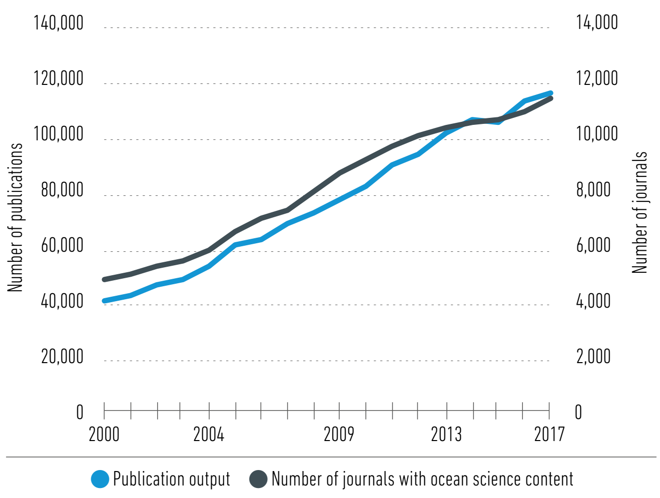



**Figure 5.1.** The global yearly trend in number of peer-reviewed ocean science publications, (blue) and number of journals with content in ocean science (black) between 2000 and 2017.
*Source:* Authors, based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

The annual growth rate in publications is mostly between 4 and 9%, with the exception of 2015 where a decrease was recorded. The decrease is mainly due to a drop in the number of conference papers indexed in Scopus in that year (Table 5.1). This drop reflects Scopus removing a few heavily-publishing journals from 2015 onwards, which accounted for ~2,000 conference proceedings from the ocean science dataset in 2014.

**Table 5.1.** Counts by paper type for the ocean science peer-reviewed publications dataset used in this report indexed by Scopus from 2000 to 2017, and publication output growth rate per annum.

| Year | All papers | Articles | Conference papers | Growth rate (%) |
|---|---|---|---|---|
| 2000 | 41 614 | 35 273 | 5 125 | |
| 2001 | 43 689 | 37 402 | 5 038 | 0.05 |
| 2002 | 47 355 | 39 217 | 6 632 | 0.08 |
| 2003 | 49 475 | 39 231 | 8 105 | 0.04 |
| 2004 | 53 874 | 41 373 | 9 605 | 0.09 |
| 2005 | 61 492 | 43 965 | 13 884 | 0.14 |
| 2006 | 63 649 | 50 316 | 10 379 | 0.04 |
| 2007 | 69 665 | 54 124 | 13 008 | 0.09 |
| 2008 | 73 335 | 58 311 | 12 664 | 0.05 |
| 2009 | 78 020 | 62 263 | 13 469 | 0.06 |
| 2010 | 83 035 | 64 826 | 15 556 | 0.06 |
| 2011 | 90 616 | 70 031 | 17 460 | 0.09 |
| 2012 | 94 881 | 74 336 | 16 852 | 0.05 |
| 2013 | 101 819 | 81 786 | 16 971 | 0.07 |
| 2014 | 107 286 | 86 429 | 17 260 | 0.05 |
| 2015 | 106 220 | 87 621 | 14 916 | -0.01 |
| 2016 | 113 586 | 93 826 | 15 625 | 0.07 |
| 2017 | 116 253 | 95 713 | 15 852 | 0.02 |

Source: Based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

At regional level, the past 18 years have seen a change in the proportion of publication outputs from the different SDG regions,[3] illustrated in Figure 5.2 for the periods 2000–2005 and 2012–2017. The most obvious change has been a 10% increase in the output from the Eastern and South-Eastern Asia region, largely driven by China, and to a lesser extent by Japan and the Republic of Korea (more information available in the GOSR data portal).[4] Other regions that have also increased their output include Northern Africa and Western Asia, Central and Southern Asia and Latin America and the Caribbean. The increase in all these regions is offset by a decrease of ~17% in the share from Europe and Northern America, and while the output in this region continues to grow and to provide the largest proportion of publications, their growth rate has declined from ~6% for the period 2000–2005 to 3% for 2012–2017 (Table 5.2).

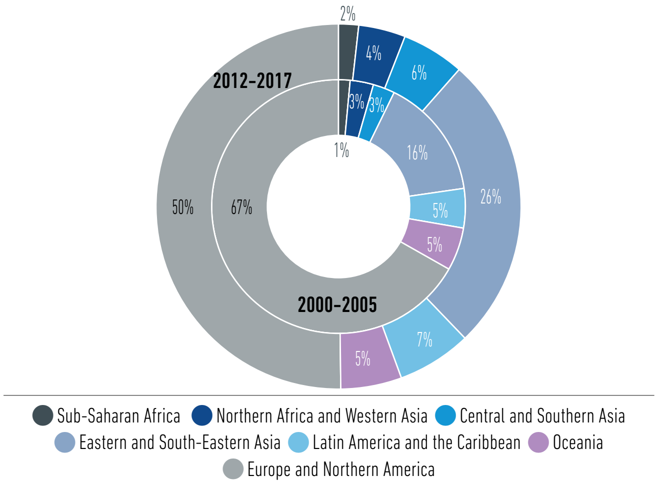



**Figure 5.2.** Changes in the proportion of global publication output by SDG regions from two different periods: 2000–2005 and 2012–2017. *Source:* Authors, based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

**Table 5.2.** Total output, proportion and average annual growth rate for each SDG region for the periods 2000–2005, 2006–2011 and 2012–2017.

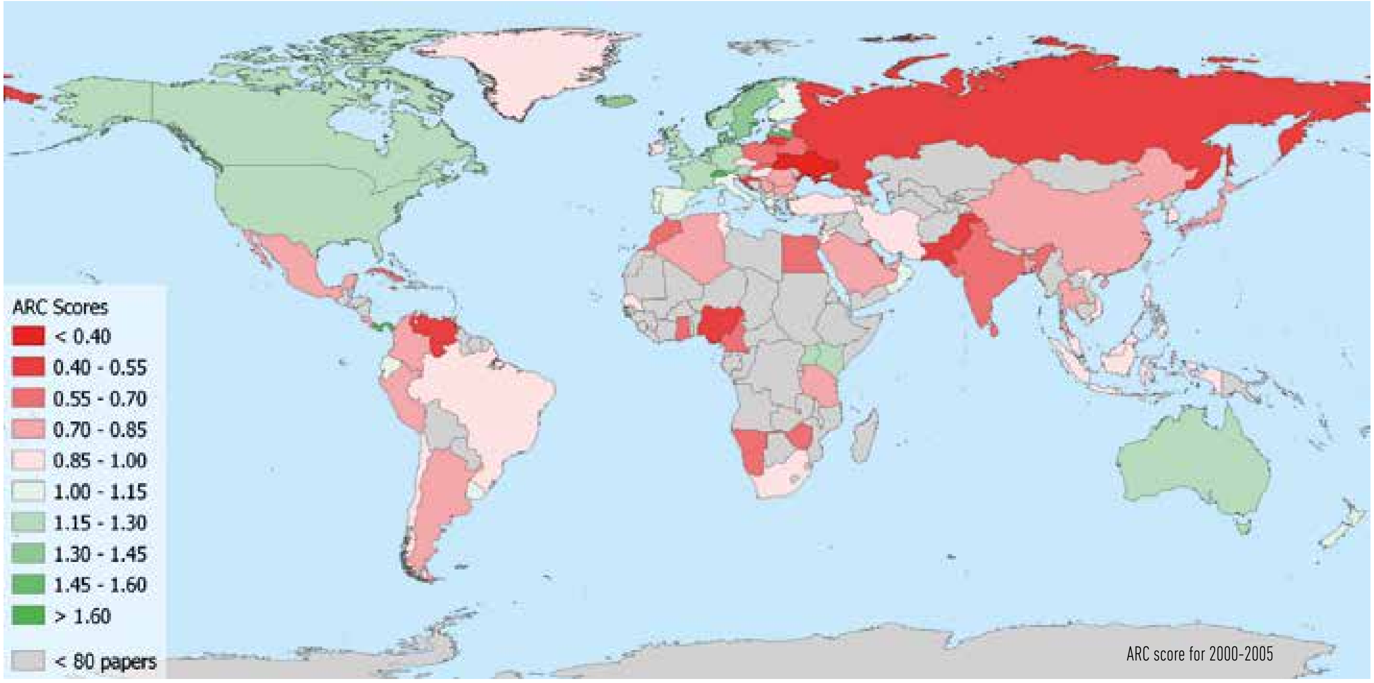
| | 2000–2005 | | | 2006–2011 | | | 2012–2017 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % | Growth rate | Total | % | Growth rate | Total | % | Growth rate |
| Sub-Saharan Africa | 4 778 | 1.47 | 0.08 | 8 362 | 1.63 | 0.07 | 13 233 | 1.77 | 0.06 |
| Northern Africa and Western Asia | 9 661 | 2.97 | 0.10 | 18 380 | 3.57 | 0.09 | 31 015 | 4.16 | 0.07 |
| Central and Southern Asia | 9 044 | 2.78 | 0.11 | 22 073 | 4.29 | 0.12 | 41 458 | 5.56 | 0.05 |
| Eastern and South-Eastern Asia | 50 304 | 15.48 | 0.12 | 112 069 | 21.79 | 0.11 | 196 386 | 26.33 | 0.06 |
| Latin America and the Caribbean | 16 324 | 5.02 | 0.09 | 31 418 | 6.11 | 0.08 | 49 112 | 6.59 | 0.05 |
| Oceania | 17 773 | 5.47 | 0.07 | 28 257 | 5.49 | 0.07 | 40 204 | 5.39 | 0.04 |
| Europe and Northern America | 217 081 | 66.80 | 0.06 | 293 673 | 57.11 | 0.04 | 374 376 | 50.20 | 0.03 |

The average annual growth rate was calculated as , where latest year and earliest years are those represented in each period (2000–2005, 2006–2011, 2012–2017) and n is the number of years within that period, i.e. 6 years.
*Source:* Authors, based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

[3] See https://unstats.un.org/sdgs/indicators/regional-groups.

[4] See https://gosr.ioc-unesco.org.

Publication output alone does not provide the complete picture for scientific impact. In this case, the number of citations could be indicative of the impact of a particular scientific work, by measuring the number of times that study has been cited in other research. The Average of Relative Citations (ARC) score is used as a measure of the observed scientific impact of research conducted in ocean science. This score calculates the average number of citations received by a nation's papers relative to the average number of citations by a nation's ocean science publications relative to the total global of ocean science publications of the same year.



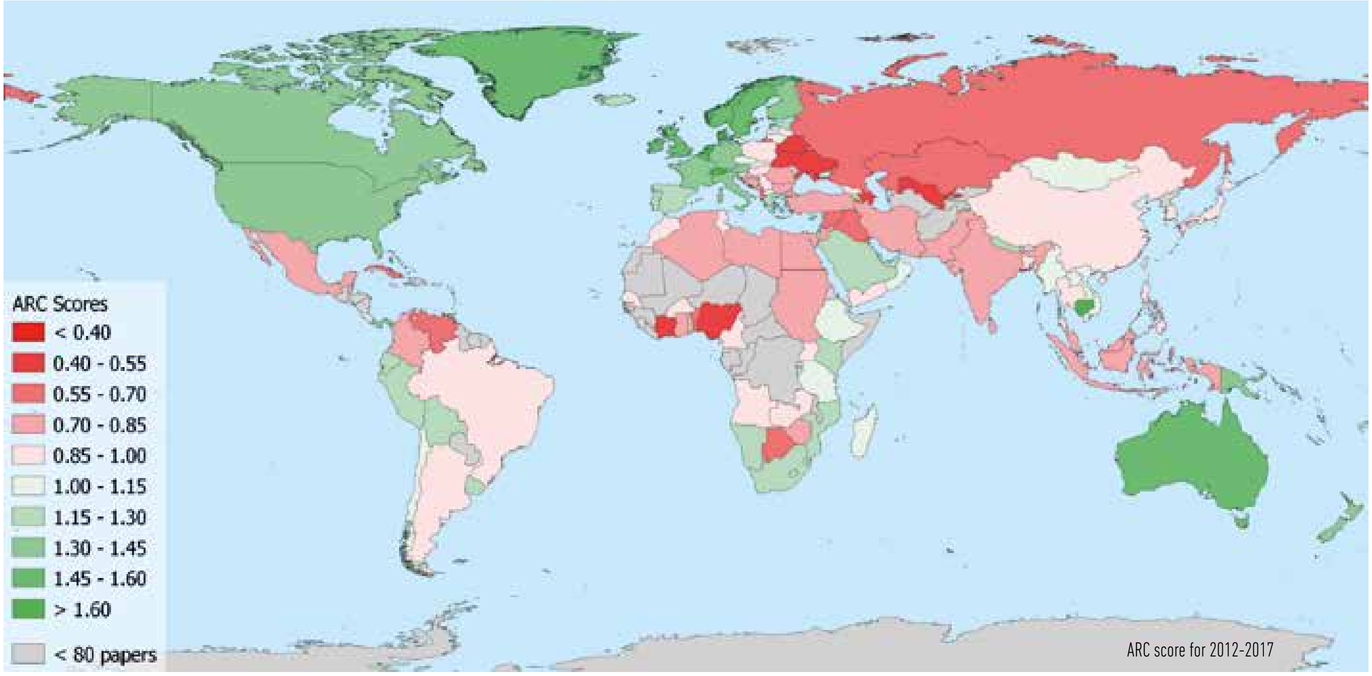




**Figure 5.3.** World maps showing the Average Relative Citation (ARC) rate by country for two contrasting periods, 2000–2005 and 2012–2017.
*Source:* Based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

The first thing to note is an increase in ARC from 2000–2005 to the most recent period 2012–2017 (Figure 5.3). The most obvious change is an overall increase in ARC, particular in Africa and Southern America. Countries showing a remarkable improvement in ARC, are Singapore, Ireland, United Arab Emirates, Qatar, Lebanon, Greenland and Madagascar. This could be a reflection of greater collaboration with other nations and the influence of capacity development activities.

## 5.2. Scientific productivity

Productivity refers to the measure of output (e.g. published articles) from a production process per unit of input (e.g. labour and capital). Productivity is a meaningful index, having efficiency connotations involving considerations of optimal time use, spending of resources and competitiveness, thereby supplying a basis for evaluating and orienting R&D (Reskin, 1977; Rørstad and Aksnes, 2015).

But measuring productivity appropriately is not a simple matter. For example, growth in the number of a country's references could merely be the result of the addition of new journals to the database and not a measure of actual productivity growth, although the addition of a new journal to the database may be the result of the emergence of a new area in science or greater relevance of a given subject. To get an indication of production, this must be normalized by population, expenditure and number of researchers, to allow for comparison. Given the multifactorial and multidimensional nature of ocean science production, which combines human resources, equipment and funding into one index, productivity is difficult to estimate. The main limitation is the availability of data and data sources. Rich and accurate data sets on expenditure on R&D (e.g. including funding, equipment, etc.) are normally both difficult and costly to collect and therefore not readily available in practice.

When the primary goal is to compare performance (research performance in this case), specialists are often inclined to focus on the technical simplicity and statistical accuracy of productivity indexes (Chew, 1988; OECD, 2001; Tangen, 2005), i.e. index based on a single-factor productivity (partial productivity measure), relating output to one particular type of input.

### *5.2.1. Country-level productivity by population*

If scientific production in terms of research papers has experienced remarkable growth in the past 18 years, both quantitatively (number of papers) and qualitatively (average of relative impact factors — ARIF), it is more difficult to evaluate the productivity by country.

For the purpose of this analysis, countries' productivity was calculated as the ratio of the number of papers published by a given country in a given year to the country' population (in millions) in the same year (UNESCO, 2010). Data on annual publications were recorded by Science-Metrix/Relx Canada and the annual countries' population data were obtained from the World Bank data.[5] This normalized index reflects the relative importance that each country is giving to ocean sciences and shows that the share of a country's research is not always dependent on its population size.

[5] See https://databank.worldbank.org/source/world-development-indicators.

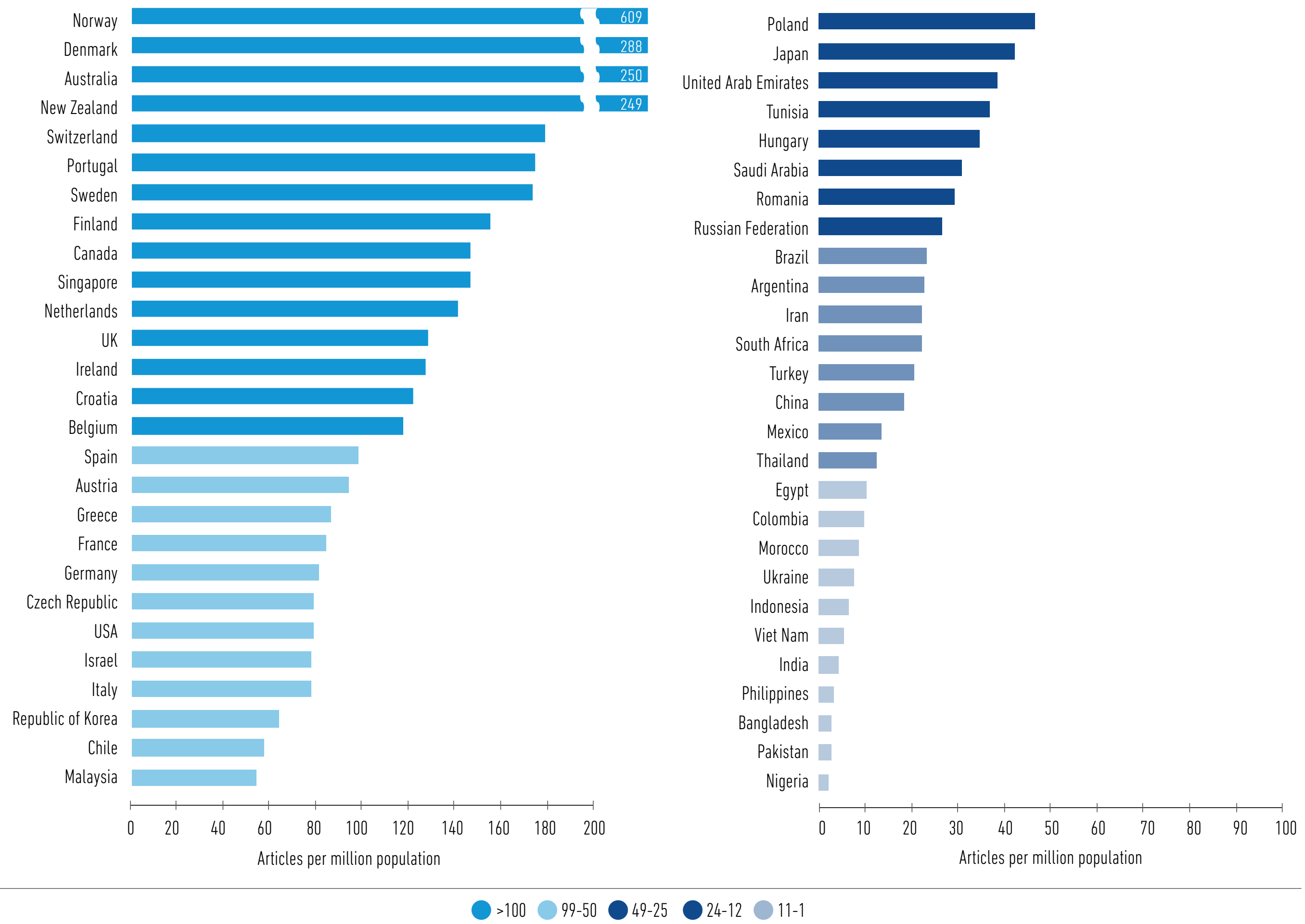



**Figure 5.4.** Relative national productivity in ocean science measured as peer-reviewed publications per million population in 2017. World average for 2017 is 26.3.
*Source:* Authors, based on bibliometric analysis of Scopus (Elsevier) data, 2017 by Science-Metrix/Relx Canada and the World Bank (population) accessed in February 2020.

Figure 5.4 shows the distribution of the countries' relative productivity by population in 2017 (only for the 55 countries releasing more than 300 publications in 2017; this was a threshold adopted for practical considerations). The year 2017 was chosen to facilitate comparisons with values presented in Chapter 4. For this indicator, the mean for 54 countries is 26.3, and the median is 50. Norway ranks first, leading a selected group of countries exceeding 100 articles per million population. This group includes four Scandinavian countries (Norway, Denmark, Sweden and Finland), Australia and New Zealand in the Oceania region, countries around the North Sea (UK, Netherlands, Belgium), Switzerland, Portugal, Singapore, Ireland, Croatia and Canada.

Despite ranking second in terms of number of publications, China attained 18 articles per million population in 2017, which is below the average (26.3), and confirms that publication output should not be the only consideration when measuring the scientific productivity of a given country. For a better insight of the evolution in the scientific empowerment of China, Japan and the Republic of Korea, the country's annual productivity was calculated for each of these three countries for the period 2000–2017 (Figure 5.5). These countries were selected because they experienced one of the largest changes in the scientific production landscape. Japan was the most productive country from 2000 to 2009. However, since then, productivity has not increased any further and currently, it is the Republic of Korea leading the region according to this indicator, although it seems that there has not been any net increase in this ratio since 2014. China continues to be behind Japan and the Republic of Korea, but has maintained a sustained growth trend in the number of articles per million inhabitants throughout the entire period.

However, the slope of this trend is modest, and it will take quite a long time to equal the productivity ratios of its neighbours.

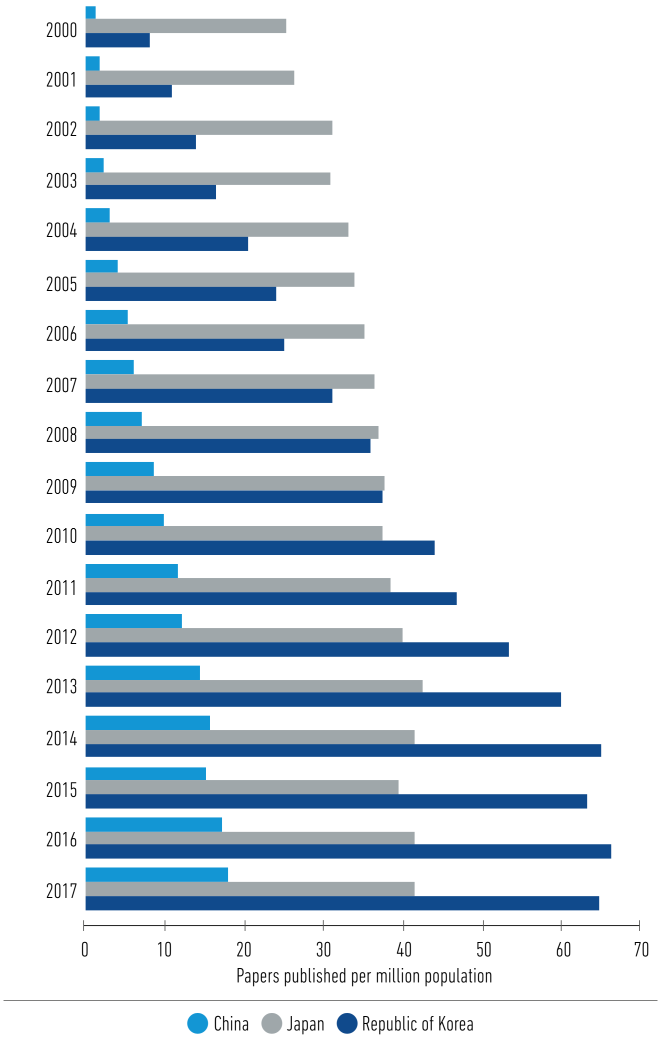



**Figure 5.5.** Productivity of ocean science in China, Republic of Korea and Japan, as the number of scientific publications per million inhabitants.
*Source:* Authors, based on bibliometric analysis of Scopus (Elsevier) data, 2017 by Science-Metrix/Relx Canada and the World Bank (population) accessed in February 2020.

It is also interesting to compare the performance of countries with a similar population. To this end, a group of 9 medium-sized countries ranging from 33 to 46 million inhabitants was selected to compare their productivity in 2000 and in 2017. Figure 5.6 shows that all the countries in this analysis (with the exception of Canada) have at least doubled their productivity ratios in the period concerned, but there are important differences that deserve some discussion. For example, there is a remarkable tenfold growth experienced in Saudi Arabia, Algeria and Iraq, and a threefold increase for Morocco.

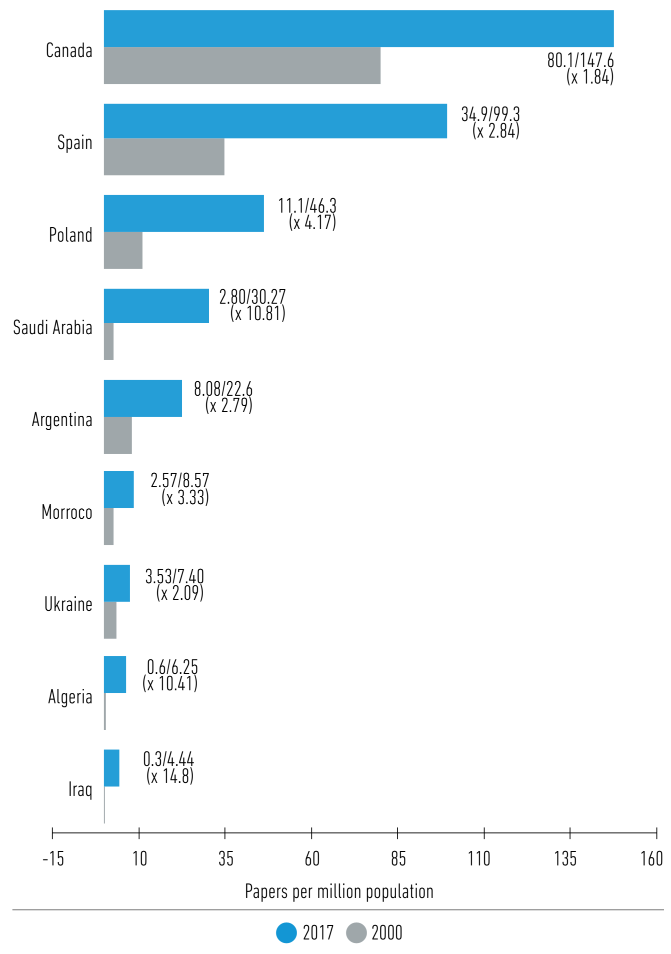



**Figure 5.6.** Scientific publications per million population in medium-sized countries (33–46 million) in 2000 and 2017 (increase factor in brackets).
*Source:* Authors, based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada and the World Bank (population) accessed in February 2020.

This finding could be an indication of societal interest in ocean science in these countries, and the role of regional organizations/commissions in fostering collaboration among countries, such as the General Fisheries Commission for the Mediterranean (GFCM) and the Mediterranean Science Commission (CIESM). It is also well noted that for the countries with longer traditions of ocean science and important commercial fishing interests (e.g. Canada, Spain, Poland and Argentina), the growth rate is not as high, but it is still important.

### 5.2.2. Ocean science productivity at the country level

Scientific productivity has often been expressed as the number of publications by a researcher during a given time period (e.g. a year). This may appear to be a rather abstract measure (as it ignores the financial support, research facilities and access to modern equipment). Nevertheless, it is a simple way of comparing and assessing scientific productivity.

To develop productivity indicators, measured as the number of publications per full-time equivalent (FTE) within a given year, data on research articles reported by Science-Metrix/ Relx Canada were combined with data on the number of researchers active in ocean science retrieved from the GOSR2017 and GOSR2020 questionnaires. For the purpose of this report, the analysis of scientific productivity was limited to the countries that have provided valid responses on the number of researchers working in ocean science in their territory (as headcounts and/or FTEs).

It must be noted that the accuracy of the information provided in the GOSR2020 questionnaire by some IOC-UNESCO Member States is uncertain, e.g. values on human resources were too low or too high. In the cases of Canada and Australia, the information provided by these countries was replaced by data from official sources (i.e. the Canadian Consortium of Ocean Research Universities (2013) for Canada and the National Marine Science Committee (2015) for Australia). The numbers on productivity should, therefore, be interpreted as estimates rather than exact measures.

It is also important to note that the productivity per researcher is not uniform (Lotka, 1926) across all researchers, concentrating on a limited number.

The results show that there is a wide disparity between countries in terms of the number of researchers in ocean science and scientific productivity (Table 5.3). For a few countries, scientific productivity is negligible, e.g. Guinea with 0.04 papers researcher$^{-1}$ year$^{-1}$ (6 articles and 156 FTEs) and Mauritania with 0.09 papers researcher$^{-1}$ year$^{-1}$ (6 articles and 68 FTEs). At the other extreme, Colombia renders 16.18 papers researcher$^{-1}$ year$^{-1}$ (453 articles and 28 FTEs) and Chile 13.45 papers researcher$^{-1}$ year$^{-1}$ (1,076 articles and 80 FTEs).

**Table 5.3.** Scientific productivity calculated as number of publications per researcher in a year.[1,2]

| Country | Annual publication per researcher |
|---|---|
| Colombia | 16.18 |
| Chile | 13.45 |
| India (2013) | 9.01 |
| Poland | 9.01 |
| Oman | 7.67 |
| UK | 6.62 |
| Ecuador | 6.51 |
| Republic of Korea | 6.18 |
| Finland | 5.90 |
| Netherlands (total ocean science personnel) | 5.12 |
| Brazil (2013, HC) | 5.05 |
| Croatia (2013) | 4.33 |
| USA (2013, HC) | 4.03 |
| Canada (2013)[3] | 3.87 |
| Bulgaria | 3.86 |
| Denmark | 3.66 |
| Peru | 3.58 |
| Mauritius | 3.55 |
| Italy | 3.44 |
| Japan (HC) | 3.31 |
| Spain | 3.10 |
| Democratic Republic of the Congo | 2.83 |
| Germany (2013, HC) | 2.53 |
| Turkey | 2.29 |
| Australia (2013)[4] | 2.29 |
| Kuwait (HC) | 2.07 |
| Iran (Islamic Republic of) | 2.01 |
| Norway | 2.01 |
| El Salvador | 2.00 |
| France (HC) | 1.72 |
| Morocco | 1.53 |
| Sweden | 1.47 |
| Kenya | 1.25 |
| Belgium (HC)[5] | 1.15 |
| Ireland | 1.10 |
| Portugal (2016) | 1.07 |
| Madagascar | 0.98 |
| South Africa | 0.71 |
| Mozambique | 0.66 |
| Benin (2013) | 0.57 |
| Angola (2013, HC) | 0.42 |
| Dominican Republic (2013, HC) | 0.21 |
| Mauritania | 0.09 |
| Guinea | 0.04 |

[1] 2017 or the latest year for which data is available (in brackets).
[2] The table is organized in descending order of country productivity and includes only those countries that provided data on the number of researchers active in ocean science — FTE, or alternatively in HC (in brackets).
[3] Number of researchers is estimated from *Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity* (CCORU, 2013).
[4] Number of researchers is estimated from *National Marine Science Plan 2015–2025: Driving the Development of Australia's Blue Economy* (National Marine Science Committee, 2015).
[5] Number of researchers reported corresponds to the 2018 Compendium count.

*Sources:* Based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada; GOSR2017 and GOSR2020 questionnaires.

In spite of the variability in productivity, which may be due to under- or overestimations of the number of researchers active in ocean science, most countries show productivity in the range of 1–2.99 papers researcher$^{-1}$ year$^{-1}$ (Figure 5.7). Within this group of countries, with productivity values between 1 and 2.99, there is no apparent pattern. Similarly, the absence of a pattern is noted in the cluster of countries with productivity values ranging from 3 to 4.99. Both groups together account for 25 countries (57%) out of the 44 countries analysed.

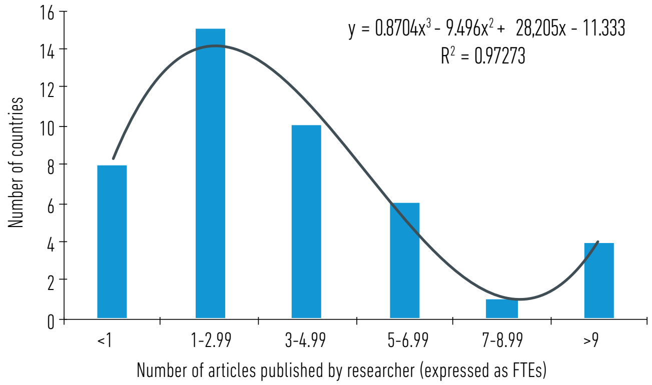



**Figure 5.7.** Diagram showing the distribution of the numbers of countries classified by their productivity performance and the regression function.
*Source:* Authors, based on bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

An interesting angle for analysis is the comparison of competitiveness of ocean science in relation to other disciplines; however, data availability is not sufficient to carry out this analysis at a global or regional scale. Nonetheless, using data from other bibliometric studies carried out in Norway for several scientific disciplines (Aksnes, 2012; Rørstad and Aksnes, 2015), the values in the number of articles published by researcher and year are quite similar (Figure 5.8). For example, humanities (2.02), social sciences (1.51), mathematics (1.90) and ocean science (2.01) are all within the range 1.51–2.02, and this homogeneity is quite remarkable.

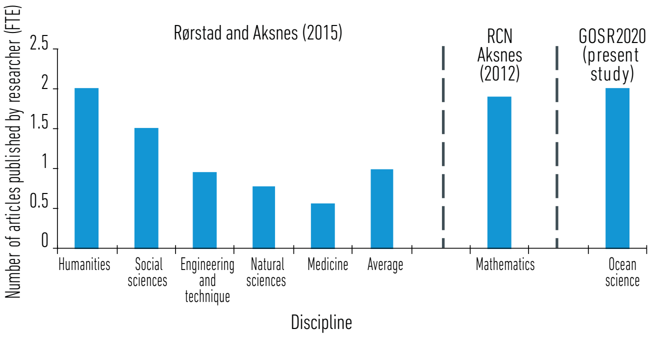



**Figure 5.8.** Performance in scientific productivity in different disciplines in Norway.
*Sources:* Authors, data based on Aksnes, 2012; Rørstad and Aksnes, 2015; the GOSR2020 questionnaire; and the regression line in Figure 5.7.

Another interesting point that can be derived from this analysis is that the ocean science community must be relatively large according to its productivity. For example, if the productivity of Norway calculated by Asknes (2.01) is taken as a valid figure, which also approaches the peak value (2.09) calculated with the regression function in Figure 5.7, then the number of ocean science researchers around the world in 2017 should have been close to 58,000 FTEs and even more than double this figure if the total human resources involved in ocean research (technicians, crew, other supporting staff) is considered.

## 5.3. A technometric view of ocean science through patents

When given the difficult task of tracking knowledge, the assessment has to rely on publications as a tangible register of its production and dissemination. Similarly, the application and granting of patents is used by researchers and policymakers to follow trends and characteristics of technological development and its dissemination across countries and technology fields. Patent databases remain extremely rich and useful sources of data for providing an overview of technological development for a whole range of purposes (see Chapter 2, De Rassenfosse et al., 2013), despite the well-documented limitations and shortcomings of using them (OECD, 2009), such as false precision or that technometric analysis is not suited for the evaluation of individual projects and professionals (Hicks et al., 2015). The simple accruing of a patent count is not a direct measure of value of the research or development being conducted.

The data and indicators presented here provide an in-depth look into ocean science-related technology by selecting a subset of ocean science-related patent families from five major patent offices: the USPTO, the EPO, the KIPO, the JPO and the CNIPA (see Chapter 2). Ocean science-related patent families are selected by applying a set of keywords in a process analogous to the one used to select ocean science publications. As patents may cite non-patent literature, this analysis also examines patterns found when they cite ocean science papers. By looking at these links, knowledge flows that exist from science into technology and how they are laid out around the globe can be detected.

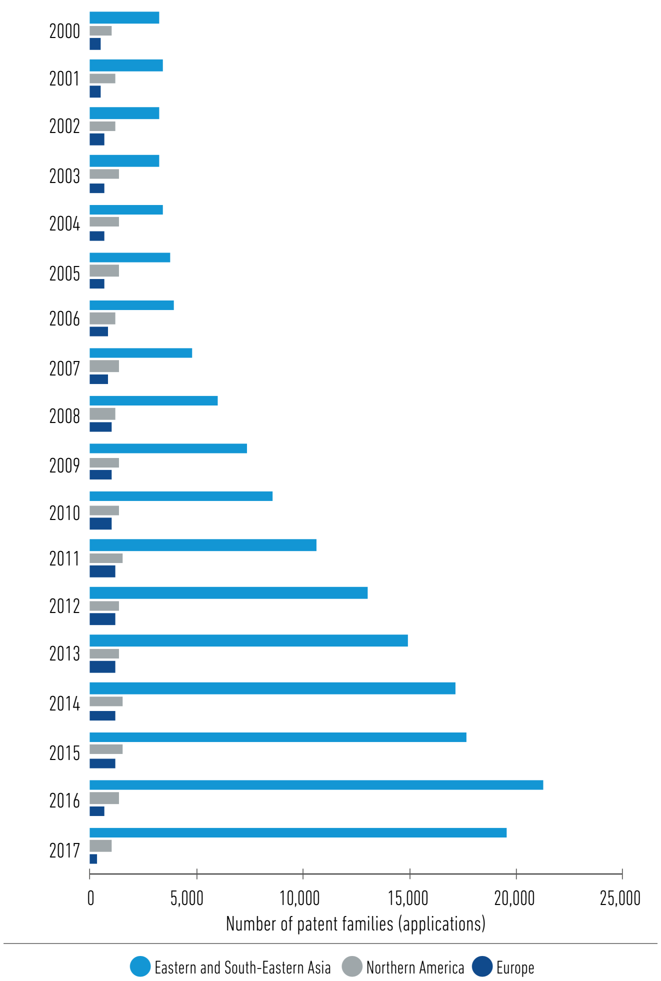



Figure 5.9. Number of patent families (applications) in ocean science for the top three regions from 2000–2017.
*Source:* Authors, based on the technometric analysis of data 2000–2017 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

The period 2000–2017 saw an impressive growth in the number of ocean science-related patent applications, as illustrated in Figure 5.9. This growth is mostly supported by patents filed at CNIPA, which saw an average 25% year-on-year growth rate. It must be stressed that decreasing numbers for more recent years are due to a delay effect in the registration process of patents and not necessarily due to a lower patent activity. At the end of the first five years of the period, the CNIPA had less than 15% of applications registered for all offices, jumping to almost 70% for the last five years.

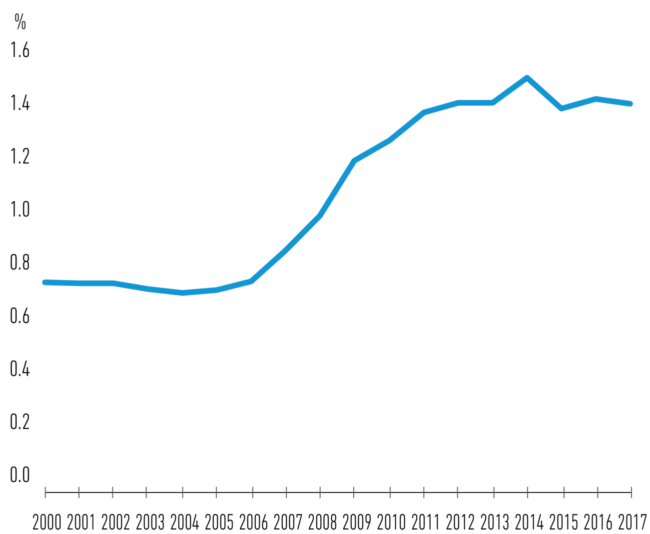



Figure 5.10. Ocean science-related patent families (applications) over time as a percentage of total patent families (applications).
*Source:* Authors, based on technometric analysis of data 2000–2017 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

The growth observed in absolute numbers (Figure 5.9) is also observed in relative terms. Figure 5.10 shows how ocean science-related patent families start off by representing about 0.8% of total applications for the selected patent offices, and rise to around 1.4% in more recent years, almost doubling their share.

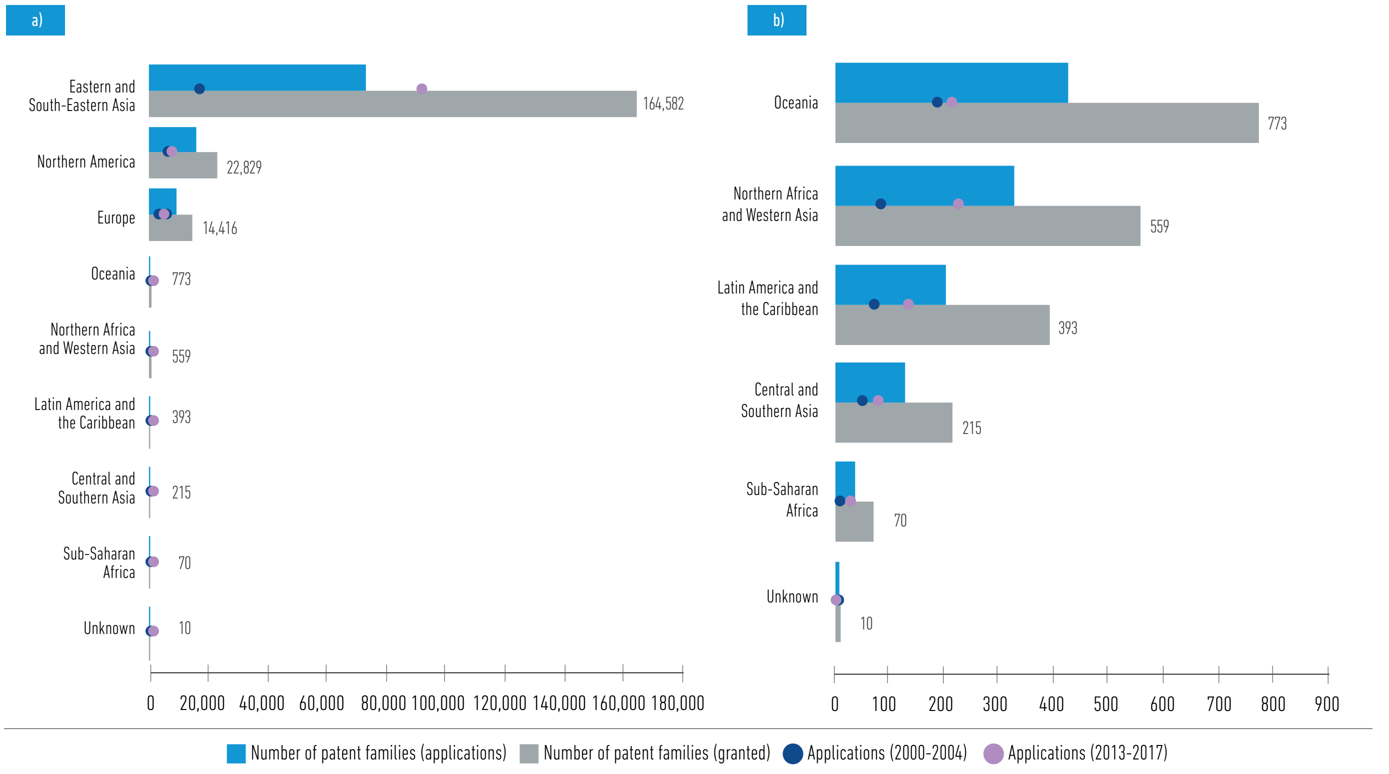



**Figure 5.11.** Number of patent families (applications) and patent families (granted) in ocean science by world region during 2000–2017: a) all regions; b) regions with less than 1% of total families (applications), scale adjusted.
*Source:* Authors, based on technometric analysis of data 2000–2017 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

Totals by region show Eastern and South-Eastern Asia as the most active (Figure 5.11*a*), accruing more than 80% of applications in the period. The region's share rose from 64% in the first five years to almost 90% in the last five. For the whole period, Northern America has 11% of the total and Europe 7%. The remaining regions account for about 1% of patent applications (Figure 5.11*b*).

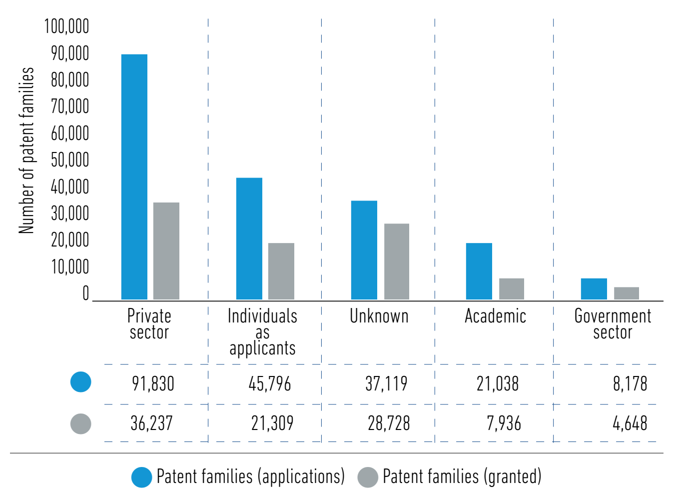



**Figure 5.12.** Number of patent families (applications) and patent families (granted) in ocean science by applicant sector 2000–2017.
*Source:* Authors, based on technometric analysis of data 2000–2017 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

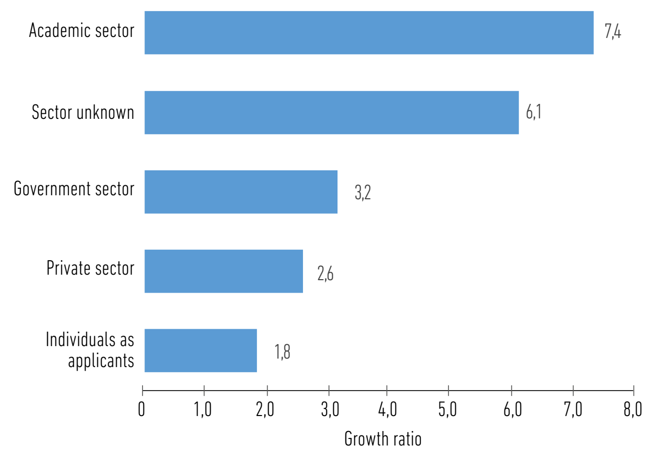



**Figure 5.13.** Growth ratio (number of patent families, regardless of grant status and patent office in ocean science) by applicant sector (2000–2007/2009–2016).
*Source:* Authors, based on technometric analysis of data 2000–2016 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

The private sector is the most active, followed by individuals as applicants (see Figure 5.12). However, it is the academic sector that saw the highest growth in the period (2000–2016), with a growth ratio (GR) of 7.4, more than twice that experienced by the government (3.2) and private sector (2.6). The GR presented in Figure 5.13 is calculated using counts from the 2000–2007 and 2009–2016 subperiods.

For each sector, the specialization index (SI) for ocean science-related patent families as presented in Table 5.4 is a measure of the share of a country's output in ocean science-related patent families (regardless of grant status and patent office) relative to the global share of ocean science-related patents among all patents, with global SI being 1.00. For example, a value of 2.03 for the private sector in the UK means that the proportion of ocean science-related patents among those by UK firms in the 2000–2018 period is more than double that for the private sector globally. It appears that UK companies are specialized and active in ocean science-related technological development compared with other technologies and the pattern found globally. Likewise, the SI of 2.15 for the Republic of Korea's government sector would suggest that ocean science-related technological development is of interest and supported by public policy and institutions.

**Table 5.4.** Specialization index (SI)[1] across sectors for the top 25 most active countries of ocean science (2000–2018).

| Country | Sector | | | | |
|---|---|---|---|---|---|
| | **All** | **Academic** | **Government** | **Private** | **Individual** |
| Norway | 15,82 | 0,53 | 0,03 | 21,31 | 21,55 |
| New Zealand | 2,41 | 0,02 | 0,39 | 2,18 | 4,86 |
| Brazil | 2,14 | 0,31 | n.a. | 2,28 | 3,31 |
| Republic of Korea | 1,81 | 0,85 | 2,15 | 1,90 | 1,78 |
| Australia | 1,64 | 0,17 | 0,09 | 1,46 | n.a. |
| UK | 1,59 | 0,10 | 0,00 | 2,03 | 2,49 |
| Denmark | 1,58 | 0,14 | 0,01 | 1,60 | 1,89 |
| Spain | 1,52 | 0,32 | 0,17 | 1,34 | 2,80 |
| Russian Federation | 1,34 | 0,05 | 0,96 | 0,40 | 3,11 |
| Netherlands | 1,32 | 0,10 | 0,01 | 1,69 | 1,60 |
| Singapore | 1,28 | 0,88 | 0,03 | 1,31 | 1,81 |
| Italy | 1,18 | 0,12 | 0,01 | 1,37 | 1,85 |
| China | 1,17 | 2,13 | 1,55 | 1,03 | 0,84 |
| Finland | 1,14 | 0,03 | n.a. | 1,50 | 1,24 |
| France | 1,10 | 0,08 | 0,99 | 0,97 | 1,53 |
| Sweden | 1,06 | 0,02 | n.a. | 1,26 | 1,71 |
| World | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 |
| Canada | 0,92 | 0,14 | 0,18 | 0,69 | 2,18 |
| USA | 0,86 | 0,13 | 0,54 | 0,65 | 1,88 |
| Belgium | 0,51 | 0,18 | n.a. | 0,56 | 0,68 |
| Japan | 0,50 | 0,06 | 0,20 | 0,73 | 0,37 |
| Germany | 0,48 | 0,04 | 0,00 | 0,62 | 0,65 |
| Austria | 0,44 | 0,08 | 0,03 | 0,35 | 1,02 |
| Israel | 0,44 | 0,04 | 0,04 | 0,35 | 0,95 |
| Switzerland | 0,41 | 0,06 | 0,00 | 0,41 | 0,73 |
| India | 0,33 | 0,06 | 1,39 | 0,20 | 0,59 |

| | | |
|---|---|---|
| n.a | >1-1.5 | 2.5-3 |
| 0-0.5 | 1.5-2 | 3-5 |
| >0.5-1 | 2-2.5 | >5 |

[1] The SI represents the ratio between the share of ocean science related output in the output of a country and the share of ocean science-related output found at the global level. It is computed for each sector and for their sum (all). Patent families are counted regardless of grant status and patent office, and over the full 2000–2018 period.

*Source:* Based on the technometric analysis of data 2000–2018 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

Of course, it has to be highlighted that a high specialization index does not equate to a high output in absolute number of patent applications. For instance, New Zealand, which is highly specialized in technology related to ocean science, as shown by its high SI, has a total of 160 ocean science-related patent family applications, whereas Germany shows a low SI compared to the world average, but their inventors contributed more than 2,600 ocean science-related patent family applications (by fractional counting, as elsewhere).

Among the most specialized in ocean science-related patents, the private sector and individual applicants are the most prominent. Norway draws its impressive performance almost exclusively from these two sectors, while the Republic of Korea finds its highest SI in the government sector. In striking contrast, Brazil has no recorded patent family in the later sector (Table 5.4). This indicates important differences between nations and the role of their respective public research institutes.

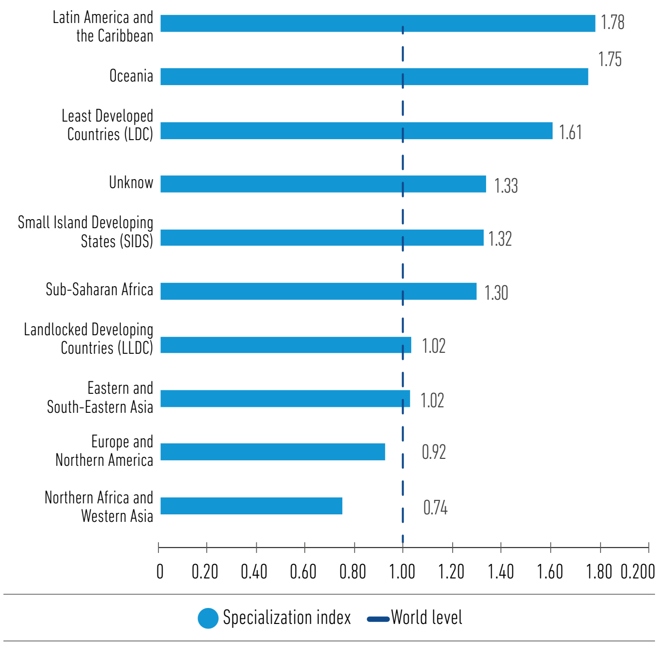



**Figure 5.14.** Specialization index of patents related to ocean science by world region.
*Source:* Authors, based on the technometric analysis of data 2000–2018 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

At regional level, the SI for the Small Island Developing States (SIDS) group is above the world average. This could suggest a focus of their national innovation systems towards the threats imposed by rising sea levels due to climate change. Accordingly, their SIs for the 'Ocean and climate' and 'Blue growth' subfields of ocean science have risen during the examined period (Tables 5.7, 5.8 and 5.9). Landlocked Developing Countries (LLDC) follow the world average at 1.02. The most specialized regions are Latin America and the Caribbean, and Oceania (Figure 5.14).

As in space exploration, it can be argued that there is a reciprocal relationship between ocean science and related technologies. The ocean as an environmental frontier poses many challenges that require increasing technological developments and knowledge, which in turn support further technological development. The analysis presented here compares citations made by ocean science-related patents to ocean science literature, and tries to characterize ocean science-technology knowledge flows across the globe.

**Table 5.5.** Origin region of scientific articles as a percentage of citations made by a region's inventors (2000–2018), based on number of citations (fractional count).

| Inventor region/ subregion | Scientific article region/subregion: Sub-Saharan Africa | Northern Africa and Western Asia | Central and Southern Asia | Eastern and South-Eastern Asia | Latin America and the Caribbean | Oceania | Northern America | Europe | LDC | LLDC | SIDS | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sub-Saharan Africa | 0% | 2% | 0% | 0% | 0% | 0% | 93% | 5% | 0% | 0% | 0% | 0% |
| Northern Africa and Western Asia | 0% | 19% | 3% | 18% | 1% | 5% | 17% | 36% | 0% | 0% | 0% | 0% |
| Central and Southern Asia | 1% | 4% | 20% | 22% | 4% | 6% | 18% | 25% | 0% | 0% | 2% | 0% |
| Eastern and South-Eastern Asia | 0% | 2% | 2% | 48% | 2% | 3% | 16% | 25% | 0% | 0% | 1% | 0% |
| Latin America and the Caribbean | 0% | 1% | 7% | 18% | 17% | 0% | 18% | 38% | 0% | 0% | 0% | 1% |
| Oceania | 0% | 6% | 1% | 21% | 1% | 11% | 21% | 38% | 0% | 0% | 0% | 0% |
| Northern America | 0% | 3% | 1% | 11% | 2% | 2% | 52% | 26% | 0% | 0% | 2% | 2% |
| Europe | 0% | 3% | 1% | 11% | 1% | 3% | 27% | 51% | 0% | 0% | 1% | 3% |
| Least Developed Countries (LDC) | 0% | 11% | 0% | 0% | 0% | 0% | 32% | 57% | 0% | 0% | 0% | 0% |
| Landlocked Developing Countries (LLDC) | 0% | 25% | 0% | 0% | 0% | 0% | 25% | 50% | 0% | 0% | 0% | 0% |
| Small Island Developing States (SIDS) | 0% | 1% | 0% | 15% | 3% | 4% | 27% | 46% | 0% | 0% | 5% | 3% |
| Unknown | 0% | 0% | 0% | 19% | 0% | 0% | 56% | 24% | 0% | 0% | 0% | 0% |

Legend: 0,00; >0-5; 5-10; 11-15; 16-20; 21-30; 31-40; 41-50; >50

*Source:* Authors, based on the technometric analysis of data 2000–2018 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

Table 5.5 shows, for each inventor region or subregion (rows), the percentage of citations made to ocean science literature by region of origin (columns). For example, the value found at the row 'Latin America and the Caribbean' and column 'Europe' is the percentage of citations found in Latin American and the Caribbean patent families that cite scientific articles from European authors. This could be understood as evidence of a flow of science knowledge from Europe to Latin American and Caribbean technological development.

The highlighted diagonal in Table 5.5 shows the percentage of 'locally sourced' articles used in support of patent applications. It characterizes science-technology links in ocean science as a global endeavour, with the highest proportions (around 50%) found in Northern America, Europe, and Eastern and South-Eastern Asia. Together, these regions account for the source of almost 90% of all citations made in scientific literature, and yet their inventors look beyond their respective regions around 50% of the time. Europe seems to be the preferred source for most other regions when they look outside their confines. Northern Africa and Western Asia, Central and Southern Asia, Latin America and the Caribbean, and Oceania cite themselves in about 20% of occurrences, with Oceania inventors citing their own literature only 11% of the time. Central and Southern Asia and Oceania inventors rely on articles from Eastern and South-Eastern Asia for more than a fifth of their citations, probably as a result of networks between their regions.

**Table 5.6.** Origin region of inventors as a percentage of citations received by a region's scientific articles (2000–2018), based on number of citations (fractional count).

| | Scientific article region/subregion | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inventor subregion | World | Sub-Saharan Africa | Northern Africa and Western Asia | Central and Southern Asia | Eastern and South-Eastern Asia | Latin America and the Caribbean | Oceania | Northern America | Europe | LDC | LLDC | SIDS | Unknown |
| Sub-Saharan Africa | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Northern Africa and Western Asia | 3% | 0% | 16% | 5% | 3% | 2% | 5% | 1% | 3% | 0% | 0% | 1% | 0% |
| Central and Southern Asia | 1% | 5% | 2% | 15% | 2% | 3% | 3% | 1% | 1% | 6% | 0% | 2% | 0% |
| Eastern and South-Eastern Asia | 15% | 12% | 7% | 20% | 42% | 18% | 15% | 6% | 12% | 31% | 24% | 16% | 2% |
| Latin America and the Caribbean | 2% | 1% | 1% | 7% | 2% | 17% | 0% | 1% | 2% | 0% | 0% | 0% | 1% |
| Oceania | 1% | 3% | 3% | 1% | 2% | 1% | 6% | 1% | 2% | 6% | 0% | 0% | 0% |
| Northern America | 55% | 65% | 51% | 42% | 36% | 45% | 47% | 75% | 44% | 40% | 46% | 66% | 63% |
| Europe | 23% | 14% | 21% | 10% | 14% | 15% | 24% | 16% | 36% | 17% | 29% | 15% | 33% |
| Least Developed Countries (LDC) | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Landlocked Developing Countries (LLDC) | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Small Island Developing States (SIDS) | 1% | 0% | 0% | 0% | 1% | 1% | 1% | 1% | 1% | 0% | 0% | 3% | 1% |
| Unknown | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

Legend: 0,00; >0-5; 5-10; 11-15; 16-20; 21-30; 31-40; 41-50; >50

*Source:* Authors, based on the technometric analysis of data 2000–2018 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

A complementary analysis looks at the transfer of ocean science knowledge from a region and how it is spread across the globe (Table 5.6). Oceania's ocean science literature receives almost half of its citations from North American patents, about one quarter from Europe and only 6% of citations from their own region's inventors. A similar, albeit less extreme, pattern is also observed for Latin America and the Caribbean, 45% of their articles being cited by patents from Northern America, 18% from Eastern and South-Eastern Asia, and 17% from the region itself. Northern America, Europe and Eastern and South-Eastern Asia inventors are responsible for more than 90% of citations made for all ocean science literature (see 'World' column in Table 5.6). As all patent offices analysed are located in these regions, it is possible that home bias could be inflating these numbers.

Figure 5.15 shows 'Mechanical engineering' as the most frequent technical sector for ocean science-related patents, being assigned to almost 50% of families. 'Chemistry' follows with around a quarter of applications. Other relevant sectors are 'Electrical engineering and instruments', attributed to about 9% of applications each. All other fields combined are just over 9%. Counts of patent families filed in multiple WIPO technical fields are fractioned between those fields (fractional counts).

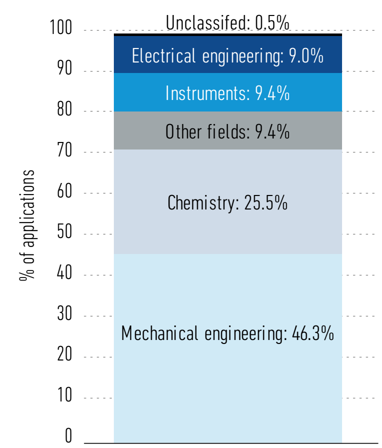



**Figure 5.15.** Share of ocean science-related patent families (applications) filed by the World Intellectual Property Organization (WIPO) technical sectors (2000–2017).
*Source:* Authors, based on the technometric analysis of data 2000–2017 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

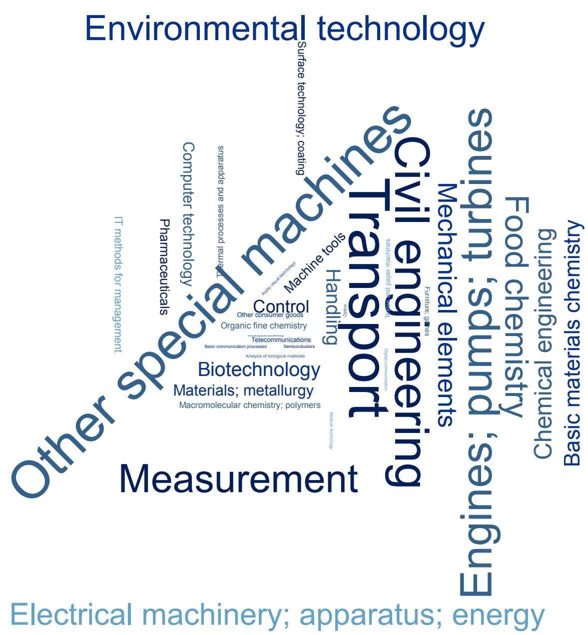



**Figure 5.16.** Word cloud of WIPO technical fields sized by fractional count of patent families (applications) (2000–2018).
*Source:* Authors, data adapted from technometric analysis of data 2000–2018 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

Examining the most frequent WIPO technical fields (subdivision of sectors), 'Transport', 'Other special machines', 'Civil engineering', 'Engines, pumps, turbines', and 'Measurement' are in the top five most frequent words, three of which belong to the 'Mechanical engineering' sector. The following two most frequent are 'Environmental technology' and 'Food chemistry'. The latter can arguably be said to link to applications of ocean science rather than specific technologies. Figure 5.16 shows a word cloud sized by count of patent families (applications) for selected WIPO technical fields.

Using the Cooperative Patent Classification (CPC) leads to a higher resolution view of technical fields linked to ocean science patent families (Figure 5.17). The most frequent class is 'Technologies or applications for mitigation or adaptation against climate change', as determined by computing the fractional count of patent families filed in each class and subclass. This is certainly a welcome outcome of the analysis, indicating that both potential and current direction of efforts in ocean science is towards SDG 13: 'Take urgent action to combat climate change and its impacts'. The class belongs to a section of CPC used for general tagging of new technological developments and tagging of cross-cutting technologies spanning several sections of the international patent classification. Since over 13% of filed patent families are attributed by fractional count to this classification, it can be assumed that a higher percentage of patent families are actually tagged in this class.

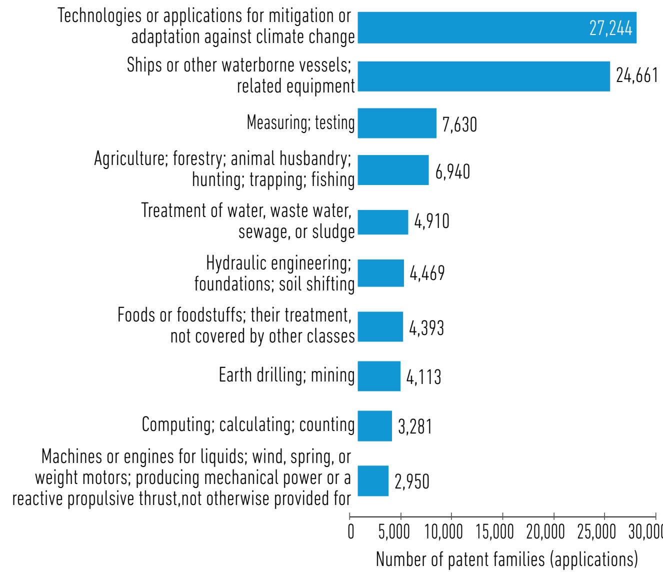



**Figure 5.17.** Top ten most frequent CPC technical field classes in the total number of ocean science patent families (applications) using fractional counts.
*Source:* Authors, based on the technometric analysis of data 2000-2018 provided by the United States Patent and Trademark Office, the European Patent Office, the Korean Intellectual Property Office, the Japan Patent Office and the National Intellectual Property Administration by Science-Metrix/Relx Canada.

The relationship between science and technology will vary, subject to the different publication and patenting practices across disciplines and industries. While the CPC subclass 'Physics // measuring; testing // geophysics; gravitational measurements; detecting masses or objects' has on average one citation to ocean science literature for every two patents, the subclass 'Performing operations; transporting // ships or other waterborne vessels; related equipment // launching, hauling-out, or dry-docking of vessels; life-saving in water; equipment for dwelling or working under water; means for salvaging or searching for underwater objects' cites ocean literature only once for every 100 patents. Other subclasses highly reliant on ocean science literature are 'Human necessities // foods or foodstuffs; their treatment, not covered by other classes // fodder' and 'Physics // measuring; testing // meteorology', both having more than one citation for every three patents.

## 5.4. Research profiles

### 5.4.1. Patterns in national and regional specialization in ocean science output by category

To enable comparisons of disciplinary strengths and weaknesses of national or regional research profiles, ocean science was disaggregated into eight different categories. These categories are:

- Blue growth
- Marine ecosystems functions and processes
- Ocean and climate
- Ocean crust and marine geohazards
- Ocean health
- Ocean observation and marine data
- Ocean technology and engineering
- Oceans and human health and well-being

See Chapter 2 for details. The information presented here encompasses 18 years of bibliometric data, from 2000–2017.

The SI was used as a metric for comparison between regions and between the top ten most publishing countries in ocean science. This index gives an overview of a nation or region's research priorities or specialization. The SI indicates the research intensity of a given entity (e.g. institution, country or region) in a given research area (e.g. a category of ocean science), relative to the intensity of a reference entity (e.g. the world or the entire output as measured by the database) for the same research area. The SI for each category in ocean science is normalized to that of the world (World=1). What this means is that when an institution is specialized in a field, it places more emphasis on that field at the expense of other research areas. For example, if an SI > 1, in conclusion the entity's research in that given field is more specialized than the world average (relative to ocean science).

The SDG regional categorization was applied to compare the relative regional specialization using radial plots. Results in Figure 5.18 encompass the entire 18-year period. In terms of the relative specialization in scientific disciplines for the different regions, the Europe and Northern America region shows a pattern closer to 1, meaning countries in the region place similar emphasis on all ocean science categories. A similar finding is shown in the patent specialization index seen in Figure 5.14. The only exception is in 'Ocean technology and engineering', where the region is slightly under-specialized, compared to the world. A similar pattern is found in all regions except the Eastern and South-Eastern Asia region, which shows higher specialization in that category. For the Latin America and Caribbean region, a higher specialization in 'Marine ecosystems', 'Blue growth' and 'Ocean health' can be observed, while the Sub-Saharan region showed strong specialization in 'Oceans and human health and well-being'.

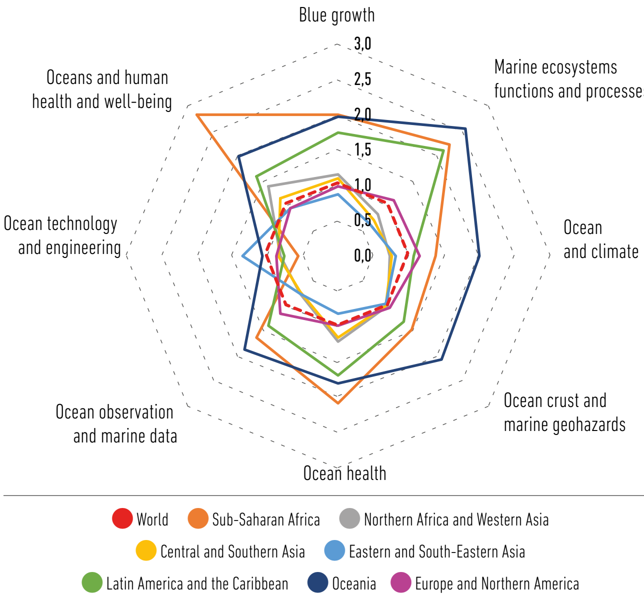
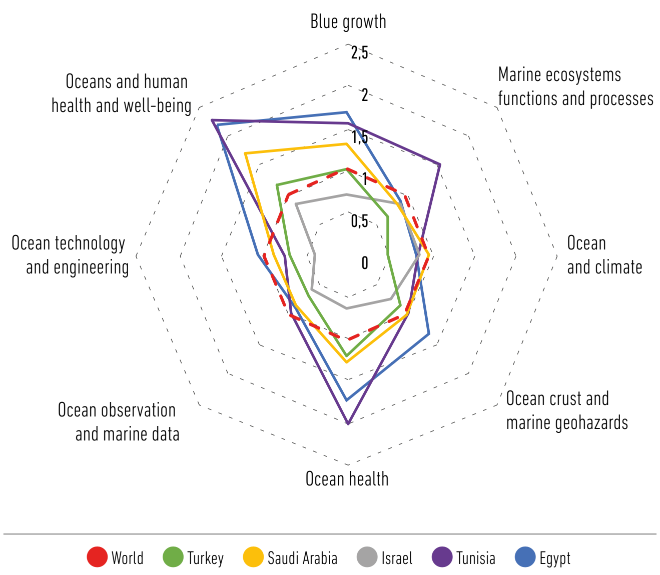


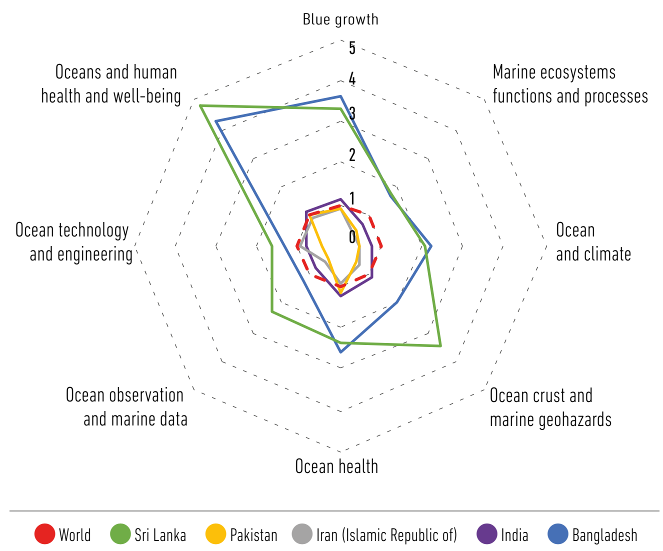

**Figure 5.18.** Strengths by SDG regions in different ocean science categories. Radial plots show the Specialization Index (SI) compared to the world (dashed red line) for the period 2000–2017.
*Source:* Authors, Based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

To check if the regional trend in SI was driven by the top five countries that publish the highest number of ocean science papers within each region, the SI for these countries was plotted (Figure 5.19). For Northern Africa and Western Asia, a stronger SI in the 'Ocean health' and 'Oceans and human health' categories for Egypt and Tunisia can be observed, as well as a high SI in 'Marine ecosystem functions and processes' for Tunisia only. The high SI in the category of 'Oceans and human health and well-being' is also seen in countries from Eastern and South-Eastern Asia (Thailand and Malaysia), Central and Southern Asia (Bangladesh and Sri Lanka) and Sub-Saharan Africa (Ghana, Nigeria and Tanzania), indicating that Oceans and human health and well-being is a priority for these three regions. It is noticeable that Sri Lanka with a high SI in 'Ocean crust and marine geohazards' differs from all other countries mentioned above.

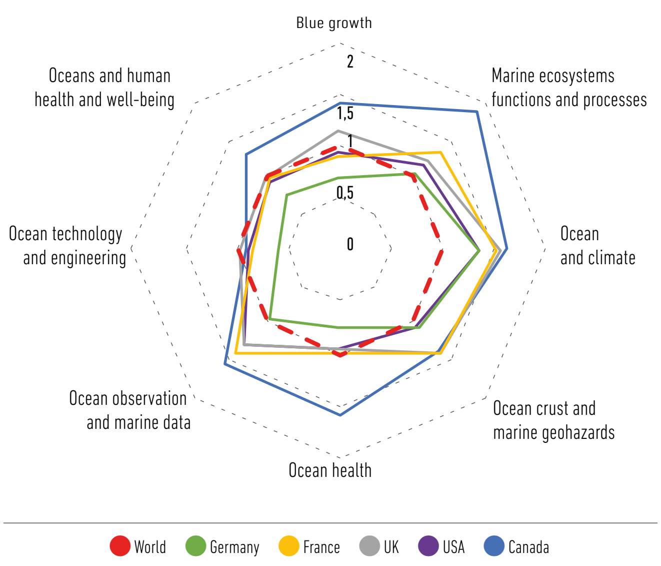
### Northern Africa and Western Asia




### Central and Southern Asia




### Europe and North America




### Latin America and the Caribbean

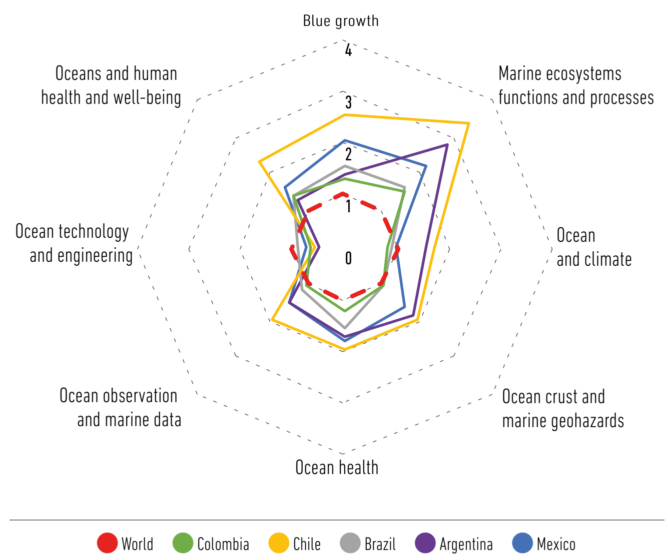



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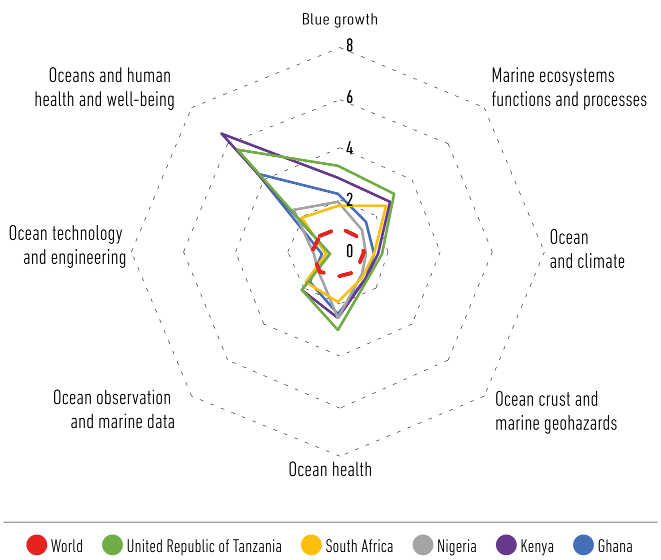
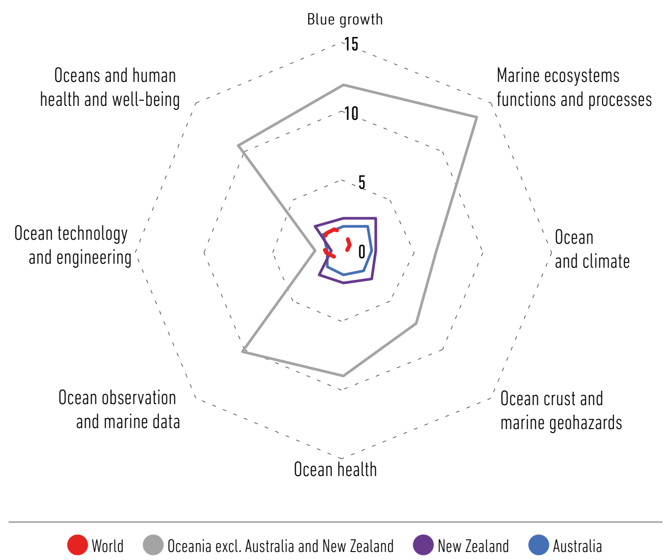
Figure 5.19. Strengths in different ocean science categories by SDG region. Radial plots show the Specialization Index (SI) compared to the world (dashed red line) for the period 2000–2017.
*Source:* Authors, based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

**Sub-Saharan Africa**




**Oceania**




**Eastern and South-Eastern Asia**

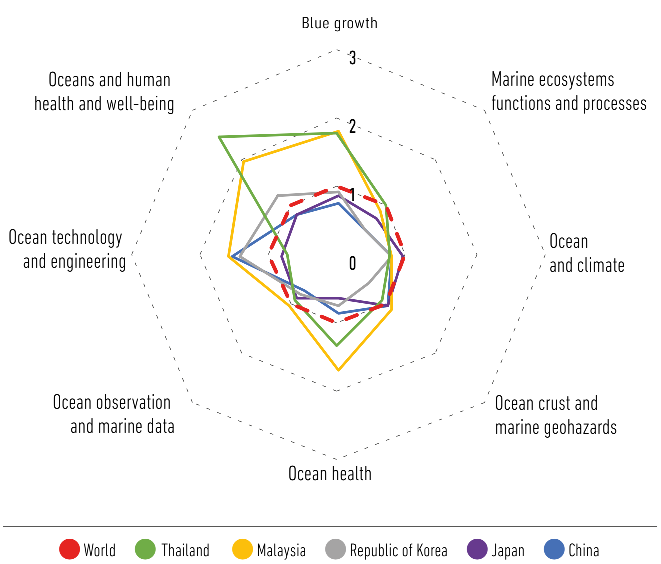



**Figure 5.19**. Continued.

Latin America and the Caribbean, on the other hand, shows a high SI for the categories of 'Ocean health, marine ecosystem functions and processes' and 'Blue growth', and a low SI in 'Ocean technology' (Figure 5.19). The low SI in the 'Ocean technology' category is also found across most regions and countries, except in Eastern and South-Eastern Asia, which is mostly driven by China, Malaysia and the Republic of Korea.

Europe and Northern America showed a more balanced SI across categories, with some slight differences in their priorities. For example, Canada showed a greater emphasis on the categories of 'Marine ecosystems and ocean health' compared to the other four countries in the region (Figure 5.19).

From these analyses, evidence suggests that the SI at the regional level is driven by the top five most publishing countries, an expected outcome as they represent over 75% of the output for their respective region.

Across time, there have been small changes in their regional priorities. A notable change is an increasing emphasis on the 'Ocean and climate' category in Oceania overall, but particularly in the SIDS, which nearly doubled from 2000–2005 to 2012–2017 (Tables 5.7–5.9). Also of interest is the low emphasis on the 'Ocean technology and engineering' category by all regions except the Eastern and South-Eastern Asia region, where SI remained above the world average, increasing over time. The same region showed an increase in SI for the 'Ocean health' category; however, it still remained below the world average.

The specialization profiles based on the publication outputs from the different regions illustrate the diversity that exists among regions and may reflect the different research priorities and needs for different nations. Similarly, when this diversity in specialization is observed through a time lens across an 18-year period, subtle but important changes can be observed in regional priorities. The challenge here is how to use this information for knowledge and technology transfer to help regions develop capability in other categories.

**Table 5.7.** Specialization Index across the eight subfields of ocean science for each region and subregion during the period 2000–2005.

| Region | Blue growth | Marine ecosystems functions and processes | Ocean and climate | Ocean crust and marine geohazards | Ocean health | Ocean observation and marine data | Ocean technology and engineering | Oceans and human health and well-being |
|---|---|---|---|---|---|---|---|---|
| **Sub-Saharan Africa** | **2.52** | **2.64** | **1.43** | **1.79** | **2.23** | **1.83** | **0.57** | **3.54** |
| **Northern Africa and Western Asia** | **1.13** | **0.76** | **0.69** | **1.07** | **1.20** | **0.60** | **0.87** | **1.54** |
| Northern Africa | 1.54 | 1.04 | 0.82 | 1.62 | 1.78 | 0.82 | 1.33 | 2.49 |
| Western Asia | 1.04 | 0.70 | 0.66 | 0.94 | 1.08 | 0.56 | 0.77 | 1.33 |
| **Central and Southern Asia** | **1.11** | **0.84** | **0.85** | **1.25** | **1.46** | **0.78** | **0.98** | **1.17** |
| Central Asia | 0.90 | 0.71 | 0.91 | 1.15 | 1.19 | 0.86 | 0.52 | 1.14 |
| Southern Asia | 1.11 | 0.84 | 0.85 | 1.25 | 1.46 | 0.78 | 0.99 | 1.17 |
| **Eastern and South-Eastern Asia** | **0.82** | **0.55** | **0.72** | **0.77** | **0.64** | **0.64** | **1.18** | **0.85** |
| Eastern Asia | 0.77 | 0.53 | 0.74 | 0.76 | 0.60 | 0.63 | 1.18 | 0.80 |
| South-Eastern Asia | 1.83 | 0.93 | 0.54 | 1.01 | 1.34 | 0.84 | 1.20 | 2.04 |
| **Latin America and the Caribbean** | **1.75** | **1.95** | **1.01** | **1.40** | **1.58** | **1.45** | **0.97** | **1.68** |
| Caribbean | 1.94 | 1.57 | 0.98 | 1.33 | 1.80 | 1.53 | 0.85 | 2.10 |
| Central America | 2.40 | 2.41 | 0.95 | 1.82 | 1.85 | 1.71 | 0.99 | 1.80 |
| South America | 1.56 | 1.85 | 1.02 | 1.28 | 1.49 | 1.37 | 0.98 | 1.64 |
| **Oceania** | **2.23** | **2.57** | **1.71** | **2.23** | **1.78** | **1.68** | **1.12** | **2.24** |
| Australia and New Zealand | 2.17 | 2.51 | 1.67 | 2.20 | 1.76 | 1.63 | 1.12 | 2.18 |
| Oceania (excluding Australia and New Zealand) | 10.48 | 11.31 | 6.42 | 8.37 | 5.72 | 8.39 | 1.59 | 10.84 |
| *Melanesia* | 9.77 | 9.21 | 7.62 | 8.34 | 4.44 | 8.66 | 1.19 | 9.39 |
| *Micronesia* | 5.44 | 16.86 | 4.20 | 6.82 | 6.89 | 5.49 | 2.22 | 7.77 |
| *Polynesia* | 20.68 | 16.10 | 4.10 | 9.36 | 11.52 | 13.00 | 3.09 | 19.47 |
| **Europe and Northern America** | **0.98** | **1.07** | **1.12** | **1.05** | **1.03** | **1.11** | **0.94** | **0.95** |
| Northern America | 1.04 | 1.11 | 1.31 | 1.04 | 1.08 | 1.31 | 1.08 | 0.98 |
| Europe | 0.93 | 1.06 | 1.03 | 1.11 | 0.99 | 0.98 | 0.82 | 0.93 |
| *Eastern Europe* | 0.45 | 0.76 | 0.80 | 0.94 | 0.74 | 0.66 | 0.60 | 0.47 |
| *Northern Europe* | 1.39 | 1.37 | 1.32 | 1.39 | 1.18 | 1.32 | 1.14 | 1.15 |
| *Southern Europe* | 1.15 | 1.18 | 0.88 | 1.09 | 1.32 | 1.12 | 0.86 | 1.24 |
| *Western Europe* | 0.70 | 1.00 | 1.13 | 1.10 | 0.84 | 0.92 | 0.65 | 0.82 |
| **Least Developed Countries (LDC)** | **2.94** | **2.40** | **1.85** | **2.17** | **2.16** | **1.85** | **0.60** | **5.11** |
| **Landlocked Developing Countries (LLDC)** | **1.09** | **1.02** | **0.99** | **1.25** | **1.15** | **0.99** | **0.40** | **2.05** |
| **Small Island Developing States (SIDS)** | **1.28** | **0.99** | **0.57** | **0.87** | **1.15** | **1.00** | **1.16** | **1.59** |

*Source:* Based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

**Table 5.8.** Specialization Index across the eight subfields of ocean science for each region and subregion during the period 2006–2011.

| Region | Blue growth | Marine ecosystems functions and processes | Ocean and climate | Ocean crust and marine geohazards | Ocean health | Ocean observation and marine data | Ocean technology and engineering | Oceans and human health and well-being |
|---|---|---|---|---|---|---|---|---|
| **Sub-Saharan Africa** | **2.14** | **2.46** | **1.36** | **1.54** | **2.28** | **1.66** | **0.53** | **3.00** |
| **Northern Africa and Western Asia** | **1.17** | **0.83** | **0.73** | **0.99** | **1.29** | **0.78** | **0.77** | **1.46** |
| Northern Africa | 1.44 | 1.12 | 0.82 | 1.26 | 1.72 | 0.86 | 0.92 | 1.93 |
| Western Asia | 1.11 | 0.76 | 0.70 | 0.92 | 1.17 | 0.76 | 0.73 | 1.34 |
| **Central and Southern Asia** | **1.12** | **0.79** | **0.79** | **1.07** | **1.27** | **0.76** | **0.86** | **1.20** |
| Central Asia | 1.05 | 0.61 | 0.85 | 1.27 | 1.02 | 0.62 | 0.53 | 0.91 |
| Southern Asia | 1.12 | 0.79 | 0.79 | 1.07 | 1.28 | 0.76 | 0.86 | 1.21 |
| **Eastern and South-Eastern Asia** | **0.80** | **0.58** | **0.76** | **0.89** | **0.78** | **0.72** | **1.32** | **0.85** |
| Eastern Asia | 0.75 | 0.56 | 0.76 | 0.87 | 0.74 | 0.71 | 1.32 | 0.79 |
| South-Eastern Asia | 1.66 | 0.95 | 0.78 | 1.21 | 1.36 | 1.00 | 1.27 | 1.84 |
| **Latin America and the Caribbean** | **1.77** | **2.13** | **1.03** | **1.32** | **1.67** | **1.37** | **0.75** | **1.51** |
| Caribbean | 1.86 | 2.15 | 1.32 | 1.43 | 1.62 | 1.69 | 0.73 | 1.91 |
| Central America | 2.28 | 2.34 | 0.98 | 1.71 | 1.97 | 1.51 | 0.78 | 1.61 |
| South America | 1.66 | 2.10 | 1.03 | 1.23 | 1.61 | 1.32 | 0.74 | 1.47 |
| **Oceania** | **2.05** | **2.58** | **2.03** | **2.22** | **1.79** | **1.94** | **1.12** | **1.97** |
| Australia and New Zealand | 1.98 | 2.51 | 2.00 | 2.18 | 1.75 | 1.87 | 1.11 | 1.92 |
| Oceania (excluding Australia and New Zealand) | 12.24 | 14.12 | 7.33 | 8.20 | 9.56 | 11.38 | 2.03 | 10.04 |
| *Melanesia* | 12.11 | 13.81 | 8.39 | 7.66 | 9.67 | 11.49 | 2.33 | 11.48 |
| *Micronesia* | 10.78 | 13.89 | 5.72 | 7.77 | 11.31 | 10.54 | 1.15 | 8.86 |
| *Polynesia* | 15.61 | 18.85 | 6.17 | 11.51 | 9.76 | 15.53 | 0.99 | 14.00 |
| **Europe and Northern America** | **1.00** | **1.13** | **1.18** | **1.06** | **1.00** | **1.14** | **0.89** | **0.98** |
| Northern America | 1.02 | 1.21 | 1.37 | 1.08 | 1.03 | 1.33 | 0.93 | 0.99 |
| Europe | 1.00 | 1.12 | 1.14 | 1.12 | 0.99 | 1.06 | 0.86 | 0.98 |
| *Eastern Europe* | 0.61 | 0.84 | 0.83 | 1.00 | 0.81 | 0.67 | 0.67 | 0.59 |
| *Northern Europe* | 1.38 | 1.42 | 1.53 | 1.39 | 1.11 | 1.39 | 1.11 | 1.19 |
| *Southern Europe* | 1.25 | 1.26 | 1.07 | 1.17 | 1.37 | 1.24 | 0.88 | 1.30 |
| *Western Europe* | 0.79 | 1.10 | 1.26 | 1.11 | 0.83 | 1.03 | 0.69 | 0.82 |
| **Least Developed Countries (LDC)** | **2.60** | **2.08** | **1.64** | **1.85** | **2.16** | **1.63** | **0.61** | **3.97** |
| **Landlocked Developing Countries (LLDC)** | **1.33** | **1.17** | **1.07** | **1.34** | **1.28** | **1.03** | **0.45** | **1.76** |
| **Small Island Developing States (SIDS)** | **1.36** | **1.25** | **0.85** | **1.00** | **1.10** | **1.18** | **1.20** | **1.40** |

*Source:* Based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

**Table 5.9.** Specialization Index across the eight subfields of ocean science for each region and subregion during the period 2012–2017.

| Region | Blue growth | Marine ecosystems functions and processes | Ocean and climate | Ocean crust and marine geohazards | Ocean health | Ocean observation and marine data | Ocean technology and engineering | Oceans and human health and well-being |
|---|---|---|---|---|---|---|---|---|
| **Sub-Saharan Africa** | **1.74** | **2.00** | **1.34** | **1.34** | **1.87** | **1.56** | **0.54** | **2.43** |
| **Northern Africa and Western Asia** | **1.09** | **0.82** | **0.75** | **0.98** | **1.16** | **0.77** | **0.79** | **1.28** |
| Northern Africa | 1.36 | 0.98 | 0.81 | 1.16 | 1.54 | 0.81 | 0.88 | 1.73 |
| Western Asia | 1.00 | 0.76 | 0.73 | 0.93 | 1.03 | 0.76 | 0.76 | 1.14 |
| **Central and Southern Asia** | **0.99** | **0.65** | **0.69** | **0.87** | **1.02** | **0.69** | **0.77** | **1.02** |
| Central Asia | 0.77 | 0.46 | 0.80 | 1.00 | 0.79 | 0.84 | 0.55 | 0.50 |
| Southern Asia | 1.00 | 0.66 | 0.69 | 0.87 | 1.02 | 0.69 | 0.77 | 1.02 |
| **Eastern and South-Eastern Asia** | **0.92** | **0.69** | **0.86** | **1.04** | **0.89** | **0.81** | **1.36** | **0.96** |
| Eastern Asia | 0.84 | 0.67 | 0.85 | 1.03 | 0.85 | 0.79 | 1.35 | 0.88 |
| South-Eastern Asia | 1.70 | 1.01 | 0.95 | 1.18 | 1.35 | 1.02 | 1.45 | 1.86 |
| **Latin America and the Caribbean** | **1.69** | **2.16** | **1.11** | **1.27** | **1.71** | **1.37** | **0.67** | **1.58** |
| Caribbean | 1.99 | 2.28 | 1.52 | 1.55 | 2.08 | 2.46 | 0.58 | 2.36 |
| Central America | 1.94 | 2.51 | 1.13 | 1.50 | 1.84 | 1.58 | 0.62 | 1.85 |
| South America | 1.64 | 2.10 | 1.09 | 1.21 | 1.67 | 1.29 | 0.69 | 1.50 |
| **Oceania** | **1.85** | **2.50** | **2.06** | **1.93** | **1.78** | **1.90** | **1.00** | **1.87** |
| Australia and New Zealand | 1.80 | 2.43 | 2.04 | 1.90 | 1.74 | 1.85 | 0.99 | 1.83 |
| Oceania (excluding Australia and New Zealand) | 11.94 | 14.35 | 6.58 | 6.74 | 9.85 | 10.45 | 2.22 | 10.91 |
| *Melanesia* | 11.59 | 12.07 | 6.19 | 5.42 | 8.61 | 9.37 | 2.45 | 10.31 |
| *Micronesia* | 11.41 | 19.14 | 10.44 | 8.63 | 11.96 | 11.22 | 1.34 | 9.48 |
| *Polynesia* | 15.79 | 23.84 | 6.45 | 11.02 | 15.57 | 15.61 | 1.71 | 15.11 |
| **Europe and Northern America** | **0.99** | **1.14** | **1.21** | **1.06** | **1.00** | **1.17** | **0.88** | **0.97** |
| Northern America | 0.96 | 1.26 | 1.44 | 1.09 | 1.03 | 1.33 | 0.81 | 1.00 |
| Europe | 1.02 | 1.13 | 1.18 | 1.10 | 0.99 | 1.13 | 0.92 | 0.98 |
| *Eastern Europe* | 0.59 | 0.82 | 0.76 | 0.93 | 0.81 | 0.75 | 0.69 | 0.64 |
| *Northern Europe* | 1.43 | 1.46 | 1.68 | 1.39 | 1.11 | 1.49 | 1.19 | 1.18 |
| *Southern Europe* | 1.30 | 1.28 | 1.13 | 1.14 | 1.35 | 1.31 | 1.01 | 1.29 |
| *Western Europe* | 0.82 | 1.18 | 1.36 | 1.14 | 0.87 | 1.15 | 0.74 | 0.88 |
| **Least Developed Countries (LDC)** | **2.23** | **1.64** | **1.71** | **1.66** | **1.74** | **1.36** | **0.70** | **3.19** |
| **Landlocked Developing Countries (LLDC)** | **1.02** | **0.91** | **1.04** | **1.12** | **1.01** | **0.89** | **0.46** | **1.46** |
| **Small Island Developing States (SIDS)** | **1.62** | **1.49** | **1.05** | **1.12** | **1.38** | **1.44** | **1.30** | **1.63** |

*Source:* Based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

5

### 5.4.2. National positional analysis in ocean science by category

Similar to the GOSR2017, a positional analysis to visualize the composite performance of the different countries was used (Figure 5.20). This analysis combines three separate indicators: the number of peer-reviewed ocean science publications, the SI and the ARC. The analysis allows easy interpretation and comparison of the strengths and weaknesses of the different nations in each of the ocean science categories, and any changes over time. In these graphs, the axes represent the world average, and the distance from these axes reveals the degree of strength or weakness relative to the world average. The top right-hand corner is the first quadrant and represents high specialization and high impact, and quadrant numbers progress anticlockwise. Therefore, bubbles in the second and third quadrants are less specialized than the world average while bubbles in the third and fourth quadrants show an ARC lower than the world average. The top 40 most publishing countries in ocean science were used for this analysis for three different time periods: 2000–2005, 2006–2011 and 2012–2017.

Firstly, this analysis shows a trend towards the axes with time, with a less dispersed distribution in 2012–2017 period compared to 2000–2005, and an increase in the ARC of most nations. Some of the most notable changes are from China, Japan and the Republic of Korea, moving from an SI below world average towards world average. Also evident was an improvement in the ARC from Chile, South Africa, Czechia and Italy from below or at world average to above world average. Improvement in the ARC is also evident for the Russian Federation and Poland, which are approaching the world average (see Figure 5.3 for further detail).

While the publication output from most of the nations represented in this analysis remained stable, China's output increased by one order of magnitude from 2000–2005 to 2012–2017. However, China's ARC has remained below average, although with some improvement. It could be argued that their low ARC could be linked to language, with all the countries with an ARC below the world average being non-native English-speaking. It is likely that many of their researchers publish in national journals in their language, and this may have an effect on their impact. Indeed, adding English translation to regional journals can help increase their impact and increase collaboration with researchers from other countries (see Box 5.1).

**Box 5.1.** How the Boletín de Investigaciones Marinas y Costeras [Bulletin for Marine and Coastal Research] increased its impact

In the 2018 list published by Scimago Journal Ranking (SJR), Colombia is ranked 52nd in the world and in 5th place in Latin America and the Caribbean in the 'Water science and technology' category within the 'Environmental science' area. There are only eight journals listed for Latin America in this category. However, in Colombia, the *Bulletin for Marine and Coastal Research* is the only journal included in the list, and is located in the Q3 and Q4 quartiles for this category.

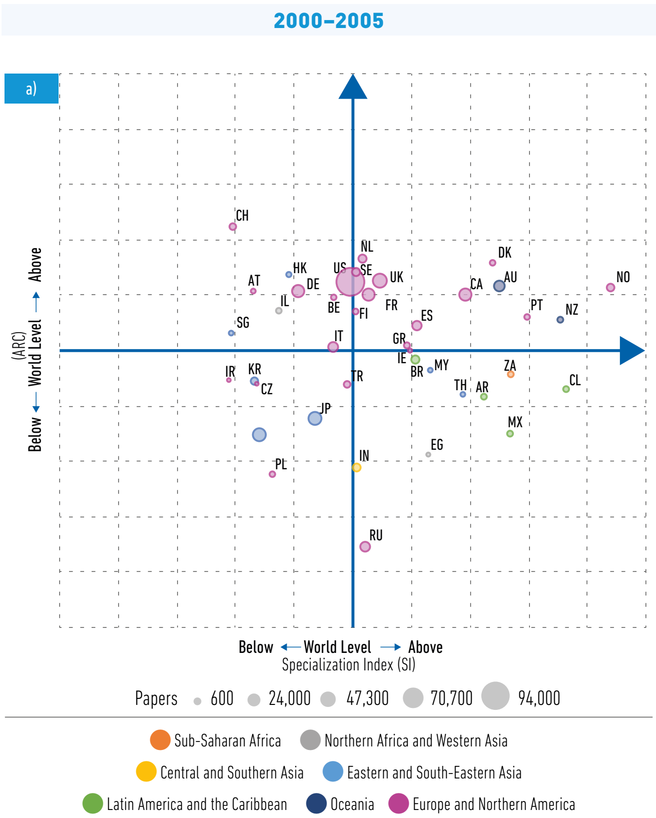
In other categories such as 'Oceanography in the Earth' in the 'Planetary science' area and 'Aquatic science' in the 'Agricultural and biological science' area, the journal is in 7th and 11th place, respectively.

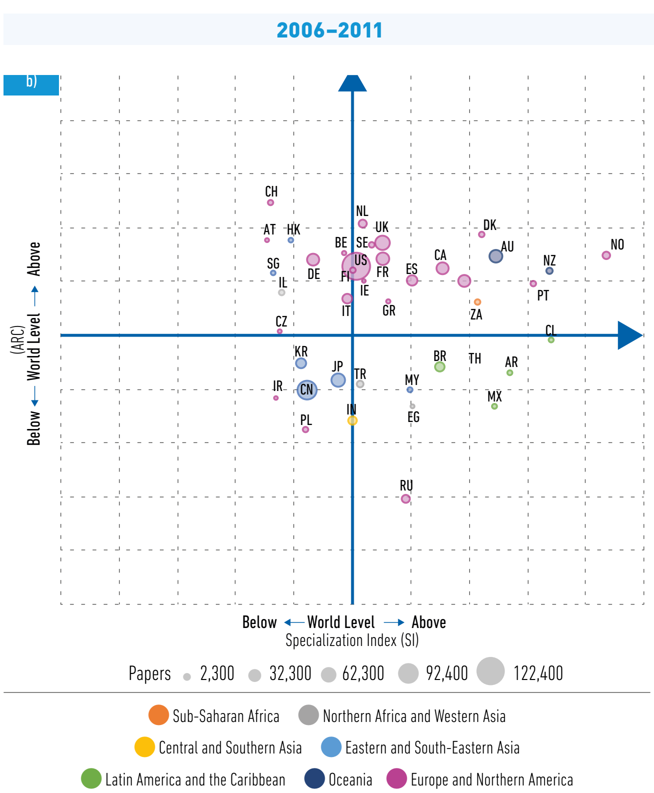
In 52 years of publication, the Bulletin has established itself as the only internationally indexed scientific journal focused on marine sciences in Colombia. It has published 670 manuscripts, of which 548 are research articles and 122 are scientific notes. Similarly, the journal is indexed in different national and international databases such as Biosis Preview, DOAJ, Google Scholar, ISI Web of Knowledge, Latindex, Periodica, Publindex, Scielo-Colombia, Scopus and the Zoologycal Record. In addition, the journal is distributed through the exchange or donation system at local, national and international levels.

In 2017, the Bulletin underwent a transition in several aspects: it relaunched as a completely bilingual publication (Spanish and English); changed format (size, layout of text and images); it made ORCID visible for authors and for members of the Scientific and Editorial Board Committee; and started to assign digital identifiers (DOI). All of these changes and the migration of the editorial process to the Open Journal System eventually led to increasing international visibility through the Scimago Journal Ranking (SJR) in the aforementioned quartiles.

After these changes, the citation index also increased by 18% compared to the previous year, with approximately 600 citations. In addition, there was a 28% increase in the submission of new scientific work for publication from Colombia, Ecuador, Mexico and Venezuela, thereby indicating a 40% foreign contribution for this journal.

*Source*: SJR Scimago Journal Ranking (2018). https://www.scimagojr.com



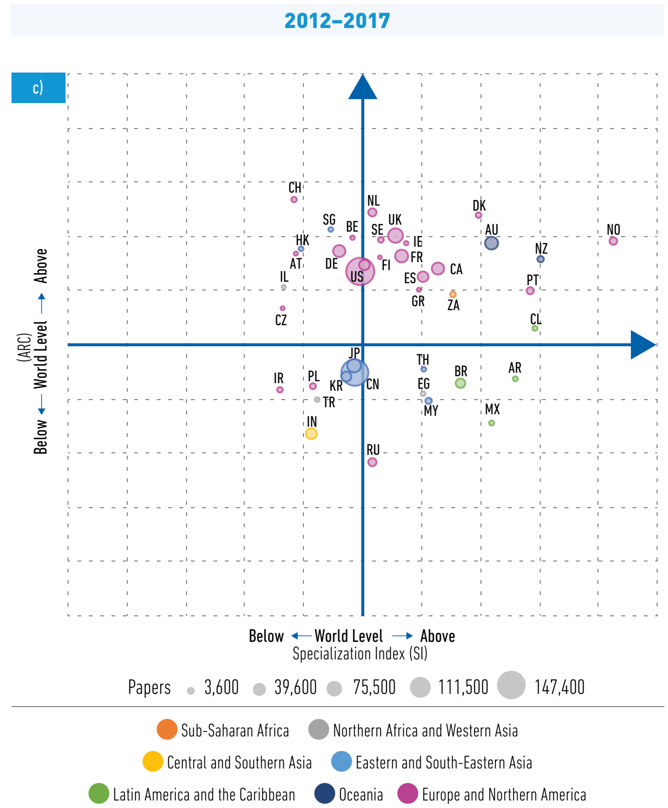




**Figure 5.20.** Positional analysis for the 40 countries included in the comparison group for ocean science output for the periods: a) 2000–2005; b) 2006–2011; c) 2012–2017. The size of the bubble is proportional to the number of publications for that country over the study period. Abbreviations: Argentina (AR), Australia (AU), Austria (AT), Belgium (BE), Brazil (BR), Canada (CA), Chile (CL), China (CN), China Hong Kong SAR (HK), Czechia (CZ), Denmark (DK), Egypt (EG), Finland (FI), France (FR), Germany (DE), Greece (GR), India (IN), Iran (Islamic Republic of) (IR), Ireland (IE), Israel (IL), Italy (IT), Japan (JP), Malaysia (MY), Mexico (MX), Netherlands (NL), New Zealand (NZ), Norway (NO), Poland (PL), Portugal (PT), Republic of Korea (KR), Russian Federation (RU), Singapore (SG), South Africa (ZA), Spain (ES), Sweden (SE), Switzerland (CH), Thailand (TH), Turkey (TR), United Kingdom of Great Britain and Northern Ireland (UK), United States of America (US).
*Source:* Based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

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A positional analysis to provide a perspective on the overall contribution of each of these nations to the different categories in ocean science is presented in Figure 5.21. The results are very similar to those shown in the GOSR2017 (IOC-UNESCO, 2017), even after the inclusion of 18 years of data for this report compared to 5 years in the previous report. For the category 'Ecosystems functions and processes' (Figure 5.21*a*), the plot shows the first quadrant is occupied by countries from Europe and Northern America plus Australia, New Zealand and South Africa, suggesting a prioritization of this particular field for these nations. The fourth quadrant showing high specialization but low ARC is mostly populated by Latin American countries (Argentina, Brazil, Chile and Mexico) which have high performance in terms of specialization but low citation rates. Most Asian and Arab States appear in the third quadrant.

In the category 'Ocean and climate' (Figure 5.21*d*), most nations are spread between the first and third quadrants. According to the results, the first quadrant is again occupied by Europe and Northern America nations, South Africa, Australia and New Zealand. One thing to note is Chile's high specialization and high ARC, and also a higher SI for the USA compared to its position in other categories. For other nations in Latin America, Argentina occupies the fourth quadrant with a high SI, Mexico is close to the world average and Brazil is slightly lower. The third quadrant is again occupied by Asian and Arab States, but less dispersed and closer to the world average compared to the 'Ecosystems functions and processes' category.

Concerning the 'Ocean health' category (Figure 5.21*b*), most nations fall in the first and fourth quadrants, demonstrating a larger interest in this category. Asian and Arab States also show a significant interest in this topic, with a higher specialization and an even larger publication output compared to the previous two categories, indicated by a larger bubble. Of interest is the lower SI from developed nations, such as the USA, the UK and Germany.

The positional analysis for 'Human health and well-being' (Figure 5.21*e*) shows an interesting distribution towards the right with most nations showing an SI above or very close to the world average, with the Russian Federation as the only exception. Notable in this distribution are the good performances of countries like Argentina, Indonesia and Malaysia, which show an ARC equal to the world average, while Chile and Saudi Arabia are higher than the world average.

Similarly to the GOSR2017 report, the first and second quadrants for 'Blue growth' (Figure 5.21*c*) are populated by small and medium bubbles, with the USA showing the largest output — around 76,000 papers over a period of 18 years.

The first quadrant for 'Ocean crust and marine geohazards' (Figure 5.21f) is populated by large bubbles compared to the other quadrants, and China and Japan show an SI and ARC similar to the world average, which signifies a big change compared to the categories above. The larger output, as well as SI and ARC, by most countries is an indication of the high interest in this category, with Indonesia, Norway and New Zealand showing the highest SI. The high interest shown by many nations is not surprising, given that this category deals with deep-sea mining, drilling and extreme events..

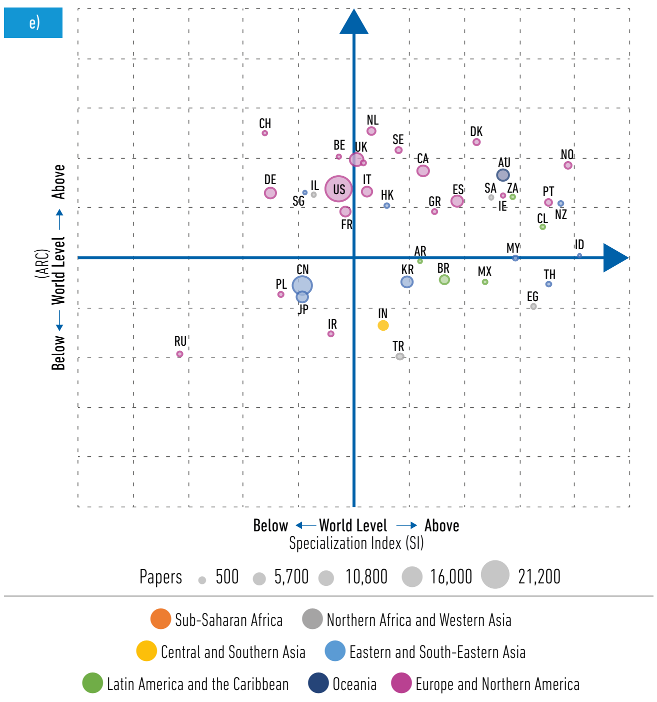
The distribution of nations shown for the category of 'Ocean technology and engineering' (Figure 5.21*g*) differs from all others, with the majority of the countries falling in the second and third quadrants and with small outputs for those with SIs above the world average. China is the only exception. The Republic of Korea is the other nation that shows a very distinctive distribution, with a high SI and the only category with a higher than average ARC.

'Ocean observation and marine data' (Figure 5.21*h*) is a category that is necessary for all other ocean science categories. The distribution is quite dispersed, with the first quadrant occupied mostly by countries from Europe and Northern America, plus Australia, New Zealand, South Africa, and notably by Indonesia. Similar to most categories, the third quadrant is occupied by Asian and Arab States.

This analysis shows how nations specialize in particular categories of research, illustrating their priorities. There are interesting patterns that remain consistent, such as Norway's steady position in the first quadrant, computing high scores for both indices (SI and ARC) in all categories. Another consistent position and high output is that of the USA with high ARC scores but close to the world SI average. A remarkable change is shown by China, which increased its output by about an order of magnitude and improved its ARC, moving from a lower SI towards the world average (Figure 5.20). This improvement in ARC with time is shown by all nations in this analysis, and while many of the countries that occupy the third and fourth quadrants are non-English speaking, changes in regional or national journals that include translations to English could be improving the impact of their research (see Box 5.1).

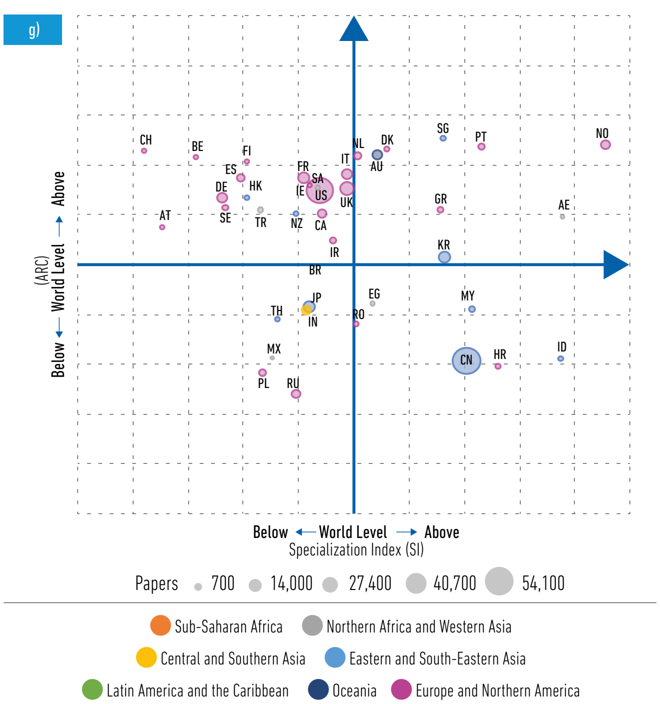

**Figure 5.21.** Positional analysis for the ocean science categories. The size of the bubble is proportional to the number of publications for that country over the study period. Abbreviations: Argentina (AR), Australia (AU), Austria (AT), Belgium (BE), Brazil (BR), Canada (CA), Chile (CL), China (CN), China Hong Kong SAR (HK), Czechia (CZ), Denmark (DK), Egypt (EG), Finland (FI), France (FR), Germany (DE), Greece (GR), India (IN), Iran (Islamic Republic of) (IR), Ireland (IE), Israel (IL), Italy (IT), Japan (JP), Malaysia (MY), Mexico (MX), Netherlands (NL), New Zealand (NZ), Norway (NO), Poland (PL), Portugal (PT), Republic of Korea (KR), Russian Federation (RU), Singapore (SG), South Africa (ZA), Spain (ES), Sweden (SE), Switzerland (CH), Thailand (TH), Turkey (TR), United Kingdom of Great Britain and Northern Ireland (UK), United States of America (USA).
*Source:* Based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

### Ocean and human health and well-being




### Ocean crust and marine geohazards


### Ocean technology




### Ocean observation and marine data

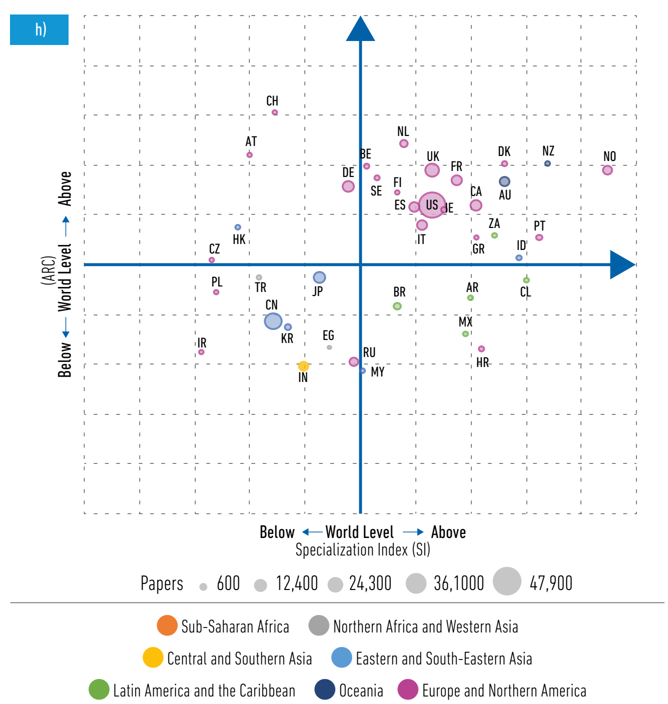



**Figure 5.21.** Continued

## 5.5. Collaboration patterns and capacity development

Scientific collaboration can bring many advantages to the researchers involved by increasing their productivity through the sharing of knowledge, expertise and techniques. Collaboration also enables people with different but complementary skill sets to come together and work as a team, dividing the workload, reducing costs by sharing equipment and resources, and enhancing the visibility of their research (Pirlet et al., 2018; Franceschet and Costantini, 2010).

Compared to previous decades, where single investigator research was common, the current scientific landscape is one of increasing collaboration because of the associated benefits, including the creation of knowledge (Bozeman et al., 2015; Claxton, 2005). Indeed, research collaborations are now a requirement by institutions, funding bodies and policymakers.

International research collaboration has increased and continues to do so, as shown in studies cited by Wagner and Leydesdorff (2005). Certainly, most of the recent cutting-edge science has been developed by large, well-funded international collaborative teams (Larivière et al., 2015). The Human Genome Project in the late 1980s and early 1990s and — more closely to marine science — the Census of Marine Life, and the Global Ocean Ecosystem Dynamics (GLOBEC) are good examples of large international collaborations. The former involved groups from many countries, sequencing different parts of the human genome that contributed to the total human gene map. In 1989, the Human Genome Organization (HUGO) was founded by leading scientists to coordinate this colossal international effort that culminated in mapping the entire human genome in 2003, an achievement only possible through international collaboration and participation. The Census of Marine Life was a 10-year international project that assessed the diversity, distribution and abundance of marine life. This programme involved 2,700 scientists, over 80 nations, 540 expeditions and a total of US$650 million in funding. This project was finalized in 2010 and provided the most comprehensive inventory of known marine life ever compiled and catalogued, and which now forms the basis for future research. GLOBEC was a 10-year international programme that produced over 3,500 publications and included several national programmes and scientists from over 30 countries, which will be discussed as an example of international cooperation at the end of the chapter.

However, international collaboration is not limited to these big science projects, and many researchers choose to collaborate because the evaluation structures for science reward highly visible research (Wagner and Leydesdorff, 2005). This visibility becomes stronger with international collaboration compared to domestic; and provides highly productive scientists with the ability to choose who to work with, but most importantly it also contributes to capacity development and transfer of marine technology for Least Developed Countries (Jappe, 2007; Wagner and Leydesdorff, 2005). Capacity development and technology transfer is a central component of the IOC-UNESCO capacity development strategy and the UN Decade of Ocean Science for Sustainable Development (2021–2030), aiming to provide equal and equitable access to marine technology.

Science can make valuable contributions to a better understanding of the ecosystem's functioning and to identify the relevant options for its sustainability and management. Ocean science seeks to understand complex, multiscale socio-economic and bio-geo-chemical systems and services, which requires multidisciplinary and collaborative research (IOC-UNESCO, 2017). This requires that fragmented knowledge, very often in distant communities, is combined to share research capacities (e.g. facilities, observation networks, transfer of know-how and data and information exchange) in order to make real progress.

The universal nature of science and research, the speed of change and its expansion in a hyper-connected world, favoured by the development of new innovative technologies, offer the opportunity to work in cooperation within and with other countries in large projects and to participate in large research infrastructures (Schmalzbauer and Visbeck, 2016). Nowadays, cooperation and collaboration between scientists has become the rule, and one way to measure this is by examining the co-authorship of scientific papers.

International cooperation has long been regarded as an essential aspect of public research, particularly when it comes to basic research. In the context of this analysis, all international scientific publications, indexed in literature databases, with the participation of at least two co-authors based in institutions/organizations in at least two different countries, were counted. Data were then converted into percentages of co-publication (i.e. International co-publication rate, ICR). In order to simplify the analysis, the study was limited to the top 100 most publishing countries (which account for more than 95% of the total published scientific literature). Data on the ICR by countries were provided by Science-Metrix/Relx Canada.

In the period 2012–2017, 61% of the papers published by ocean scientists had at least one co-author from a foreign country, compared with approximately 56% in the period 2006–2011 and 52% in 2000–2005. These changes are illustrated in Figure 5.22, which shows clearly the increase (displacement towards the right) in the international co-publication rate between the periods 2000–2005 and 2012–2017. The numbers observed in ocean science are close to other disciplines and countries. For example, in astronomy, 58% of all USA papers had foreign co-authors in 2005 and half of Canada's scientific papers were co-authored by foreign partners in 2014 (UNESCO, 2015), which ultimately means that collaboration among scientists from different countries is a sustained trend and should be seen as a very valuable and positive development.

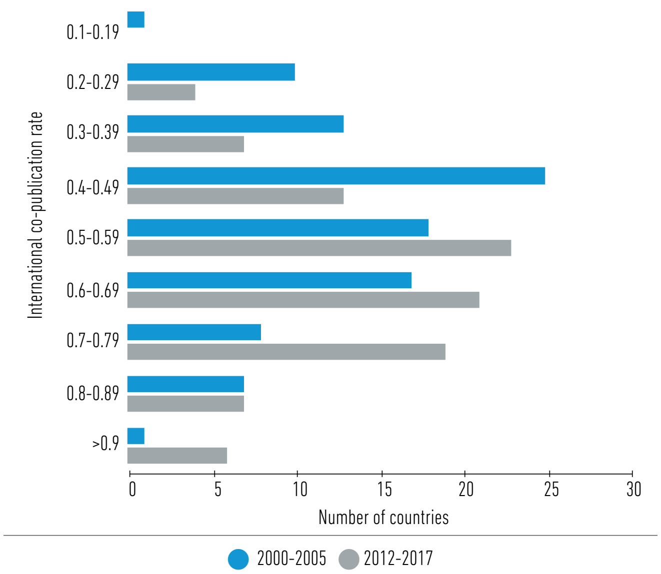



**Figure 5.22.** Changes in international co-publication rate of the 100 most publishing countries during the periods 2000–2005 and 2012–2017.
*Source:* Authors, based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

Of course, this varied among countries, as shown in Figure 5.23. For example, 24 countries of the 100 used in this analysis show ICR values under 50%. Although there is no clear pattern explaining these rates of collaboration, it can be observed that big countries such as Argentina, Brazil, China, India, the Russia Federation and the USA, and also largely populated countries such as Indonesia, Iran, Japan, Mexico and Turkey are within this group. This is likely to be because they are big enough and/or have enough research facilities and networks to uphold/enable the interchange of scientist and establish collaborations among scientific groups within their own territories. Similar results were also observed in other global bibliometric analyses (UNESCO, 2010, 2015; Royal Society, 2011).

By contrast, there is a group of 24 countries publishing more than 75% of their research articles in collaboration with foreign scientists. Again, there are no clear patterns explaining why these countries reach such high levels of cooperation, but it is possible to observe a number of small countries such as Belgium, Costa Rica, Ecuador, Monaco and Panama, some island states such as Bermuda, Fiji, Greenland, Iceland, Madagascar and New Caledonia, and also landlocked countries such as Austria, Luxemburg, Nepal and Switzerland. Obviously, for many of these countries, the need for collaboration stems from limited access to ocean science facilities (Pirlet et al., 2018), or they may attract scientists because they offer good research opportunities in environmental science, such as biodiversity and climate change, e.g. Ecuador (Galapagos Islands), Greenland, Madagascar and Ecuador.

Regardless of the motivation behind international research collaborations, it has been demonstrated that they produce higher citation rates and more impactful science with international collaboration papers cited in high-impact journals (Franceschet and Costantini, 2010; Iribarren-Maestro et al., 2009). The positive correlation between the average relative impact factor and the ICR is shown in Figure 5.24. This trend supports the view that international co-authorship research is rewarded with an increase in citation rates, which is a pattern previously observed in ocean science (IOC-UNESCO, 2017), as well as in other disciplines (Herbertz, 1995; Bornmann et al., 2012; Jarić et al., 2012).

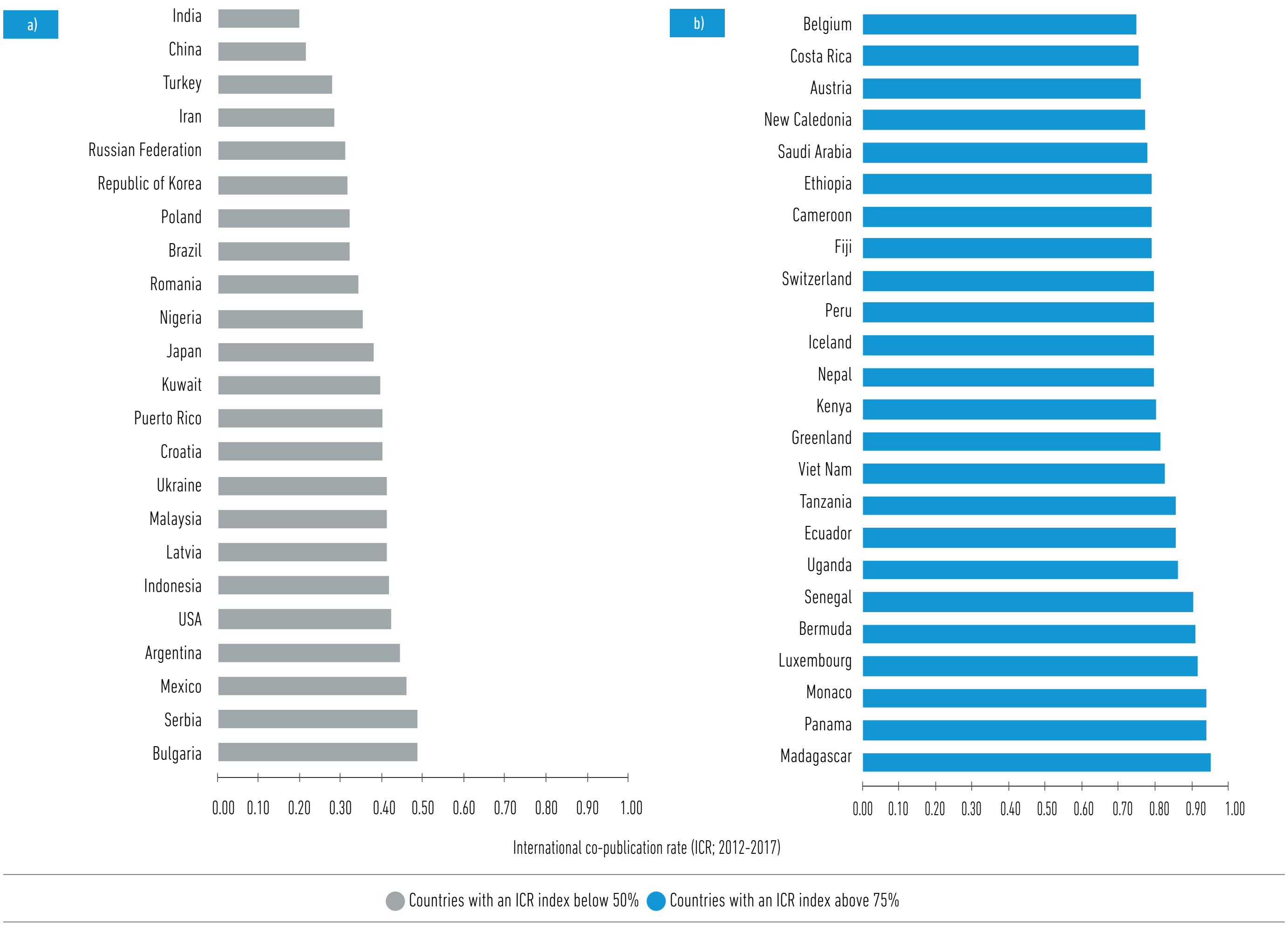



**Figure 5.23.** Classification of countries according to their level of ICR: a) below 50%; b) above 75%.
*Source:* Authors, based on the bibliometric analysis of Scopus (Elsevier) data 2012–2017 by Science-Metrix/Relx Canada.

The correlation, however, is only stronger for countries with a high output, and this relationship breaks down when it is made for countries with a very small output, even if their ICR is high (see GOSR data portal). This makes sense in that the impact factor is not only dependent on the level of international collaboration but also on the level of output by a given country.

In other words, it is not possible to have a high impact with a small number of publications, regardless of international co-authorship. Nevertheless, the visibility of the research does increase with international co-authorship, and it has been demonstrated that this is not only through self-citations (Larivière et al., 2015).

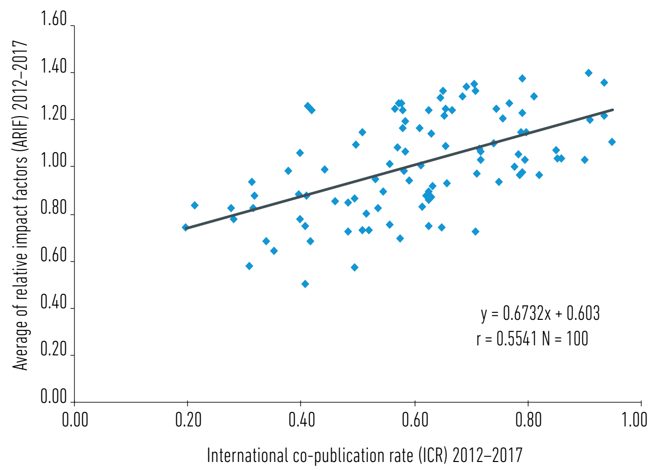



**Figure 5.24.** Comparison of ICR and ARIF of the ocean science community and ocean practitioners.
*Source:* Authors, based on the bibliometric analysis of Scopus (Elsevier) data 2012–2017 by Science-Metrix/Relx Canada.

### *5.5.1. Research neighbourhood*

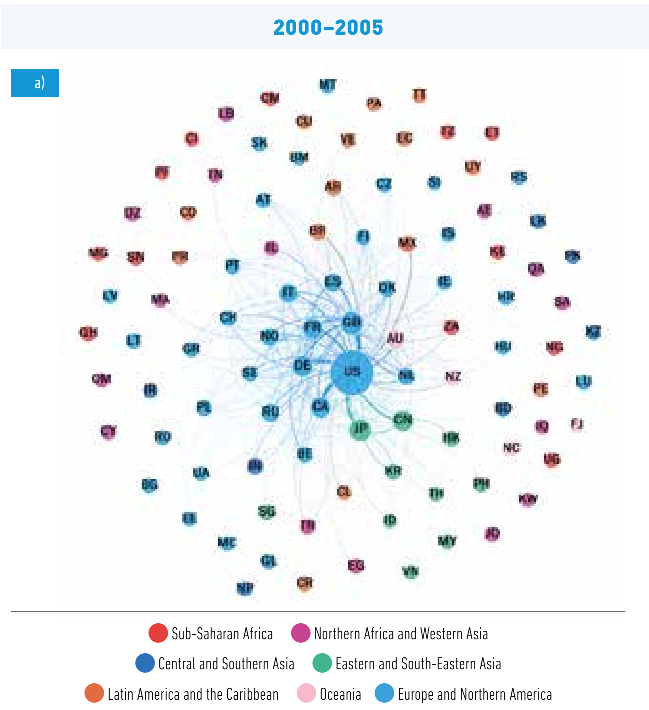
To explore further some of these international collaboration links, network analysis is used to understand which nations are acting as the engines for ocean science. This analysis allows us to visualize the collaboration intensity between nations, as well as their preferred collaboration network.

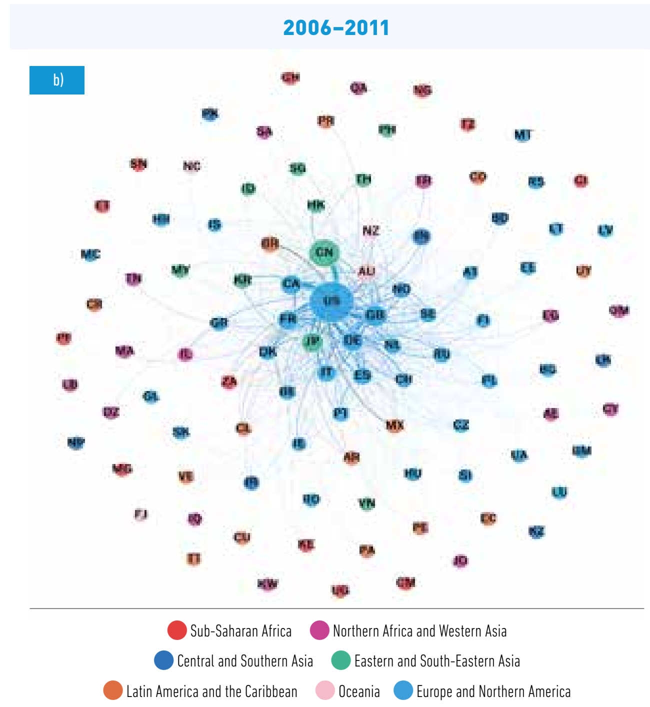
In the network analyses presented in Figure 5.25, the size of a node is proportional to the number of publications from each entity (100 most publishing countries and institutions for ocean science), while the width of an edge is proportional to the number of co-publications between the two nodes that it ties. The spatial arrangement of the network is a function of the number of collaborators and the collaboration intensity. The same analysis was done over several time periods to see the evolution of these networks since 2000.

Figure 5.25 illustrates that industrialized nations in Asia-Pacific, Europe and the USA act as the engine of ocean science research with the highest output, the strongest links and also the largest network, with the USA dominating. It is evident that over time the network is expanding, and the connection among nations is growing and changing. For example, in 2000 to 2012, Canada and the USA had the highest number of collaborations, accounting for ~10,000 over 12 years, while most recently, from 2012 to 2017, the highest collaboration for the USA has been with China, accounting for over 11,000 in just six years. The UK is another nation with a large number of publications and strong collaborations, but most of them are with other European countries, Australia and USA. What is interesting is that a similar pattern is also found in citations made by patent creators (Table 5.6) with Europe and Northern America receiving the highest number, followed by Asia.

One interesting change over time is the increase in collaboration and the tightening of links from the countries towards the centre. The change in landscape was also observed by Newman (2001), where participants established more connections over time and new participants joined. This analysis clearly illustrates how new connections are being established between new nations.

The USA is the country with the widest network, which goes beyond Europe and English-speaking countries, linking with countries located at the periphery of the network. It is important to note that these analyses only include peer-reviewed literature in English and it may be masking the collaborations between non-English speaking countries, which could be strong but will not be reflected here (see, for example, Leydesdorff et al., 2013).



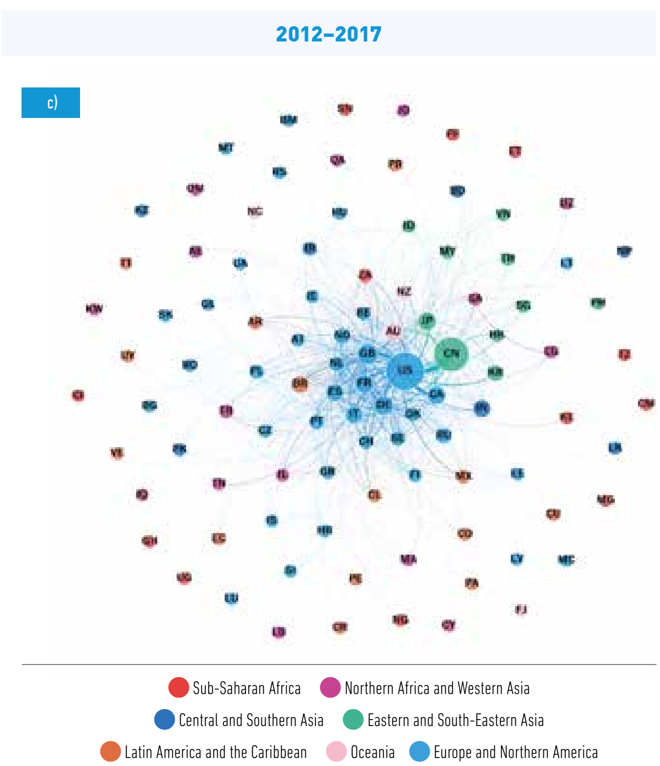




**Figure 5.25.** Network analysis of international collaboration of selected top publishing nations in ocean science, showing three time periods: a) 2000–2005; b) 2006–2011; and c) 2012–2017. The size of the nodes is proportional to the number of publications in ocean science, and the thickness of the 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. Abbreviations: Argentina (AR), Australia (AU), Austria (AT), Belgium (BE), Brazil (BR), Canada (CA), Chile (CL), China (CN), China Hong Kong SAR (HK), Czechia (CZ), Denmark (DK), Egypt (EG), Finland (FI), France (FR), Germany (DE), Greece (GR), India (IN), Iran (Islamic Republic of) (IR), Ireland (IE), Israel (IL), Italy (IT), Japan (JP), Malaysia (MY), Mexico (MX), Netherlands (NL), New Zealand (NZ), Norway (NO), Poland (PL), Portugal (PT), Republic of Korea (KR), Russian Federation (RU), Singapore (SG), South Africa (ZA), Spain (ES), Sweden (SE), Switzerland (CH), Thailand (TH), Turkey (TR), United Kingdom of Great Britain and Northern Ireland (GB), United States of America (USA).
*Source:* Based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

With regard to institutional collaborations, their strongest links are siloed within their own countries, with secondary links to outside institutions, reflecting the links seen in the analyses by country (Figure 5.26). Institutions from Australia, Europe and Northern America have built strong links among themselves and these have remained over the years. A notable change has been the strengthening of links between Japanese and USA institutions, and Chinese institutions with the rest of the world over time. CNRS from France is the organization with by far the largest output across time, while the output from NOAA (USA) has decreased and the Chinese Academy of Sciences increased (see supplementary material for more details). It is important to note that the State Oceanic Administration (SOA) was responsible for ocean science in China until 2018, and the Ministry of Natural Resources (MNR) thereafter.

The network analyses showed regional preferences or stronger research links between a small group of countries. However, multinational collaborations for large-scale research projects, where complex knowledge production requires formal management structures and resources that cannot be met by a single agency or nation, have been an important component in ocean science, where highly specialized and expensive research infrastructures are needed (Langford and Langford, 2000).

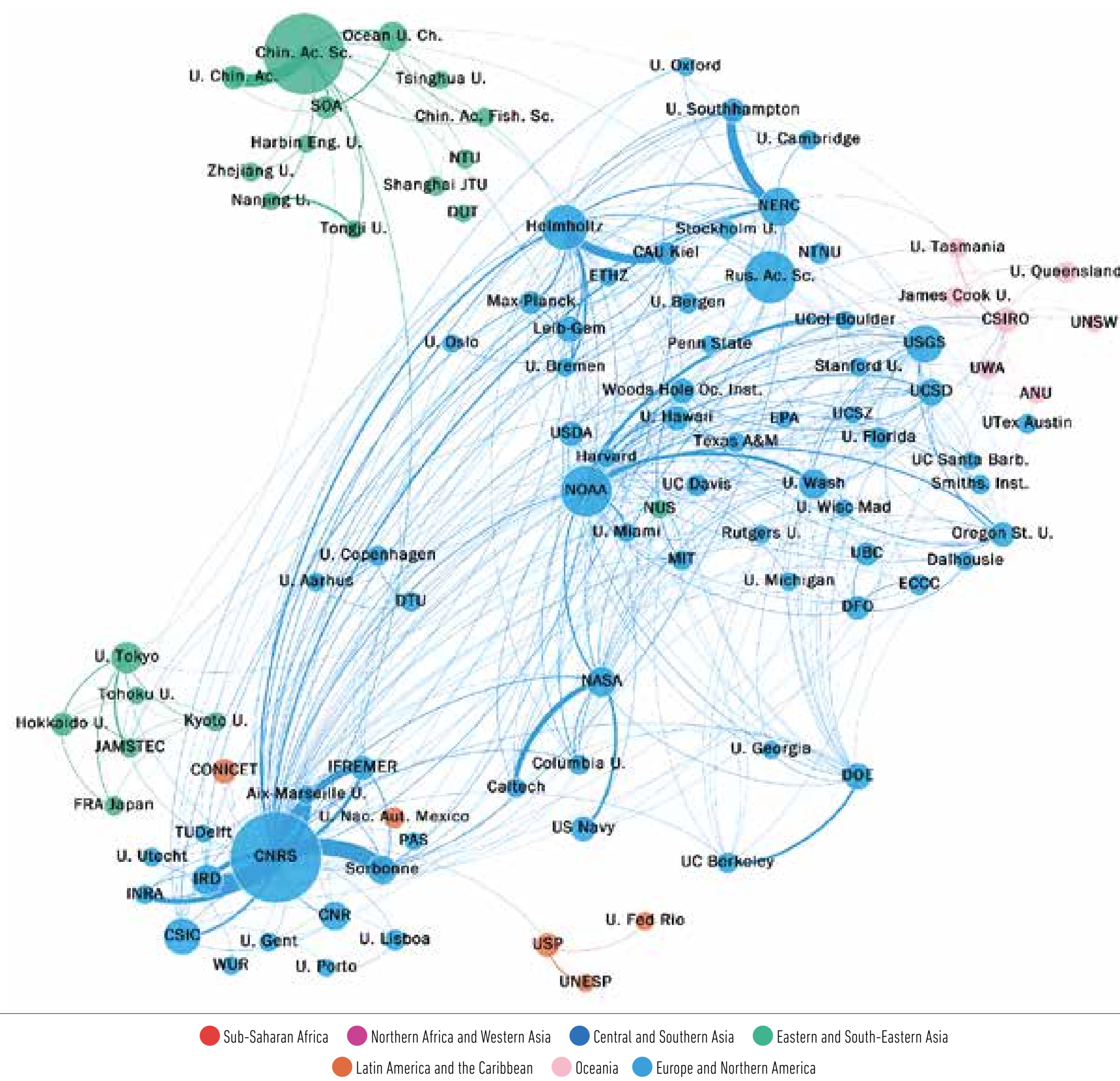



Figure 5.26. Network analysis of international collaboration of selected top publishing organizations in ocean science during 2000–2017. The size of the nodes is proportional to the number of publications in ocean science and the thickness of the lines is proportional to the number of collaborations (co-authored papers). Nodes are arranged using an algorithm where linked nodes are attracted to each other while unlinked nodes are pushed apart.
*Source:* Based on the bibliometric analysis of Scopus (Elsevier) data 2000–2017 by Science-Metrix/Relx Canada.

## 5.6. The role of collaboration opportunities in promoting excellent science and science-based management

The universal nature of science and research, and the speed of change and its expansion favoured by the development of new innovative technologies, requires opportunities to work in cooperation with other institutions, consortia partners or countries, in large projects or within large research infrastructures.

As illustrated in this chapter, collaboration is linked with the impact of the science that is delivered and published. It is therefore of fundamental importance for science to serve society and sustainable development; that governments, the private sector, governmental and non-governmental organizations provide as enabling an environment and framework as possible to facilitate scientific collaboration across countries, sectors, institutions and disciplines. From this perspective, 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 the sustainable management of the global ocean commons (IOC-UNESCO, 2017). This creates a clearly defined duty and responsibility at national, regional and international levels to provide enabling frameworks and initiatives.Along with other intergovernmental and international organizations, IOC-UNESCO has a long tradition in science diplomacy oriented towards *inter alia* building international networks; engaging scientists from developed and developing countries towards an integrated view of the ocean; enhancing interdisciplinarity and the development of activities that extend into new areas of ocean science; and establishing multifaceted engagement with sustainability and policy processes, leading to the advancement of national research programmes and the creation of new global databases that remain key to understanding ocean system processes and functioning.

There are a number of model examples of where organized collaborative science and research initiatives at the global scale have enhanced advances in ocean science. These include the World Climate Research Programme (WCRP), the Global Ocean Observing System (GOOS), the International Ocean Carbon Coordination Project (IOCCP), the Intergovernmental Panel on Harmful Algal Blooms (IPHAB) and the Intergovernmental Panel on Climate Change (IPCC), as well as other long-standing projects and programmes. The processes and activities have been operating for many years and are connected with numerous research and observation programmes, which continue to stimulate and provide synergies for collaborative climate and ocean research.

Beyond the global research objective, a key aspect of cooperative networks is the alignment of disciplines that traditionally did not work together (e.g. atmospheric and oceanic chemistry with biology, ecology and biogeochemistry), leading to an improved integrative understanding of the earth system, including past and potential future changes.

IOC-UNESCO, in collaboration with other organizations, has also launched or participated in global research programmes that were transformative for the understanding of the ocean processes and ecoystems, such as the Joint Global Ocean Flux Study (JGOFS), the Census of Marine Life (CoML, Chapter 7), the Global Ocean Ecosystem Dynamics (GLOBEC, see Box 5.2) and others. All of these, together with other programmes and projects under the International Geosphere-Biosphere Programme (IGBP), ended when the IGBP reached the end of its timeline in the 2010s.

For some scientific questions, international, large-scale, ambitious programmes have become a prerequisite because: (i) international collaboration and advanced research facilities are needed to answer major and complex questions, (ii) connecting researchers with other researchers and large infrastructures, wherever these might be, helps science to advance, and (iii) big science encourages innovation and the development of existing and new key technologies. Big scientific programmes have demonstrated that they can be expected to show a faster impact in terms of highly cited papers, multi-authorship papers and spin-off projects at national and regional level than other more limited and local initiatives (for more detailed information, see Box 5.2).

The UN has agreed on various agendas to tackle societal and scientific challenges (e.g. the UN 2030 Agenda, the Paris Agreement and the UN Decade of Ocean Science for Sustainable Development). Starting in 2015, the 2030 Agenda and its SDGs set the framework and starting point for almost all initiatives that have the slightest relevance for a sustainable future — a fundamental paradigm shift in itself. Science can make valuable contributions to improve the understanding of the SDGs and to identify relevant options for their implementation. There is tremendous scope for the scientific community to engage in and develop forward-looking collaborative research that has the potential to support new interconnected development pathways, particularly in highly interlinked areas of the SDGs.

## Box 5.2. GLOBEC

GLOBEC Great progress in ocean science has been achieved through internationally coordinated research projects. This research approach, the so-called 'megascience' (OECD, 1994; Tindemans, 1997), started around 40 years ago and opened up new opportunities for networking, distributed facilities, interdisciplinary research and the transfer of knowledge and technologies.

The Global Ocean Ecosystem Dynamics project (GLOBEC) was created with the support of IOCUNESCO, the Scientific Committee on Oceanic Research (SCOR) and the International Geosphere- Biosphere Programme (IGBP), with the aim of understanding how global change, in the broadest sense, will affect the abundance, diversity and productivity of the marine populations comprising a major component of oceanic ecosystems. Although its roots go back to 1992, it was formally launched as a ten-year international programme in 1999 and came to an end on 31 December 2009.

GLOBEC developed capacity by establishing a network of scientists beyond national boundaries and governmental organizations, mobilizing new resources at different levels (scientific, intellectual and material) and producing synergies by stimulating cooperation between researchers and organizations. GLOBEC results were disseminated in different ways: through the website, newsletter, the promotion of conferences and symposia and, of course, scientific papers. Over the ten years, the accomplishments of GLOBEC were numerous (Perry and Barange, 2009), including over 3,500 publications in the period 1994–2009 (Figure 5.27).

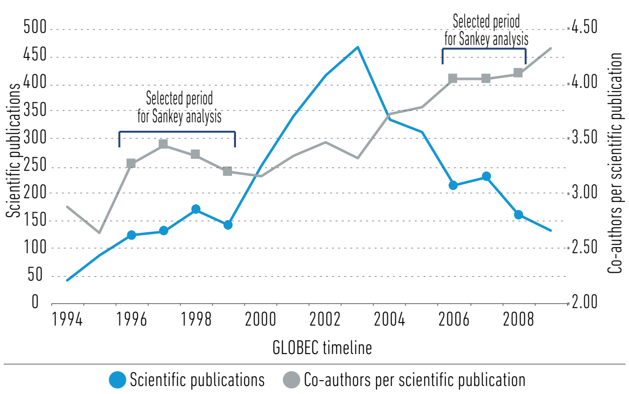



**Figure 5.27.** GLOBEC production of peer-reviewed papers and average co-authors/paper.
*Source:* Adapted from working document GLOBEC S4D Workshop, Paris 2010.

In order to study the dynamics in the number of co-authors in GLOBEC peer-reviewed scientific publication, two time periods with an interval of ten years (1996–1999 and 2006–2008), and with a similar number of publications (543 and 606, respectively), were selected and compared using a Sankey analysis. The Sankey diagrams plotted in Figure 5.28 show that at the beginning of GLOBEC timeline, only one-third of the scientific publications were written by four or more scientists; the average number of co-authors per article was 3.31 (Figure 5.27). Conversely, at the end of GLOBEC, as the project gained in multidisciplinarity and the networks were better established, the number of co-authors increased as well — more than half of the scientific papers were co-authored by four or more scientists (Figure 5.28) with the average number of co-authors per article at 4.05 (Figure 5.27). These results show that GLOBEC was a successful project, producing synergies by stimulating cooperation between researchers and organizations.

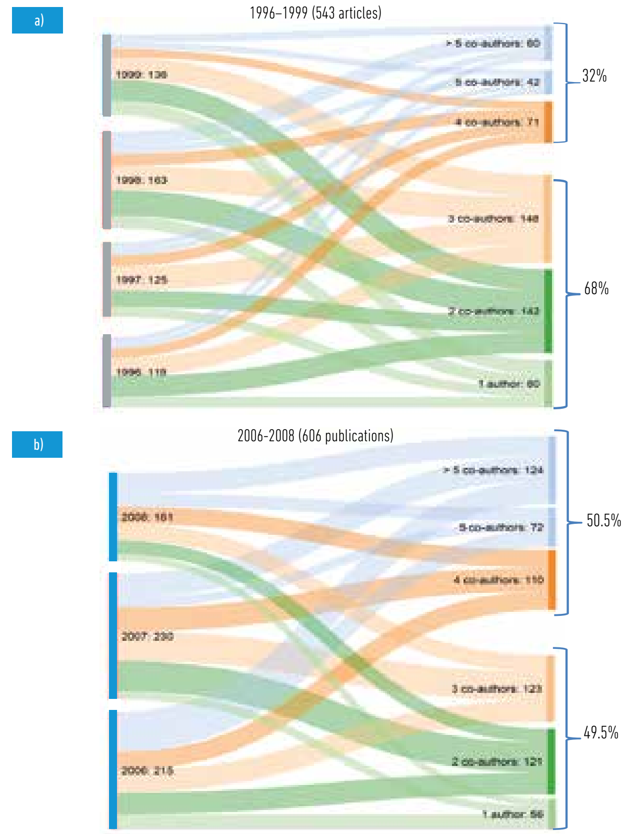



**Figure 5.28.** Sankey diagrams showing the changes in GLOBEC peer-reviewed publications co-authorship in the periods 1996– 1999 (543 articles) and 2006–2008 (606 articles).
*Source:* Adapted from working document GLOBEC S4D Workshop, Paris 2010.

Regardless of the individual willingness to cooperate with other scientists at national or international level, the importance of the role of intergovernmental organizations in providing a sustained scientific policy framework (e.g. via international projects) that encourages international cooperation, including the provision of financial support, must be acknowledged. The internet has served as an enabler of this interest in cooperation; there are constantly increasing numbers of scientists in the world, and they are becoming more mobile. These burgeoning collaborations and facilities for communication are reflected in the production and co-authoring of scientific literature. But overall, the desire of individual scientists to give their work greater visibility is underpinned and catalyzed by the opportunities that a favourable international scenario supporting global research programmes offers, to enable, stimulate and consolidate successful communities of practitioners. In summary, the conclusion that follows from this discussion is that global programmes, such as GLOBEC, are strategic for ocean science, and their promotion and support should be a priority for IOC-UNESCO as well as for other UN and intergovernmental agencies.

A major enabling initiative for society to achieve the targets set out under SDG 14 on 'Life Below Water' (and other SDGs) is the Ocean Decade (2021–2030), which will support efforts to reverse the cycle of decline in ocean health, and unite ocean stakeholders worldwide behind a common framework that will ensure ocean science can fully support countries in establishing the necessary conditions for a sustainable relationship between humans and the ocean.

The Ocean Decade Implementation Plan[6], the Decade Challenges and the science action therein aim to provide a framework within which targeted scientific and knowledge-generating efforts can be developed and delivered. The challenges form one of the essential components of the Implementation Plan for the Ocean Decade, along with other plans (governance, communication, business, capability development etc.). The plan sets out a series of globally deployable strategic objectives, supported by a number of actions under which portfolios of programmes, projects and activities that deliver those actions can be formulated by all stakeholders contributing to achieving the societal outcomes of the Ocean Decade.

New models will be required for how ocean science is carried out, communicated and used. This, in part, provides the rationale for the Ocean Decade. Its success will depend on the extent to which funders and existing research communities are able to develop core projects. In this regard, one example is the large research programme Seabed2030, which aims to have 100% of the ocean floor mapped by 2030. This project, funded by the European Commission and the Nippon Foundation-GEBCO, is an example of a large-scale endeavour where the data and science delivery is made possible through a global coordinated effort.

In summary, broad scientific and societal questions and challenges should be approached with a new type of programme, inspired and involving action and collaboration across the boundaries of disciplines, institutions and sectors. Big science has now become a necessary precondition for many issues and the role of the UN is becoming more significant in enabling international cooperation. Delivering big science requires broad and diverse forms of collaboration — multidisciplinary, interdisciplinary and cross-sectoral collaboration, as well as collaboration between fundamental, applied and practice-oriented research.

Now is the time to emphasize the importance of scientific knowledge with coherent programming, maintaining the highest standards of integrity. The capacity to achieve such multidisciplinary and interdisciplinary collaboration between researchers, disciplines and institutions based on long-term core programmes is a major challenge for UN agencies, and other entities engaging with science policy and diplomacy, to give us the ocean we need for the future we want.



[6] See Implementation Plan of the UN Decade of Ocean Science for Sustainable Development https://oceanexpert.org/document/27347.

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# 6

# Ocean science for sustainable development

# 6. Ocean science for sustainable development

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## 6.1. Introduction

The international community has aligned with the United Nations 2030 Agenda for Sustainable Development — a shared blueprint for peace and prosperity for people and the planet, now and in the future, as outlined in the Sustainable Development Goals (SDGs). These 17 goals identify shared societal, economic and environmental aspirations for all countries to meet. They promote a journey towards a future that is free of poverty and hunger, one that adapts to the impacts of climate change and to the increasing human demand for natural resources. The SDGs serve as a call for governments, institutions and the general public to rally behind measurable goals, targets and indicators, and to take up actions, singly and collectively, that will enable the world to reach this shared and prosperous future. This ambition is also reflected in the vision of the upcoming UN Decade of Ocean Science for Sustainable Development (2021–2030) (the Ocean Decade) — 'The science we need for the ocean we want' — and in its mission 'Transformative ocean science solutions for sustainable development, connecting people and our ocean'. Ocean science is inherently multidisciplinary; it encompasses natural and social science disciplines, local and indigenous knowledge, and the technology and infrastructure required to conduct research. Scientific ocean research may be inspired by the application of ocean science for societal benefit, which includes knowledge transfer and applications in regions that are lacking science capacity, and the science-policy and science-innovation interfaces. Ocean science inspires exploration and appreciation of the natural world and illuminates the central role of the ocean in the Earth system, covering the land-sea, ocean-atmosphere, and ocean-cryosphere interfaces.

The conservation and sustainable use of the ocean and coastal areas are specifically called for in SDG 14: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'. Inclusion of this goal in the 2030 Agenda demonstrates recognition of the critical role of the ocean in human well-being. The ocean represents the largest biome on the globe, contributing essential resources supporting human nutrition, health and spiritual connection to the natural world. Hence, by working to achieve SDG 14, nations will also be contributing to all the other SDGs in profound ways.

SDG 14 comprises ten targets and while ocean science is indispensable to achieve all of them, ocean science, and in particular marine technology transfer, are mentioned in SDG target 14.a. This target encourages the international community to '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 SIDS and LDCs'.[1] SDG target 14.a cuts across all other targets. As an enabling target, it contributes to the achievement of the overall objective of SDG 14 and many other SDGs. However, the ambition and action of countries depends on specific needs, which differ between regions (see Section 6.2).

This chapter will analyse how ocean science contributes to SDG 14 and to specific outcome challenges of the Ocean Decade.[2] Sections of this chapter highlight national efforts in measuring progress towards SDG 14, particularly its targets and indicators, the contribution of ocean science to achieving SDG 14, and the support provided by ocean science to attain other SDGs. Lessons learned from these actions and activities could help nations, organizations and business sectors to improve current strategies and develop new transformative ones.

We recognize that, in meeting SDG 14, there will be contributions to all other SDGs (ICSU, 2017). However, the following sections will refer only to a selection, based on foci of the Ocean Decade, as well as overall IOC-UNESCO priorities, principally SDG 5 which addresses gender equality and empowerment of women and girls, and SDG 13, which focuses on climate. In addition, as shown in Chapter 4 with respect to capacity development and in Chapter 5, which deals with ocean science output, successful ocean science relies on partnerships and can help to establish new collaborations between different stakeholders and across countries. Each actor is like a piece of the puzzle and, as highlighted in SDG 17, which promotes peaceful and inclusive societies as well as global partnerships for sustainable development, only cooperation will enable the assembly of multiple stakeholders pursuing a common sustainable development agenda for the ocean.

## 6.2. National strategies and mechanisms to achieve SDG 14

The responses to the GOSR2020 questionnaire indicate that more than 70% of 37 countries across the globe have strategies and a roadmap to achieve the goals of the 2030 Agenda. However, only 21% of the nations reported that they have a specific strategy focusing on the ocean and SDG 14 (Figure 6.1).

[1] SIDS — small island developing states; LDCs — least developed countries.

[2] See Implementation Plan for the United Nations Decade of Ocean Science for Sustainable Development Version https://oceanexpert.org/document/27347.

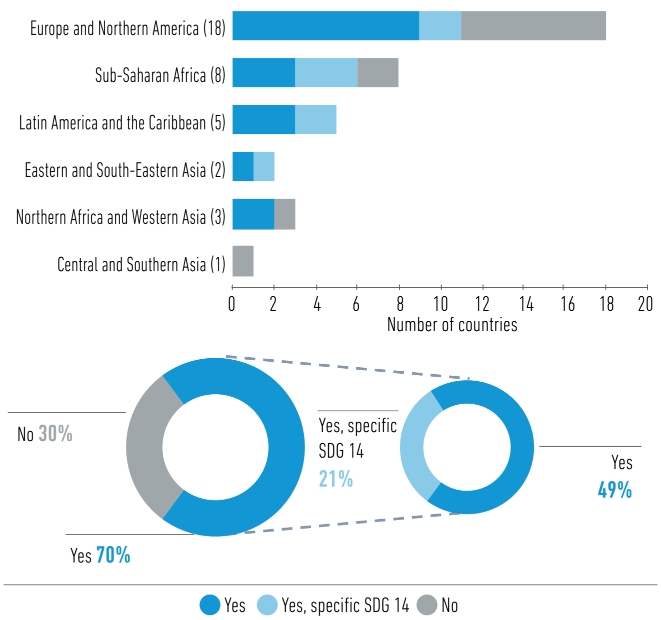


**Figure 6.1.** Distribution of countries which reported to have a national strategy to achieve the 2030 Agenda and/or SDG 14 globally by SDG regional groupings.
*Source:* Data based on the GOSR2020 questionnaire.

Within the region of Sub-Saharan Africa, six countries have an overarching SDG strategy and three developed a strategy with a specific focus on SDG 14. This focus on SDG 14 may be attributed to the emerging dialogue on the blue economy in the region, including in countries such as South Africa, Kenya and Mozambique. Examples highlighting the increased awareness of the role of a sustainably managed ocean for the national economy was the Sustainable Blue Economy Conference, held in Nairobi in November 2018, as well as the *2050 Africa's Integrated Maritime Strategy*.[3] Representatives of 184 countries participated in the event and a total of 191 commitments were made at the conference, which addressed plastics and waste management, marine and water resources protection, partnerships, infrastructure, policy and regulatory measures, private sector support, biodiversity and climate change, technical assistance and capacity building, as well as fisheries development. Out of these commitments, eight countries and three organizations declared monetary commitments valued at over US$172 billion. These initiatives continued in May 2019, when Mozambique hosted the Growing Blue Conference to discuss investments in key ocean sectors. Furthermore, South Africa has invested in a project called Operation Phakisa, which focuses on unlocking the potential of South Africa's ocean to contribute to the national gross domestic product (GDP). In addition, countries such as Guinea have programmes that target the ocean, specifically ocean science and the establishment of related capacity development activities at the university level.

Ireland reported that strategies to guide SDG interventions such as *The Sustainable Development Goals National Implementation Plan*; *Harnessing our Ocean Wealth*; *the National Biodiversity Action Plan 2017–2021; Foodwise 2025;* the Geohive National Data Catalogue;[4] and a *National Climate Adaptation Strategy* (2018) are already in place. The Irish *Sustainable Development Goals National Implementation Plan* provides guidance on how the interventions to achieve the different goals and targets will be conducted and how the government plans to align their development aid to support other countries around the globe. These strategies are reviewed and reported on a continuous basis, thereby enabling the country to track its progress towards the achievement of the UN 2030 Agenda for Sustainable Development.

The presence of a national SDG 14 focal point is an important indicator for reporting on achievements on the different targets. Globally, more than 60% of the responding countries to the GOSR2020 questionnaire indicated that a focal point for SDG 14 was assigned (Figure 6.2).

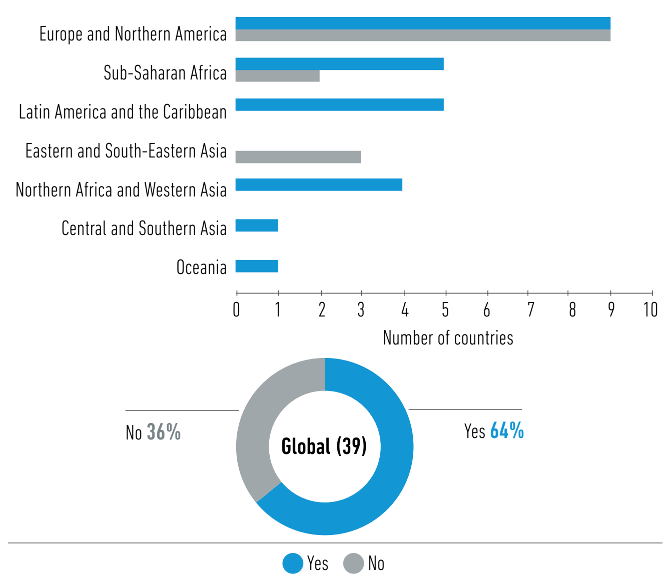


**Figure 6.2.** Distribution of countries which reported to have (or not) appointed a national SDG 14 focal point at the global level by SDG regional groupings.
*Source:* Data based on the GOSR2020 questionnaire.

The affiliation of the focal points, whether they are associated with ministries or other national organizations, varies among countries. Some focal points are employees of the country's

[3] See https://au.int/en/documents-38.

[4] See https://geohive.ie/catalogue.html.

ministry of foreign affairs, others of the ministry of trade, ministry of environment or ministry of fisheries. Iran's focal point is in the Iranian National Committee for Oceanography, while Canada has a specific SDG unit, which was established in 2018 to ensure the effective coordination of the 2030 Agenda activities across federal departments, agencies and with Canadian stakeholders. This unique arrangement allows Canada to track progress with respect to the SDGs in general, and SDG 14 in particular.

In terms of reporting mechanisms for the individual SDG 14 targets and indicators, 25 countries confirmed that they have reporting mechanisms in place (Figure 6.3).

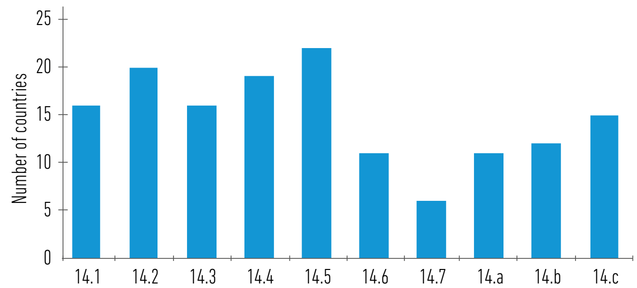


**Figure 6.3.** Number of countries (out of 25) which have national reporting mechanisms in place for the different SDG 14 targets and related indicators.
*Source:* Data based on the GOSR2020 questionnaire.

Most nations indicated that they report on SDG target 14.5, which states: 'By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information'. This was followed by SDG target 14.2 which aims to: 'By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans'. *The responses also show that many countries concentrate their efforts on regulating fisheries through support for SDG target* 14.4, which reads: 'By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics'.

The responses on SDG reporting are mirrored by the answers to the GOSR2020 questionnaire relating to the importance of marine and coastal ecosystem services. The three priority areas of importance related to ocean services were food provisioning, recreation and tourism, and coastal protection (Figure 6.4).

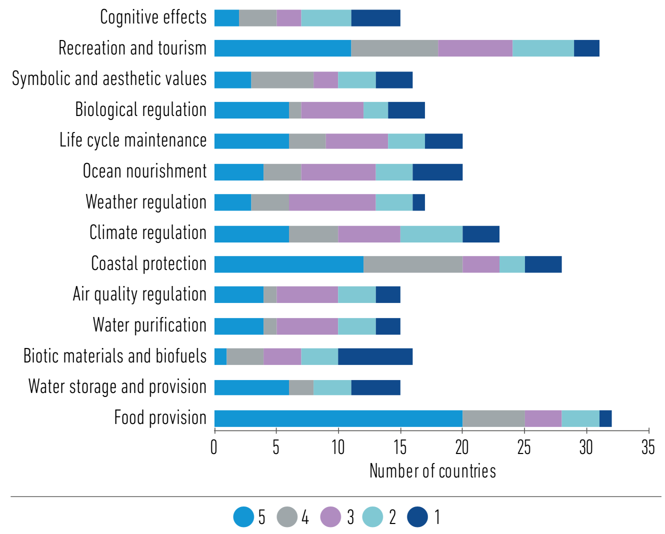


**Figure 6.4.** Importance attributed by countries to the different ocean services (5 high importance — 1 low importance).
*Source:* Data based on the GOSR2020 questionnaire.

## 6.3. Contribution of ocean science towards the achievement of the SDG 14 targets

The following sections provide a more in-depth review of how ocean science contributes to and potentially can help achieve the specific SDG 14 targets and measure progress via the SDG 14 indicators (Table 6.1). Data from the GOSR2020 questionnaire also provides analysis of national reporting of specific SDG targets.

**Table 6.1.** List of SDG 14 targets, indicators, indicator tier classification as of July 20201 and SDG 14 indicator custodian agencies and partner agencies.

| SDG 14 target | SDG 14 indicator | SDG indicator tier classification (2020)1 | SDG 14 indicator custodian agency — partner agencies |
|---|---|---|---|
| **14.1** By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution | **14.1.1** (a) Index of coastal eutrophication; and (b) plastic debris density | Tier II | UNEP — IOC-UNESCO, IMO, FAO |
| **14.2** By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience and take action for their restoration in order to achieve healthy and productive oceans | **14.2.1** Number of countries using ecosystem-based approaches to managing marine areas | Tier II | UNEP — IOC-UNESCO, FAO |
| **14.3** Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels | **14.3.1** Average marine acidity (pH) measured at agreed suite of representative sampling stations | Tier II | IOC-UNESCO — UNEP |
| **14.4** By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics | **14.4.1** Proportion of fish stocks within biologically sustainable levels | Tier I | FAO |
| **14.5** By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information | **14.5.1** Coverage of protected areas in relation to marine areas | Tier I | UNEP-WCMC, UNEP, IUCN-Ramsar |
| **14.6** By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation | **14.6.1** Degree of implementation of international instruments aiming to combat illegal, unreported and unregulated fishing | Tier I | FAO |
| **14.7** By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism | **14.7.1** Sustainable fisheries as a proportion of GDP in small island developing States, least developed countries and all countries | Tier I | FAO, UNEP-WCMC |
| **14.a** 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 | **14.a.1** Proportion of total research budget allocated to research in the field of marine technology | Tier II | IOC-UNESCO-UNEP |
| **14.b** Provide access for small-scale artisanal fishers to marine resources and markets | **14.b.1** Degree of application of a legal/ regulatory/policy/institutional framework which recognizes and protects access rights for small-scale fisheries | Tier I | FAO |
| **14.c** Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in the United Nations Convention on the Law of the Sea, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of 'The future we want' | **14.c.1** Number of countries making progress in ratifying, accepting and implementing through legal, policy and institutional frameworks, ocean-related instruments that implement international law, as reflected in the United Nations Convention on the Law of the Sea, for the conservation and sustainable use of the oceans and their resources | Tier II | UN-DOALOS, FAO, UNEP, ILO, other UN-Oceans agencies |

[1] Tier classification criteria/definitions: Tier 1: Indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by countries for at least 50% of countries and of the population in every region where the indicator is relevant. Tier 2: Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries. Tier 3: No internationally established methodology or standards are yet available for the indicator, but methodology/standards are being (or will be) developed or tested.
*Source:* UN Statistical Commission.[5]

[5] See https://unstats.un.org/sdgs/files/Tier%20Classification%20of%20SDG%20Indicators_17%20July%202020_web.pdf.

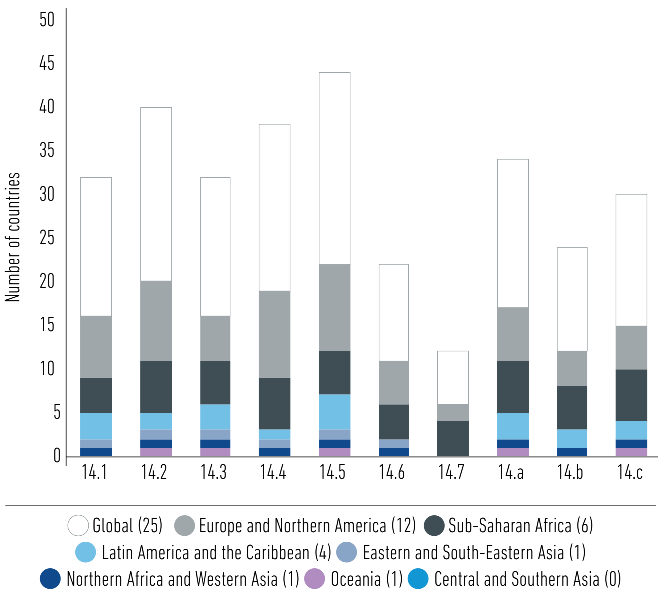


**Figure 6.5.** Number of countries with reporting mechanisms addressing the different SDG 14 targets by SDG regional groupings. *Source:* Data based on the GOSR2020 questionnaire.

**SDG target 14.1:** By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

From the 39 countries which responded to the relevant questions in the GOSR2020 questionnaire, the European and North American and Sub-Saharan Africa regions reported the highest number of countries with reporting mechanisms measuring the progress made towards SDG target 14.1 (Figure 6.5). Limited action in this regard might lead to reduced governance and policy-level interventions in dealing with marine pollution, which is critical in keeping the ocean alive and healthy.

Recognition of the problem pollutants pose for the ocean is relatively recent outside the scientific community, with the assumption that 'dilution is the solution to pollution' applies especially to the ocean, given the vast volumes of water in ocean basins. Nevertheless, in the 1970s scientists were already beginning to document the effects of nutrient over-enrichment in coastal waters worldwide as a consequence of the dramatic increase in the use of manufactured fertilizers (Boesch, 2002).

Excess nutrients, in particular nitrogen, were observed to trigger algal blooms in estuaries and marine coastal waters, which resulted in areas of low-dissolved oxygen and declines in seagrass beds and other valuable coastal habitats (National Research Council, 2000). Thanks to ocean science, evidence of contamination of coastal areas by other pollutants, such as heavy metals, polychlorinated biphenyls (PCBs) and petroleum compounds soon followed (National Research Council, 1989)

Efforts to develop solutions to the pollution of coastal waters quickly uncovered the complexity of this problem, both in identifying the sources and outcomes of pollution but also in understanding the impacts on ecosystems, including some of the negative impacts of proposed solutions (e.g. remobilization of contaminants in sediments causing increased toxic exposures to fish). To tackle this complexity in a systematic fashion, scientists adapted procedures used for human toxicological risk assessment to formulate an ecological risk assessment approach, the results of which could be applied to risk-based decision-making for the development of policies and regulations (Norton et al., 1992).

In terms of sustainability, the impacts of pollution affect society through many avenues, including human health (e.g. toxins, reduced seafood availability), lower fisheries productivity, reduced opportunities for recreation, lost revenues from tourism and lost benefits (ecological and economic) from decreased biodiversity (Millennium Ecosystem Assessment, 2005). To quantify these benefits, an analysis is required of the 'provisioning services' for connecting ecosystem characteristics to their usefulness to society. Documentation of these production functions requires research and scientific monitoring to ensure that the value of ecosystems receives consideration in policymaking.

SDG target 14.1 and the related indicators focus on nutrient pollution and plastic debris. Nutrient pollution and how to manage it was investigated by a wealth of studies carried out over the past 50 years documenting the effects and identifying sources. However, regional management of nutrient inputs to the marine environment continues to be a struggle, requiring the development of nutrient budgets to assess the inputs from various sources and to identify interventions that are likely to have a significant impact on the problem. In addition, ocean science can contribute to the development of solutions to reduce over-enrichment of coastal waters that are cost-effective and implementable. For instance, coastal wetlands are recognized as major sinks for excess nutrients. Restoring lost coastal wetland areas using science-based methods could help remediate excess nutrients while providing other ecosystem services such as fish habitat (Alexander et. al., 2016). Furthermore, the accumulation of plastic in the ocean has captured the attention of both the scientific community and the public over the past decade. It has been featured within the marine pollution focus area, starting with the first Our Ocean conference in 2014 and has also been a topic highlighted in statements by the Science20 (S20), comprising the national academies of the G20 countries.[6] In terms of the Ocean Decade, this serves both as Decade Challenge 1: 'Understand and map land and sea-based sources of pollutants and contaminants and their potential impacts on human health and ocean ecosystems, and develop solutions to mitigate or remove them'[7] and forms part of the societal outcome 'A clean ocean where sources of pollution are identified, reduced or removed'. The science of plastics in the ocean, however, dates back to studies of the Sargasso Sea in the 1970s (Carpenter and Smith, 1972) and the coining of the term 'Great Pacific Garbage Patch' to describe the accumulation of plastic in the North Pacific Subtropical Gyre (Moore et al., 2001). Since then, there have been numerous publications describing and documenting the presence of microplastics (Thompson et al., 2004) and the first long-term, 25-year time series documenting plastic content in surface waters (Law et al., 2010). In 2015, a synthesis paper estimated the contributions of 192 individual countries to the mass of mismanaged plastic waste generated in 2010 (Jambeck et al., 2015). Their results showed that although many developed nations have relatively low rates of mismanaged waste (2%), their higher daily per capita plastic waste generation (prior to waste management, recycling or incineration) results in substantial quantities relative to the total amount of plastic waste. In view of these findings, there is a continued need to improve countries' reporting towards this target to enable collective global action on waste management.

**SDG target 14.2:** By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans

Globally, countries that responded to the GOSR2020 questionnaire indicated that they have specific activities contributing to the sustainable use of ocean resources and/or have developed a blue/ocean economy strategy (Figure 6.6). This demonstrates a global awareness and that attempts are being made to focus on sustainability in ocean development strategies. In line with the findings of Figure 6.6, several countries in Europe and Northern America and Sub-Saharan Africa reported mechanisms to assess the achievement of SDG target 14.2 (Figure 6.5).

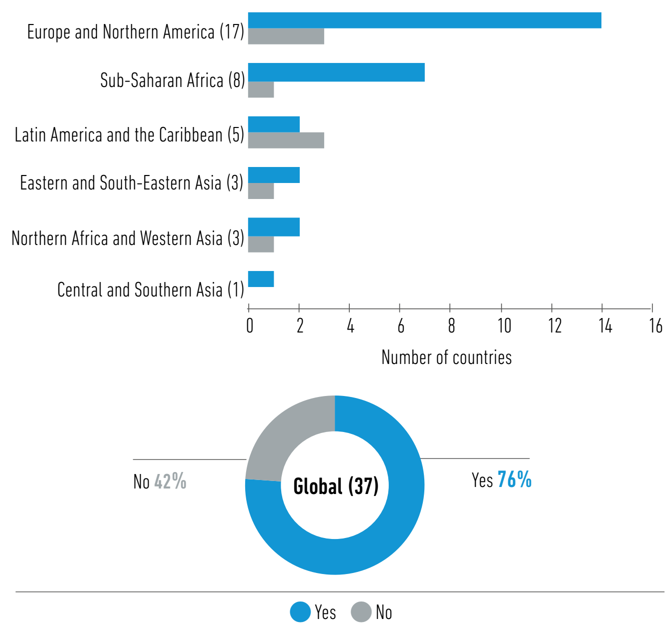


**Figure 6.6.** Distribution of countries which reported conducting specific activities in relation to the sustainable use of ocean resources and/or developed a blue/ocean economy strategy at the global level by SDG regional groupings.
*Source:* Data based on the GOSR2020 questionnaire.

These strategies (Figure 6.6) range from a bioeconomy strategy in Italy and a blue belt initiative in Morocco to Operation Phakisa in South Africa. Sustainable management of marine and coastal ecosystems is also enshrined in the marine spatial planning process that is well advanced in several countries and currently being taken up in less developed regions of the world. Marine spatial planning (MSP) presents a way of developing strategies to balance conservation and sustainable use of the ocean through spatial and temporal allocation of areas for various uses, while ensuring they retain their ecosystem services.[8]

One aspect of MSP is the establishment of Marine Protected Areas (MPAs) to ensure the conservation of marine species and habitats. Moreover, there are a variety of area closures used for region-specific applications, such as Locally Managed Marine Areas (LMMAs).

6 See http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-24-s20jp2019-1.pdf.

7 See Implementation Plan for the United Nations Decade of Ocean Science for Sustainable Development Version 2.0 https://oceanexpert.org/document/27347.

8 See http://msp.ioc-unesco.org.

Several countries have policies for sustainable use of ocean spaces directed towards supporting aquaculture. For instance, Canada has the Fisheries and Aquaculture Clean Technology Adoption Program, which aims to invest CA$20 million over a 4-year period from 2017 to 2021 to assist Canadian fisheries and aquaculture industries in improving their environmental performance.

In order to ensure the safety of aquaculture products and the health of the marine environment, mussel watch programmes were started in the mid-1960s. In these programmes, mussels are used to monitor levels of contaminants and toxic algae in the water column to ensure that they remain within acceptable limits. Over the years, however, ocean science detected new contaminants in the ocean, such as new generation pesticides, pharmaceutically active compounds, antibiotics and new pathogens, which may have adverse impacts on human health (Rodriguez y Baena and Thébault, 2007).

Scientific assessments have shown that healthy coral reef ecosystems have the capacity to dissipate up to 97% of wave energy reaching the shoreline (Meriweather et al., 2018) and they contribute to the formation of beach sands (Shaghude et al., 2013). Their functionality is threatened by ocean warming, ocean acidification, dredging and pollution, among other anthropogenic factors, and there are concerted efforts worldwide to restore degraded reef areas. Seagrasses, which in tropical regions are located between mangroves and corals, are important in sediment retention, dissipation of wave energy and carbon storage. However, seagrass restoration efforts are still in their infancy, with many trials in different parts of the world showing mixed levels of success based on the specific type of stressor to the ecosystem (Meriweather et al., 2018).

In 2019, in recognition of the need for worldwide attention to degradation of ecosystems, the United Nations General Assembly (UNGA) proclaimed 2021–2030 as the Decade on Ecosystem Restoration. This is a call to promote the conservation and restoration of ecosystems. The UN Environment Programme (UNEP) and Food and Agriculture Organization of the United Nations (FAO) are mandated to lead the implementation of actions within this decade. The vision of the Decade on Ecosystem Restoration is to scale up scientifically supported, previously mentioned restoration efforts to large areas covering millions of hectares.

All modes of adaptation and mitigation require efforts to conduct institutional, individual, socio-cultural, engineering, behavioural, and/or ecosystem-based measures simultaneously. The effectiveness and performance of different adaptation options across spatial and social scales are influenced by their social acceptance, political feasibility, cost-efficiency, co-benefits and trade-offs (Jones et al., 2012; Adger et al., 2013; Eriksen et al., 2015). Furthermore, the management of marine ecosystems can be a viable low-tech, cost-effective adaptation strategy that would yield multiple co-benefits from local to global scales, improving the outlook for the environment and people in the future (Roberts et al., 2017).

### SDG target 14.3: Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels

Figure 6.5 shows the number of countries which have reporting mechanisms in place to address SDG target 14.3 on ocean acidification. In total, only 16 have developed these to date, with 5 countries situated in the Europe and Northern American region and 5 in the Sub-Saharan region.

The ocean has taken up between 20–30% of total anthropogenic $CO_2$ emissions since the 1980s. From the end of that decade, there has been a decline in the open ocean surface pH of 0.017–0.027 pH units every ten years — a process called ocean acidification (IPCC, 2019). Ocean acidification puts marine ecosystems at risk due to the effects of lower pH and lower carbonate ion availability on marine organisms (Orr et al., 2005; Gehlen et al., 2011; Kroeker et al., 2010). Ocean acidification affects the habitable area and biodiversity of coastal ecosystems, as well as ecosystem functioning and services (IPCC, 2019). Together with ocean warming and deoxygenation, ocean acidification can lead to dramatic changes in ecosystem assemblages, biodiversity, population extinctions, coral bleaching and infectious disease, change in behaviour (including reproduction), as well as redistribution of habitat (e.g. Gattuso et al., 2015; Molinos et al., 2016; Ramírez et al., 2017). Marine heat waves, combined with extremes in deoxygenation and acidification can cause unexpectedly rapid and dramatic change with respect to marine biodiversity and ecosystem functioning (Frölicher et al., 2018; Smale et al., 2019).

For coastal areas, the pattern of ocean acidification is often complicated by natural processes like freshwater input, coastal upwelling, biological activities and temperature changes, among others. These factors make it more difficult to predict and manage responses to ocean acidification in the highly dynamic and productive coastal areas.

In recent years, there has been a host of international efforts towards supporting and implementing a global system for observing ocean acidification. The monitoring of surface ocean pH has become a focus of many international science initiatives, such as the Global Ocean Acidification Observing Network (GOA-ON) (Newton et al., 2013). In order to detect ocean acidification, observations must be made with a frequency that is adequate for describing variability and trends in carbonate chemistry. Only this can help to deliver critical information on the exposure to ocean acidification and its impacts on marine systems. It is also indispensable to increase ocean science capacity all over the world, so that ocean acidification observation data are of sufficient quality and complemented with comprehensive metadata information to enable integration with data from other sites, at the regional and at the global level.[9] IOC-UNESCO is the UN organization responsible for the SDG Indicator 14.3.1, which measures progress towards SDG target 14.3.

However, in order to develop appropriate adaptation measures for ocean acidification, and to mitigate the effects, multiple parameters must be taken into account, including the extent and rate of ocean acidification, climate change, risk attitudes and social preferences of individuals and institutions (Adger et al., 2009; Brügger et al., 2015), as well as access to financial support, technical and human capacities (Berrang-Ford et al., 2014; Eisenack et al., 2014).

**SDG target 14.4:** By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics

Ten countries in the European and American region, as well as six in the Sub-Saharan African region, said that they had reporting mechanisms for SDG 14.4 in place (Figure 6.5), which indicates a recognition in these countries for the need to develop and implement sustainable fisheries management practices.

Among the many services provided by the ocean, fisheries and aquaculture are notable for steadily increasing their contribution to food security, livelihood and income (FAO, 2020). And while fisheries and aquaculture historically were limited to coastal areas, technology has made it possible for these activities to move offshore into deeper waters (Mengerink et al., 2014), including international waters, where there is little regulation and enforcement to ensure sustainable practices.

After the expansion of the territorial seas and the declaration of the 200-mile Exclusive Economic Zones (EEZs) under the 1982 UN Convention on the Law of the Sea, many coastal nations sought to expand their fishing fleets to take advantage of their new ocean territory and the resources therein. In order for these nascent industries to compete with the established commercial fisheries, governments provided subsidies to help build the industry in their countries. As industry expanded and increased its capacity, coastal fisheries' yields in some regions began to decline due to overfishing, incentivizing those with the capability to move farther offshore. Many countries responded with increased regulation to better manage their resources and to better match the catch of fish with the available resource. However, some subsidies persist that sustain fisheries as stocks decline and finance the expansion of fisheries into international waters, in some cases pursuing fisheries in territorial waters of other coastal nations that lack capacity either for fishing offshore or for patrolling their territorial waters (Sakai et al., 2019) leading to illegal, unreported and unregulated (IUU) fisheries.

Interventions to combat IUU fishing have become an international priority. In 2009, the FAO adopted the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (PSMA); this came into effect in 2016 (FAO, 2020). Currently, there are 66 parties to the PMSA agreement. Through adoption of measures targeted towards the entry of foreign vessels into ports, the implementation of PMSA will help to ensure the detection of IUU fishing. This will include measures covering the further investigation of suspicious activity and, importantly, reporting and notification such that the effectiveness of these actions and progress towards eliminating IUU fishing can be monitored.

However, estimating the magnitude of IUU fishing is a complex matter that depends on many factors, such as the type of fishery and the availability of information, and estimates need to be comparable (FAO, 2020). In order to appropriately account for the progress made towards the achievement of the objective to stop IUU fishing, new innovative ways to gather relevant information are needed. This could include development of innovative technologies for improved satellite imagery and tracking, image analysis for vessel identification and location, electronic monitoring, and increased traceability through tests that can determine the species and origin of seafood. This is a concrete example of how, in essence, ocean science remains central to management and the enforcement of law.

[9] See https://oa.iode.org.

The Global Initiative Against Transnational Organized Crime and Poseidon — Aquatic Resource Management Ltd. launched an index to track IUU fishing. This index uses a suite of 40 indicators, with each indicator related to both a 'responsibility' and a 'type'. Coastal responsibilities relate to a state's management of its EEZ. 'Flag' responsibilities are measures states should take to manage vessels they flag. 'Port' responsibilities relate to control of fishing activity in ports. 'General' indicators are those not specific to coastal, flag or port state responsibilities. Types of indicators relate to vulnerability (the risk of exposure to IUU fishing) and prevalence (known or suspected IUU fishing and response) actions by a state to reduce IUU fishing. Data for the indicators are derived from both secondary sources and expert opinion, often based on ocean observation and ocean science.[10]

For many less developed nations, artisanal fisheries provide an important source of income and an essential source of protein for coastal communities. In addition, fisheries are steeped in culture and tradition, with businesses passed down through generations, in much the same way as farming has been handed down through families on the land.

The UN organization responsible for the corresponding SDG Indicator 14.4.1 (proportion of fish stocks within biologically sustainable levels) is the FAO. The indicator is based on FAO assessments of major fishing areas and needs to be adapted for country-level assessment. The assessment of stocks straddling EEZs and high seas relies on data collected through different approaches among the concerned fisheries, from artisanal to industrial scale, and this can be difficult for some developing countries because gathering these data is skill-intensive and expensive. New genetic approaches are being developed, based on analysis of environmental DNA in water samples, that show promise for providing a sensitive and affordable methodology for monitoring both the diversity of fish and potentially the abundance of fish for use by resource managers (Kelly et al. 2017; Liu et al. 2019). New techniques for using autonomous vessels to conduct acoustic surveys of fish abundance are also being developed, which promise to expand data collection capacity without requiring investments in ships.[11] Again, such new methods and techniques are all based on the findings of ocean science.

Regional cooperation is important to ensure that data are collected in a harmonized manner following guidelines on methodologies, standards and operational procedures of estimating and reporting on SDG indicator 14.4.1 (FAO, 2018). Recent results show, however, that progress towards SDG target 14.4 by 2020 is insufficient to meet its objective (FAO, 2019).

### SDG target 14.5: By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information

The GOSR2020 questionnaire revealed that globally IOC-UNESCO Member States prioritized and valued food provision, coastal protection, recreation and tourism as important to their populations (Figure 6.4). Underlying these services are healthy and clean coastal and marine environments, and SDG target 14.5 aims to increase the conservation of these environments to ensure that ocean services continue to be provided. Further analyses show that Europe and Northern America lead in having reporting mechanisms for SDG target 14.5 followed by Sub-Saharan Africa (Figure 6.5).

In January 2018, 3.6% of the ocean, including areas beyond national jurisdiction, were classified as marine protected areas (MPAs), of which only 2% were under total protection (areas where all human activities including fishing are prohibited). There has been the intention to protect another 1.6% and commitments have been made by countries and conservation bodies to protect an additional 2.1% (Sala, 2018). Scientific assessments of fully protected MPAs show an increase in fish biomass and species richness, demonstrating the value of full protection to maintain ocean services such as food provision, coastal protection and recreation/tourism. Effective design, implementation and monitoring of the ecological state of MPAs requires a scientific understanding of the habitats and living resources targeted for protection. Adaptive management, in which the management measure is designed to resolve scientific uncertainties, can be used to develop more effective approaches for areas under protection. In order to achieve SDG target 14.5, future actions should be monitored to document the levels of protection and provide the data necessary to track progress.

Challenges to conservation efforts include competing demands for space for coastal development, a lack of scientific expertise, and the need for funding beyond the implementation phase to study the effects of management actions and adjust as necessary. The journey towards increasing the area and effectiveness of ocean area conservation must include a suite of conservation actions, such as the development of zoning plans

[10] See http://iuufishingindex.net/methodology.pdf.

[11] See https://www.fisheries.noaa.gov/feature-story/autonomous-vehicles-help-scientists-estimate-fishabundance-while-protecting-human.

and biodiversity offsetting[12] which are part of MSP processes worldwide (Meriweather et al., 2018). One possibility is to use MSP to create networks of MPAs, with buffer zones around vulnerable MPAs, and establishing blue corridors to support the exchange between different populations and life stages of the same species. This will also contribute to the achievement of SDG target 14.2 (Rees et al., 2018).

**SDG target 14.6:** By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated (IUU) fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation

SDG target 14.6 addresses policy issues with — at first glance — less direct impacts on ocean science. Yet, because subsidies and IUU fishing lead to the depletion of marine resources, the application of ocean science is necessary to document stock status for use in the development of management and governance regimes. The FAO recently estimated that as much as 20% of the global fish catch originates from IUU fishing,[13] an indication of the scale of this problem for increasing the sustainability of marine fisheries.

Subsidies can damage fisheries if they support an unsustainable level of fishing capacity (Sumaila et al., 2019). However, some subsidies have been considered beneficial. Among these are programmes that lead to investment in natural capital assets and enhance the growth of fish stocks through conservation, and the monitoring of catch rates through control and surveillance measures to achieve maximum long-term sustainable net benefits.

Sumaila et al. (2010) emphasized the critical need to improve the transparency and accountability in subsidy reporting. Greater transparency of the industry's accounts will help quantify the need for subsidies. Increased monitoring of the impact of subsidies on the sector in order to determine which subsidies are the most beneficial would also be helpful.

Since 2001, the World Trade Organization (WTO) has been negotiating rules for fisheries subsidies, with a goal to prohibit subsidies that contribute to overcapacity and overfishing. It is envisaged that a related agreement will be adopted at the 2020 Ministerial Conference.[14]

Based on the results of the GOSR2020 questionnaire, only 11 countries confirmed reporting mechanisms addressing SDG target 14.6 — 5 in Europe and Northern America, 4 in Sub-Saharan Africa, and 1 in both Eastern and South-Eastern Asia, and Northern Africa and Western Asia — making it impossible to measure progress towards the achievement of the target. The sustainable management of fisheries in the future will only be enabled by increasing efforts and policitcal will (Figure 6.5).

**SDG target 14.7:** By 2030, increase the economic benefits to Small Island Developing States (SIDS) and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism

The UN organization responsible for SDG Indicator 14.7.1 is the FAO. While the target promotes the sustainable use of marine resources 'including of fisheries, aquaculture and tourism', the indicator as determined by the IAEG-SDGs[15] focuses on the sustainable use of marine resources by fisheries only. The methodology proposed by the FAO thus measures sustainable fisheries as a percentage of the GDP.[16] Of the 39 countries answering the relevant question in the GOSR2020 questionnaire, only 6 appear to have a reporting mechanism in place relating to SDG target 14.7 — 4 in Sub-Saharan Africa and 2 in Europe and Northern America — highlighting the insufficient data base for assessing progress towards the target so far.

In focusing on SIDS, it is important to take a holistic approach rather than a single sector approach. SIDS often have extensive networks of national protected areas and their governments are working towards a protection of a majority of their EEZs. Ocean management and governance is, however, a complex task, which ought to consider political, social, economic and environmental systems, supported by applied ocean science (Prakash et al., 2019). This type of ocean science generates knowledge about the local and regional systems, allowing already developed countries around the world to apply integrated ecosystem management and integrated spatial management. At the local level, Pacific societies have used local management tools, such as protecting some areas from fishing pressures, for

[12] Biodiversity offsets are measurable conservation outcomes designed to compensate for adverse and unavoidable impacts of projects, in addition to prevention and mitigation measures already implemented.

[13] See http://www.fao.org/port-state-measures/en.

[14] See https://www.wto.org/english/tratop_e/rulesneg_e/fish_e/fish_e.htm.

[15] Inter-agency and Expert Group on SDG Indicators.

[16] See https://unstats.un.org/sdgs/metadata.

generations. Locally Managed Marine Areas, with their strong cultural foundation, are commonly used tools in this regard. Country scholarships and long-term leadership opportunities that recognize the expertise of residents and citizens of SIDS in solution design and proposal development need to be further fostered.

In order to achieve SDG target 14.7, it is important to acknowledge that aquaculture is currently the world's fastest growing food industry and now accounts for over 50% of the total global seafood supply. However, aquaculture, as mentioned previously, faces immense challenges in the future. As part of the Sustainable Development Impact Summit,[17] several sustainable technologies requiring investments in related ocean science have been discussed, including: moving aquaculture into land-based recirculating systems using recirculating aquaculture systems (RAS); offshore aquaculture systems using marine net pens; multitrophic aquaculture installations; and investing in renewable energy sources to power aquaculture.

Ecotourism supports local communities by providing an alternative source of livelihood to the local community that is more sustainable, conserves resources, maintains biological diversity and promotes the sustainable use of resources, thus enabling travellers to experience nature while at the same time conserving the ecological functions of the environment and providing economic benefits. For SIDS, ecotourism supported by ocean science has the potential to protect coral reefs, and nurseries for fish and other marine life, which in turn would support the sustainable use of ocean resources and therefore the overall achievement of SDG 14.

### SDG target 14.a: 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.

Ocean science is the focus of SDG target 14.a. It cuts across all SDG 14 targets.

Again, only 11 countries confirmed reporting mechanisms in place addressing 14.a (Figure 6.5). However, this is a clear underestimation, as data submitted in respect of SDG indicator 14.a.1, shown in Chapter 3, are based on information submitted by 27 countries. IOC-UNESCO is the custodian agency for the respective SDG indicator 14.a.1, which reports the proportion of total research budget allocated to research in the field of marine technology. For some countries, ocean science budgets varied significantly between 2013 and 2017. Over time, 14 countries increased their average budgets, while 9 reduced them, in some cases quite markedly (see Chapter 3). While this proxy indicates increased awareness for the importance of ocean science for sustainable development in some areas of the world, the underlying data base is limited and mainstreaming related data collection and analysis will be required to appropriately identify trends and developments. Funding ocean science is an investment in the future; however, SIDS and LDCs often only have limited capacity to meet the demand for scientific support, resulting in gaps of ocean observation and research in the global South (see Chapter 4 and 5). It is expected that interregional and global partnerships will offer great opportunities to overcome this obstacle. Global meetings that focus on ocean science, in particular the Ocean Decade, provide support to research and enable new networks and a community of scientists who work together to help bridge the technological and financial gaps.

In order to achieve the second part of SDG target 14.a, putting ocean health at the centre of action, new science identifying the existing marine biodiversity, and understanding the causes for change and underlying mechanisms, will need to be conducted. Understanding further what exists and how it is threatened will allow countries to develop sustainable blue economy strategies, ensuring the well-being of coastal communities.

### SDG target 14.b: Provide access for small-scale artisanal fishers to marine resources and market

The indicator of SDG target 14.b is formulated as the 'progress by countries in adopting and implementing a legal/regulatory/policy/institutional framework which recognizes and protects access rights for small-scale fisheries'. The largest proportion of countries reporting on this target is from Sub-Saharan Africa (Figure 6.5), emphasizing the extent to which communities on these coastlines rely on small-scale artisanal fisheries for livelihood support.

SDG indicator 14.b.1 measures the 'access rights' aspect of the target. It is a composite indicator based on FAO member country responses to the survey questionnaire of the Code of Conduct for Responsible Fisheries (CCRF), which is circulated by the FAO every two years to member states, intergovernmental organizations (IGOs) and international non-governmental

[17] See https://www.weforum.org/events/sustainable-development-impact-summit.

organizations (INGOs). This indicator is calculated on the basis of the efforts being made by countries to implement selected key provisions of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (SSF Guidelines — FAO, 2015), as reported in a given year of the survey.

These SSF guidelines are a result of a global bottom-up community consultation process, including different stakeholders such as marine scientists. Between 2011 and 2014, more than 4,000 participants worked together, including representatives of governments, small-scale fishers and fish workers and their organizations, regional organizations, oceanographers and fisheries scientists, development partners and other relevant stakeholders. The outcomes of this process provided the basis for the work of an FAO technical consultation, which finalized the SSF guidelines, providing a fundamental tool to secure sustainable small-scale fisheries and enabling the sector to contribute to eradicating hunger and poverty.

The SDG Indicator 14.b.1, and the SSF guidelines in particular, are illustrative examples of how data and knowledge generated by research contribute to effective decision-making on small-scale fisheries by policymakers, and enable fishing communities and advocates to make a strong case for support in the sector. In this way, research supports implementation of the SSF guidelines and progress towards the achievement of the Sustainable Development Goals.

The UN General Assembly has declared 2022 the International Year of Artisanal Fisheries and Aquaculture (IYAFA 2022), intended to stimulate action on target 14.b by increasing the understanding of the role that small-scale fishers, fish farmers and fish workers play in food security and nutrition, poverty eradication and sustainable use of natural resources. IYAFA 2022 falls within the UN Decade of Family Farming (UNDFF 2019–2028) and the joining of these two is expected to provide greater visibility to small-scale producers.

### SDG target 14.c: Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want

Implementing and enforcing an international 'Law of the Sea' is the objective of SDG target 14.c, again an overarching and cross-cutting target similar to targets 14.a and 14.b. While the achievement of this target is not directly dependent on ocean science, it provides the legal framework for solution-orientated ocean science focusing on the sustainable use of the ocean and its resources.

Figure 6.5 shows the number of countries in the different SDG regions which have reporting mechanisms for SDG target 14.c.

Several decisions undertaken in the context of the United Nations on global issues, such as mitigating and adapting to climate change, and conserving and sustainably and equitably using biodiversity, are informed by ocean science. For example, in the area of climate change, findings from scientific research and systematic observations have allowed the calculation of the global carbon budget and the ocean contribution therein, as well as variations in emissions and in how the ocean behaves subsequently, and this information has been used as a basis for negotiations among party members to the United Nations Framework Convention on Climate Change (UNFCCC) and its Paris Agreement. Moreover, the approaches of sustained ocean observations and lessons learned over the years in relation to ocean observation operations have directly informed the 'adequacy report' of the UNFCCC as to how observations can best match the needs of party members for data and information.

Another example of ocean science in action in relation to international decision- and policymaking is the wealth of research findings on biodiversity from the deep seabed, including their implications for health and industry. This knowledge, generated through ocean research, corroborated with scholarly research on the policy implications and applications of such findings, has paved the way to a groundbreaking agreement by the international community to protect and sustainably use the biodiversity of areas beyond national jurisdiction through a dedicated implementation agreement under the United Nations Convention on the Law of the Sea (UNCLOS), for the benefit of current, and especially future, generations.

The communication between ocean science and policy is not a direct one and is mediated by the process of scientific assessments, such as the work of the Intergovernmental Panel on Climate Change (IPCC) and that of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). These 'social' processes, which see the findings of research and observations assessed and digested in a language that is usable by policymakers, provide an essential interface to bridge the ocean science machinery with the political machinery, and this interaction proves of particular importance in relation to the need to tackle pressing unresolved or emerging sustainability issues related to climate change, ocean health and, increasingly, human well-being.

## 6.4. Highlighting some contributions of ocean science to other specific SDGs

It is acknowledged that SDG 14 is linked to the achievement of the 2030 Agenda as a whole, as well as to all other SDGs (ICSU, 2017; UN, 2019). The strength of the relationship with and co-dependence on the other SDGs varies (Singh et al., 2018). Furthermore, working hand in hand with the 2030 Agenda, the Sendai Framework for Disaster Risk Reduction 2015–2030[18] is the roadmap for how we make our communities safer and more resilient to disasters. Many Tsunami and Global Ocean Observing System activities contribute to the achievement of this framework (UN, 2019). In this section, three SDGs including specific targets are highlighted as beneficiaries of ocean science or as contributing to the achievement of SDG 14. These are: SDG 5 with the focus on gender equality; SDG 13 addressing sustainable development in the context of climate change; and SDG 17 highlighting the importance of partnerships. These three SDGs are in line with UNESCO's overall priorities on gender and climate change, as well as desired outcomes and challenges identified during the preparation period of the Ocean Decade.

These linkages are important in assisting policymakers to recognize that policies developed to propel one SDG forward have implications for other SDGs. The relationships documented here are not exhaustive but illustrate opportunities that are available for nations to look at all SDGs as being complementary to each other, rather than as standalone independent units (Le Blanc et al., 2017).

### SDG 5: Achieve gender equality and empower all women and girls

SDG 14 does not specifically address gender, yet women play a critical role in ocean science, fisheries and resource conservation (Agarwal, 2018). In particular, targets 14.4, 14.5, 14.6, 14.7, 14.a and 14.b have linkages to SDG target 5.5 (Le Blanc et al., 2017; Singh et al., 2018). Previous studies have shown the impact on women from structural inequalities in the fishery value chain, vulnerability due to degradation of resources, gendered invisibilities due to gender-blind policies, gendered access barriers to items like credit, education etc., as well as access to governance, where their voice is seldom heard due to customary norms (Österblom et al., 2020). This issue is addressed by SDG target 5.5, which works 'towards women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life', and SDG target 5.c which urges 'to adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels'.

The GOSR2017 showed that women make a big contribution to ocean science and constitute 10% more scientists than in other research areas. These results are confirmed by the GOSR2020 (see Chapter 4). However, female scientists are still under-represented in many categories of ocean science, such as technology development and ocean observation. Efforts to feature women in ocean science and to promote their research will be required to allow business and policy stakeholders to benefit from the intellectual potential of women, which is currently neglected (see Chapter 4). The achievement of SDG 14 requires more women to take part in policy and governance level dialogues. The inclusion of women and girls in education and capacity building opportunities for the blue economy has led to the involvement of more women in blue growth sectors such as shipping, mining and research. There is a need to move beyond what has been documented in the educational achievements of women and translating this into equity in participation in policy and governance frameworks, and into strategic decisions about inclusivity and mainstreaming of gender equality in ocean science, management, conservation interventions, policy and treaty negotiations (Gissi et al., 2018; Österblom et al., 2020). The inclusion of gender equality into the SDG 14 dialogue is important, as it will lead to a shift from equality blindness to equality-activating policies (Österblom et al., 2020).

### SDG target 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

As mentioned previously, the ocean has been documented to be the new frontier in the climate change battle. The ocean absorbs 93% of the heat generated through human-generated carbon dioxide ($CO_2$) emissions and it is becoming warmer and more acidic. The consequences of this can be seen in the extinction of coral reefs, ocean acidification, declining fish stocks and

[18] See UN A/RES/70/1.

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changing weather patterns. Ocean science can mitigate against these climate change effects through support for alternative renewable energy sources, such as scoping for offshore wind energy, research on seaweeds for alternative fuels, support for conservation and restoration of blue carbon ecosystems, and scaling up low carbon feed options (Hoegh-Guldberg, 2019).

LDCs of the world, including many SIDS, are impacted by climate change stressors such as ocean acidification, warming, extreme weather events, sea level rise and change in rainfall regimes, despite the fact that they contribute less than 1% of global greenhouse gases (Meriwether et al., 2018; Singh et al., 2018). These climate change effects impact the provision of food from the ocean, carbon storage ecosystems, erosion, coastal tourism and the aesthetic value of the ocean (Singh et al., 2018). Coastal ecosystems such as mangroves, seagrasses and corals are recognized as providing protective barriers against extreme weather events, and nature-based solutions such as the establishment of MPAs, coastal zone management and MSP are essential tools to safeguard them. These conservation measures form part of SDG target 14.2, which further recognizes the need for restoration of these critical habitats and thus supports nature-based solutions for the protection of the shoreline. In the aftermath of the 26 December 2004 tsunami in the Indian ocean, ecosystem restoration efforts have increased and focused particularly on mangroves, with a strong call for the establishment of buffer areas to safeguard impacts on coastal developments. In addition to this, there is also a call to ensure that there is a cost analysis of nature-based restoration and infrastructure-based solutions (Meriwether et al., 2018), such that the most practical and cost-effective mitigation measures are used. All the management interventions are informed by ocean science.

Furthermore, ocean acidification addressed in SDG target 14.3 is the other side of climate change, as it is also a consequence of increased $CO_2$ concentrations. Each country which aims to mitigate climate change decreases ocean acidification and vice versa. Adapting to climate change means adapting to ocean acidification. Actions based on ocean science at global, regional and local levels help society to combat climate change via supporting adaptation strategies addressing ocean acidification.

## SDG 17: Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

SDG 17 target 17.6, which guides us to 'Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism', is of particular relevance for ocean science. Further to this, SDG target 17.17 'encourages and promotes effective public, public-private and civil society partnerships', building on the experience and resourcing strategies of partnerships, and is therefore an equally relevant target. According to the questionnaires underpinning the GOSR2017 and the GOSR2020, countries contribute to this target in the area of ocean science via, for example, facilitating the participation of external experts in national ocean science projects and policymaking processes (Figure 6.7).

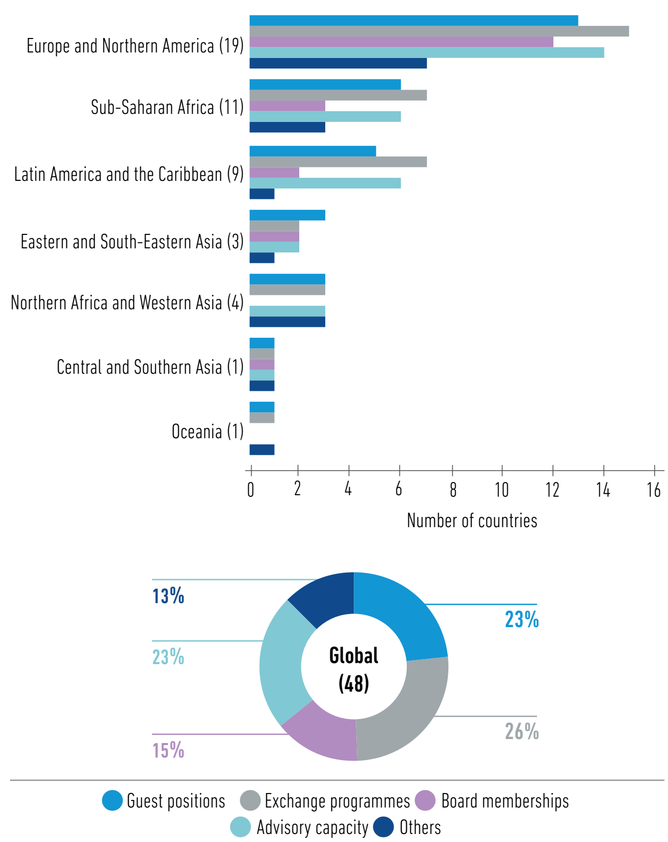


**Figure 6.7.** Distribution of countries which reported to have mechanisms in place to facilitate the participation of outside national experts in national ocean science and policymaking at the global level and by SDG regional groupings.
*Sources:* GOSR2017 and GOSR2020 questionnaires.

The findings from the GOSR2017 and GOSR2020 questionnaires reveal that partnering is happening in all regions of the world, the most popular mode being through exchange programmes, followed by guest positions and partnerships with external experts in an advisory capacity. These results illustrate that partnerships are key for the advancement of ocean science joint programmes, and that they enhance access to technologies that would otherwise not have been available in some countries. Other modes of partnership include consultations, meetings and workshops, cooperation as part of a consortium, and membership of large projects such as Horizon 2020, Fulbright programmes, Marie Curie partnerships and the Partnership for Observation of the Global Ocean (POGO). Beyond projects, regional and international associations of scientists, such as the Scientific Committee on Oceanic Research (SCOR), Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) and The Western Indian Ocean Marine Science Association (WIOMSA), play a huge role in strengthening scientific networks of ocean scientists. Partnerships are further strengthened by the fact that former students from LDCs continue to partner with their laboratories and research groups in developed countries where they studied. Further, multistakeholder partnerships occur in ocean science and they are anchored in technology exchange and capacity development. These cooperations and collaborations ensure that ocean science in SIDS and LDCs continues to progress and that it is able to keep up with global trends.

Although partnerships across different sectors have contributed to the scientific enterprise in the past, they are now recognized as an imperative strategy for more effective resource use and increasing participation in science, supporting their application in policy, e.g. via the promotion of partnerships as a theme for the Global Ocean Observing System 2030 Strategy (IOC-UNESCO, 2019). Governments have historically been the major players in ocean observing systems and in ocean research more generally. However, there are new opportunities for the private and non-profit sectors to contribute to and become involved in various aspects of the system, from new technology development and shared infrastructure to data collection, analysis and development of information products and applications. POGO[19] is an example of an international partnership among oceanographic institutions in support of the integrated global ocean observing system.

Furthermore, several private foundations have undertaken various aspects of the ocean science enterprise as part of their mission (see Chapter 3).

[19] https://www.ocean-partners.org.

## 6.5. Conclusions

Research and scientific monitoring furnish the information for nations to sustainably benefit from the ocean's provisioning of food, tourism and coastal protection, as indicated in the regional responses to the GOSR2020 questionnaire. However, the value of conservation for biodiversity and the aesthetic value for human health and well-being are equally important, and ocean science can also help society to understand and protect these values, which in turn can inform societal choices affecting the management and sustainability of ocean and coastal areas that are not based on solely economic considerations (see Chapter 3).

As stated earlier, more than 60% of the countries responding globally to the GOSR2020 questionnaire indicated that a focal point for SDG 14 was assigned. However, the extent to which inter-sectoral/ministerial coordination mechanisms develop and implement related policies remains unclear.

Based on the assessment here, it is obvious that many targets of SDG 14 might not be achieved on time, particularly targets 14.2, 14.4, 14.5 and 14.6, which were agreed to be achieved by 2020. Half of SDG 14 indicator methodologies remain at Tier II (Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries). As of 2020, SDG indicators 14.4.1, 14.5.1, 14.6.1, 14.7.1 and 14.b.1 are classified as Tier I (Indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by countries for at least 50% of countries and of the population in every region where the indicator is relevant), which is expected to expand the current data base to evaluate progress made towards these targets.

With respect to SDG target 14.1, it is clear that having a reporting mechanism for the reduction of pollution is an important commitment to taking action and enforcing policies that control the use of pollutants, such as plastics, thereby keeping our ocean clean. SDG target 14.2, which is anchored around the sustainable management and protection of marine and coastal ecosystems through restoration actions, attracted a great deal of regional attention when agreed upon and will be one of the areas which will hopefully benefit from the actions undertaken during the UN Decade on Ecosystem Restoration. Similarly, SDG target 14.3 on ocean acidification has received a high degree of global attention and the related science is developing fast, indicating that relevant reporting will improve and that corresponding actions are/will be taken to reduce the carbon footprint of nations. While the SDG indicator

14.4.1 is now Tier I, SDG target 14.4 on the regulation of IUU and destructive fishing practices remains elusive, as several countries which support IUU fishing activities do not have reporting mechanisms for this target. Established reporting mechanisms in SDG target 14.5 focusing on the conservation of ocean resources are expected to support the achievement of the objective. Like SDG target 14.4, SDG target 14.6 on subsidies is largely subject to political will, and it must be ensured that the newly established reporting methodologies will receive both scientific and political support. SDG target 14.7 aims to further support the sustainable management of fisheries, aquaculture and tourism in SIDS; this will only be achievable with a greater focus on ensuring that SIDS are globally supported in taking action. As already stressed, ocean science is key to all SDG 14 targets, and SDG target 14.a provides the opportunity to focus on respective actions. The Intergovernmental Oceanographic Commission of UNESCO plays a key central role in fostering the improvement of ocean health through increasing scientific knowledge. Certainly, the development of research capacity and transfer of marine technology (TMT) need to be equalized through all regions of the IOC-UNESCO network, and the upcoming Ocean Decade will provide numerous opportunities for this. The development of strategic measurable actions that can be assessed at the end of the Ocean Decade will be essential. Based on the assessment presented here, the largest proportion of countries reporting on SDG target 14.b are from Sub-Saharan Africa, indicating a high reliance on small-scale artisanal fisheries to support the livelihoods of communities on these coastlines. These fisheries are in nearshore areas, where the implementation of conservation and fisheries management actions highlighted in several other SDG 14 targets (SDG targets 14.2, 14.4 and 14.5) may cause conflicts and exclusions during enforcement. It is therefore necessary to ensure that actions taken are complementary to each other and do not cause the displacement of small-scale fishers who need nearshore areas for their survival. The analysis of SDG target 14.c highlights the legal frameworks required for the conservation and sustainable use of the ocean and its resources. Its achievement will be essential to providing the enabling framework for solution-orientated ocean science.

With only 25 countries responding to the relevant questions, the assessment of the current status of the SDG 14 and its targets is limited. However, gaps in the implementation of SDG 14 are evident. In addition, gender equity is assumed, as no target addresses gender equity and its mainstreaming, which are critically important in ensuring equitable access to resources.

Partnerships continue to strengthen ocean science and there is a need to explore new relationships with the private sector and businesses to enhance the application of knowledge through strong ocean literacy and citizen science programmes, which will ensure that the ocean begins to matter to the nations of the world.

True progress towards realizing SDG 14 will require the delineation of steps for reaching the targets, identification of discrete milestones, and possibly the monitoring of additional national and regional indicators. As described in this chapter, many of the SDG 14 targets and other SDGs require scientific information to develop these steps, identify milestones and measure progress. For example, SDG target 14.3: 'Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels', will require scientific information on the spatial and temporal parameters of ocean acidification, which is dependent upon a scientifically designed measurement scheme providing the necessary geographical and temporal coverage, utilizing globally applied observation techniques and sampling protocols. The goal is to obtain data, which will then be incorporated in science and management applications.

Advances in ocean science have been and will continue to be propelled forward by advances in technology. The development of new sensors and remote platforms has provided 'new eyes' on the ocean, allowing scientists to track the ocean's physical, chemical and biological properties at a frequency and scale that would have been impossible when ocean sampling was limited to ship-based measurements. New technologies have often reduced the costs of measurements, which increases opportunities for developing nations to enhance their capabilities for data collection, an essential component for advancing SDG 14.

As shown, analysis and application of data remains a challenge, but there are avenues for rapid advancement through broad access to data repositories, cloud-based computational resources and, most critically, training and collaboration opportunities through online networks of scientists, resource managers and educators (see Chapter 7). Undoubtedly, the achievement of SDG 14 will enhance the accomplishment of the objectives of all the other SDGs and therefore it is imperative to ensure that the overarching nature of this goal is recognized.

The upcoming Ocean Decade is expected to renew interest in and focus on access to ocean data and information tailored to stakeholder purposes, obtained via co-designed research and observation. Capacity development and TMT activities and actions complementing thematical aspects of ocean science, conducted at national, regional and global levels in the framework of the Ocean Decade, will strive to develop transformative ocean science solutions for sustainable development, better connecting people and our ocean.

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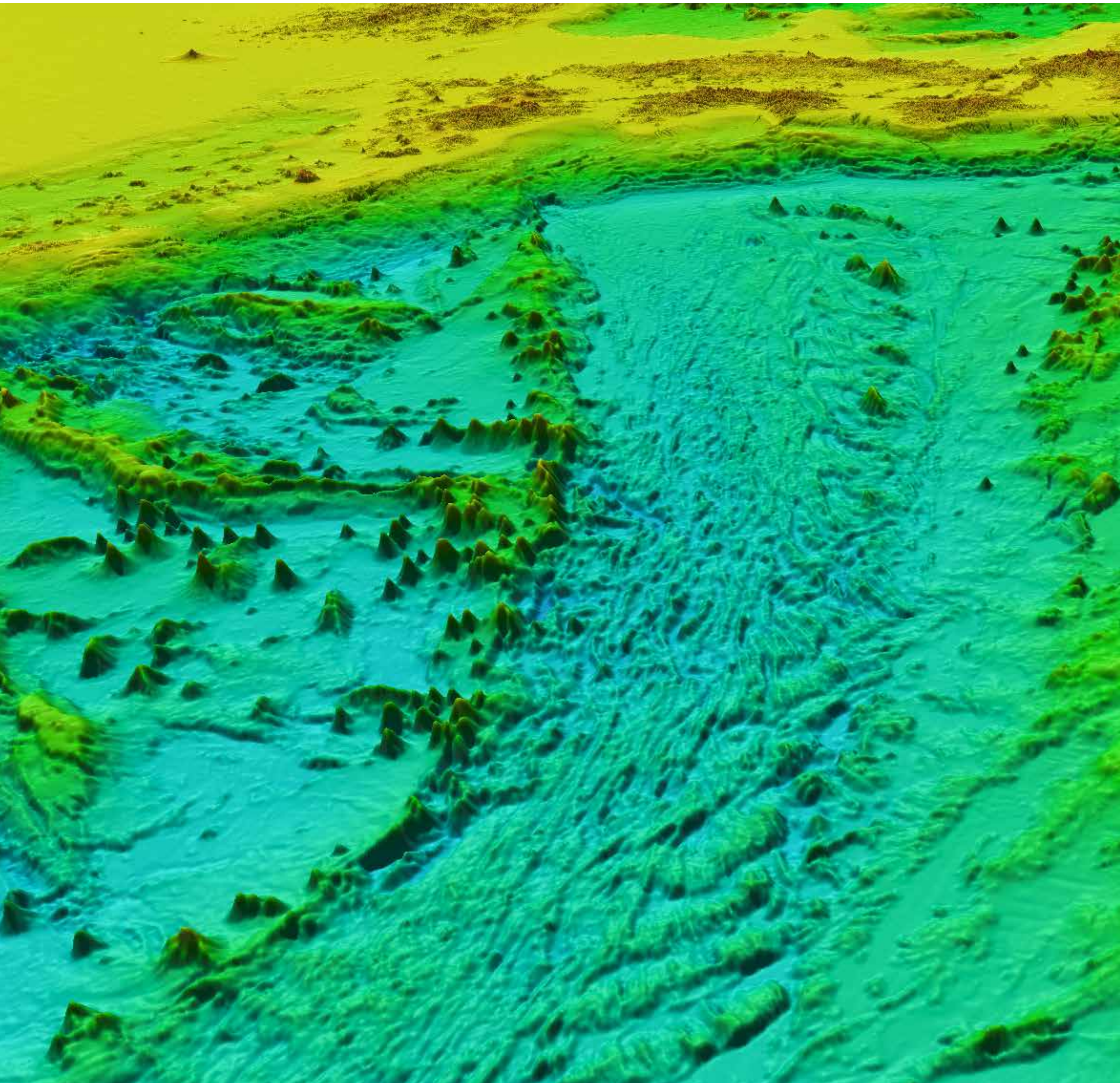

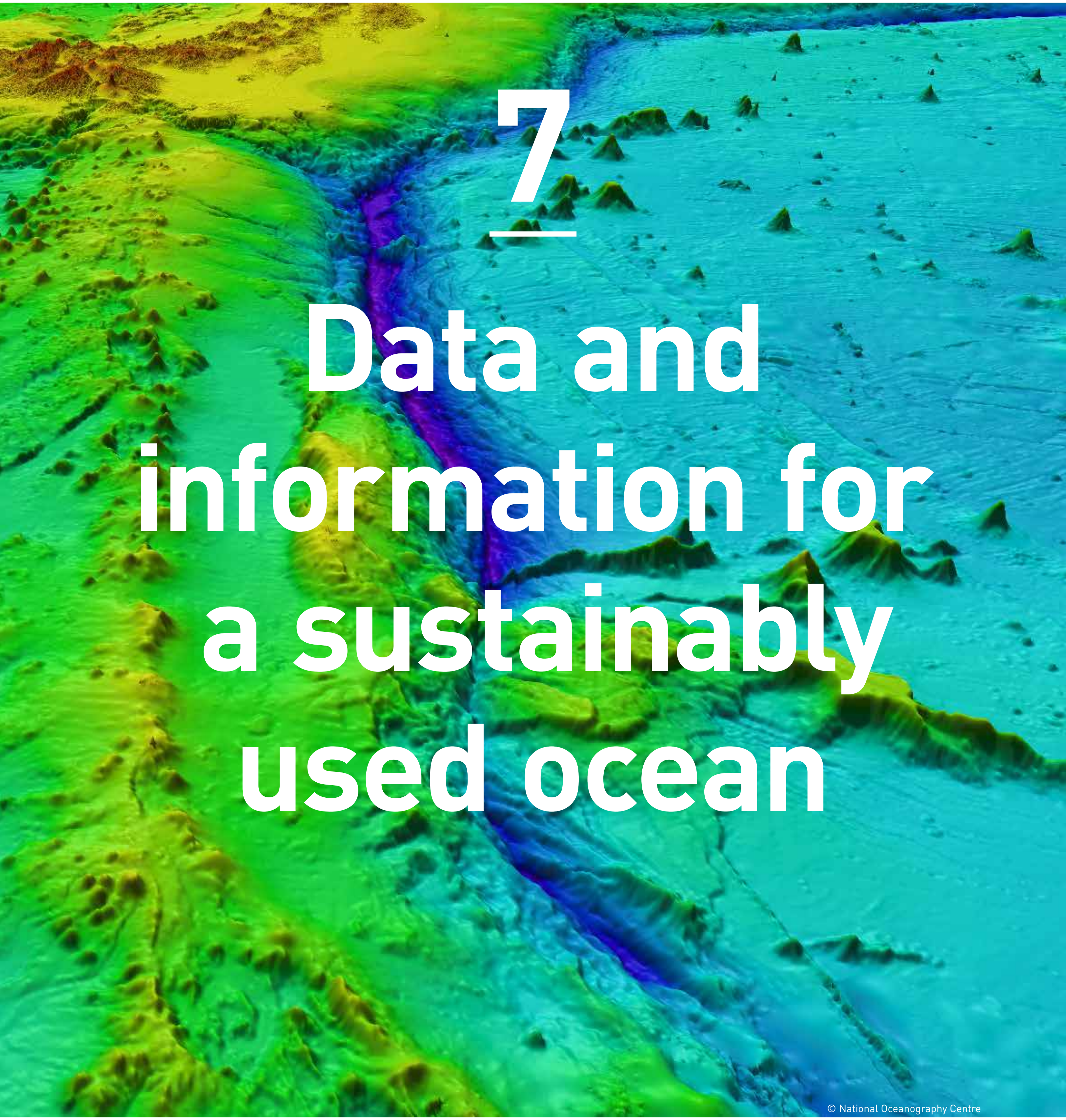

# 7

# Data and information for a sustainably used ocean

# 7. Data and information for a sustainably used ocean

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## 7.1. Introduction

Knowledge of the ocean — including its cycles, its interactions with the atmosphere, land and humans, its current and future ecosystem services — is derived from state-of-the-art science. Unprecedented amounts of data and diversity of types of data have been produced via *in situ* observations and raw data analysis, such as mapping, modelling and forecasting by the scientific and non-academic sector. Therefore, new innovative strategies have to be developed in order to manage and use these data and information, whereby all nations, stakeholders and citizens have access to related ocean data and information technologies, and the capacities to inform their decisions (Ryabinin et al., 2019). First and foremost, availability and access to data and information are essential for describing the current state, variability and change of the ocean which can then be combined, in a science-based and integrated approach, with a wide range of data synthesis and modelling efforts. Newly acquired understanding and knowledge provide the foundation for tailored and responsive decision-making for societal and sustainable economic benefit, while limiting environmental and ocean change, and supporting the development of adaption strategies for ongoing and future changes.

Recent international conventions, treaties, agreements and services have called for countries to adopt science-based and informed decision-making, thus highlighting 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 ocean science. The UN Decade of Ocean Science for Sustainable Development (2021–2030) (the 'Ocean Decade'), adopted in 2017 by the UN General Assembly (UNGA) through its Resolution A/RES/72/73, aims to generate the scientific knowledge, underpinning infrastructures and partnerships needed to inform policies in support of all the Sustainable Development Goals (SDGs) of the UN 2030 Agenda for Sustainable Development. It is stated that the Ocean Decade must lead to a data-sharing revolution and develop guidelines for implementing a data system which is FAIR — findable, accessible, interoperable and reusable (Tanhua et al., 2019; Wilkinson et al., 2016). It is envisaged that the Ocean Decade will establish an ethical agreement to ensure a timely release and open sharing of data and information, which will serve the societal outcomes, in particular: 'A transparent and accessible ocean with open access to data, information and technologies' (IOC-UNESCO, 2020).

The demand for ocean science, data and information is particularly apparent with the knowledge requirements of the UN 2030 Agenda for Sustainable Development targets and SDG 14 indicators, which relate to the conservation and sustainable use of the ocean, seas and marine resources. Similar demands exist in other forums, including the Sendai Framework for Disaster Risk Reduction 2015–2030, the SIDS Accelerated Modalities of Action (SAMOA) Pathway, the decisions adopted under the 1992 United Nations Framework Convention on Climate Change, such as the 2015 Paris Agreement, and many other marine-related initiatives led by international bodies. Furthermore, in 2015 the UNGA adopted 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 in areas beyond national jurisdiction (BBNJ), which has prompted discussions at the international level on effective ways and means to access and use ocean data, e.g. marine biodiversity data, information and products. During the BBNJ negotiations, countries repeatedly emphasized the need for a clearing house mechanism on biological diversity of marine organisms in the areas beyond national jurisdiction. In this context, the Ocean Biodiversity Information System (OBIS)[1] has been recognized by states as a critical element.[2] In addition to this, ocean data are required to provide everyday services, such as weather and natural hazard predictions and forecasts, as well to develop and model future climate scenarios delivered by many national and international organizations/consortia, such as the World Meteorological Organization (WMO), Tsunami warning systems and the Intergovernmental Panel on Climate Change (IPCC).

It is obvious that in order to characterize ocean variability and change, the international scientific community needs access to the most complete and reliable scientific databases of historical physical, chemical, geological, biological oceanographic observational and modelled data, including information about relevant human activities. In the past, however, the different types of oceanographic data have been collected by different observing systems for different purposes, and data were stored separately in specialized databases.

To date, different ocean-observing systems provide access to a large amount of data, measured *in situ* and remotely: 'Essential Climate Variables' (ECVs),[3] as defined by the Global Climate Observing System (GCOS), and 'Essential Ocean Variables' (EOVs),[4] as outlined by the Global Ocean Observing System

1 Originally, OBIS was established as Ocean Biogeography Information System in the project Census of Marine Life (CoML).

2 UNGA A/RES/72/249.

3 See https://gcos.wmo.int/en/essential-climate-variables/about.

4 See https://www.goosocean.org/index.php?option=com_content&view=article&id=170&Itemid=101.

(GOOS). These systems support modelling exercises, which in turn also produce 'big data'. The Argo project[5] initiated in early 2000s, for example, is generating a large amount of global temperature and salinity water column profiles and data for additional biogeochemical parameters are starting to be collected. However, the quantity and complexity vary considerably among the variables, and related programmes are again often designed to collect only certain variables. Some key EOVs are in place — temperature, salinity, ocean currents, nutrients, dissolved organic and inorganic carbon, dissolved gases such as oxygen, transient tracers, plankton, etc. With the application of effective and innovative FAIR data management, the integration into common data metadata standards and quality-controlled databases, the utilization of ocean data and metadata for scientific products, e.g. gridded products, re-analyses, SDG and global climate indicators, will increase. These products, rather than raw data, are the basis for many policy decisions and economic development.

International projects and associated databases, such as the World Ocean Database (WOD), the Global Oceanographic Data Archaeology and Rescue (GODAR), the Global Temperature and Salinity Profile Programme (GTSPP), the Global Ocean Surface Underway Data Pilot Project (GOSUD), the International Quality Controlled Ocean Database (IODE-IQuOD) and OBIS have stimulated the exchange of historical and modern oceanographic data over the past decades (Table 7.1). Furthermore, these projects have promoted synergy, leading to the development of quality-control procedures and the integration of research-quality data at different spatial scales (local, regional and global), resulting in a continued increase of ocean data stored in these databases. In parallel, the Marine Climate Data System (MCDS) and Global Data Assembly Centres (GDACs) serve as data flow mechanisms to support the integration of oceanographic data streams through enhanced regional and global coordination.

Currently, the Intergovernmental Oceanographic Commission (IOC) programme International Oceanographic Data and Information Exchange (IODE) is developing the concept of the IOC Ocean Data and Information System (ODIS), an e-environment system which will enable users to discover and access coastal and ocean data, information and associated products or services provided by IOC-UNESCO Member States, projects and other partners associated with IOC-UNESCO. IODE will contribute to ODIS through works with existing stakeholders, linked and not linked to the IOC-UNESCO, to improve the discovery, access, semantic and technical interoperability of existing data and information by leveraging established solutions where possible.

[5] See http://www.argo.ucsd.edu.

**Table 7.1.** Databases and data-related projects established by or maintained with the support of IODE.

| Database name | Year of establishment |
|---|---|
| Global Temperature and Salinity Profile Programme (GTSPP) | 1990 |
| Global Oceanographic Data Archaeology and Rescue (GODAR) | 1993 |
| World Ocean Database (WOD) | 1994 |
| Ocean Biodiversity Information System (OBIS) | 2000 |
| Global Ocean Surface Underway Data Pilot Project (GOSUD) | 2007 |
| International Quality Controlled Ocean Database (IODE-IQuOD) | 2015 |
| IOC Ocean Data and Information System (ODIS) | Under development |

*Source:* Compiled by authors from related databases.

Since 1999, the IOC-WMO Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) has promoted closer cooperation of oceanographic data and information management with the meteorological community. Successful cooperative activities by the JCOMM/IODE Expert Team on Data Management and Practices (ETDMP) include efforts such as the development of Ocean Data Standards (ODS) and technical assistance for updating the strategy of the Marine Climate Data System (MCDS). Following JCOMM's significant contributions over 20 years, IOC-UNESCO and WMO decided to further enhance cooperation by establishing the IOC-WMO Joint Collaborative Board (JCB), while discontinuing JCOMM. It is expected that ongoing joint activities implemented under the framework of JCOMM will be maintained — or even enhanced — within the new collaborative structure of JCB. The scope of work of the new board will go beyond observations and encompass the whole value chain of joint activities between the two organizations, from research to observations, data collection and analysis, modelling and predictions, and the delivery of related products and services.

As mentioned earlier, different types of oceanographic data have previously been collected over time by different observing systems for different purposes, mostly on a project basis. This means that once a project has ended, both the collection of new data and management of past data are neither secured nor ensured. Thus, the main challenges and potential gaps with respect to the collection, management and exchange of data and information as pointed out in the GOSR2017 still remain: (i) sustaining and extending robust ocean observing systems that include EOVs; and (ii) ensuring that observational and modelled data collected by different countries are made accessible in an open and timely manner through robust databases using common data and metadata standards and best practices — and served using interoperable data delivery systems. Only an improved understanding of data processing and management will be indispensable to serve future needs posed by governments and the private sector. Similar issues were included in the recommendation prepared by the Scientific Academies of G20 countries for the Osaka G20 meeting held in 2019 (Science 20, 2019).

Therefore, this chapter aims to provide some of the baseline information required to overcome the current shortcomings and to achieve the objectives outlined above. It presents the current status of ocean data and information management collected and assembled for global ocean science, based on the analysis of answers submitted to the GOSR2020 questionnaire as well as information provided directly by the IODE programme office. Finally, it addresses the strengths and challenges with regard to ocean science data in light of the upcoming Ocean Decade.

## 7.2. National ocean science data management infrastructures and strategies

The term 'data management' encompasses 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, curation and management, as well as the dissemination of archived data to those who seek it (Austin et al., 2017).

In the GOSR2017, raw data alone are insufficient to address a specific problem. Only the provision of metadata alongside the data will allow appropriate use and application. Metadata describe the auxiliary information around the measurement or data record: how, where, the instrumentation used, collection procedures, precision and calibration, to name but a few. Assembling both data and metadata requires a strong connection between data collectors, data managers and scientific experts. With this in place, a safe and long-term (i.e. eternal) storage of data and metadata will allow present and future generations to access ocean science data and information. However, to facilitate the use of ocean data, data managers also have to focus on the user community, which is not restricted to the data providers but also includes scientists, engineers, the public (e.g. policymakers) and the private sector. The capacity of these different groups to handle digital data, especially in complex data structures, varies. Nevertheless, it is vital that all users have the opportunity to judge the appropriateness (e.g. relevance, quality, reliability) of the data received for the problem they are addressing (see Box 7.1).

Beyond delivering the observational data in digital form, data systems and archives also give access to information via data products (IOC-UNESCO, 2017), for example projections and forecasts of future and past environmental status, maps of data availability, maps of measurement types (e.g. sea-surface temperatures), statistical analyses of the contents of archives, such as error rates detected in processing, and so on.

Data management integrates many components, and good data management requires expertise, which relies on sustained human and financial support. International commitments and strong science community supports are prerequisites for stable and sustained ocean data management systems, as a building block for progress in ocean science and the sustainable use of the ocean.

## 7.3. IODE network of data and information infrastructures

Under the umbrella of the IODE, the number of National Oceanographic Data Centres (NODCs) has grown steadily since 1961 to the current total of 57 (active) in 2020 (Supplementary material 7.1). 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, is increasing (Tanhua et al., 2019; Snowden et al., 2019). The IODE network collaborates with these data centres under the umbrella of Associate Data Units (ADUs),[6] 30 of which have been established since 2013 (Supplementary material 7.2); an additional 5 Associate Information Units (AIUs)[7] have been established since April 2019 (Supplementary material 7.3). According to the submissions to the GOSR2020 questionnaire (38 relevant responses), about 90% of the centres maintain regional collaboration and almost 80% have established international collaboration outside the IODE network (Figure 7.1).

6 The projects established under the IODE Associate Data Units (ADUs) are intended to bring in the wider ocean research and observation communities as key stakeholders of the IODE network.

7 IODE Associate Information Units are defined as national programmes, institutions or organizations, or regional or international projects, programmes, institutions or organizations (including academia) that carry out marine information management functions, and/or provide marine information services/products.

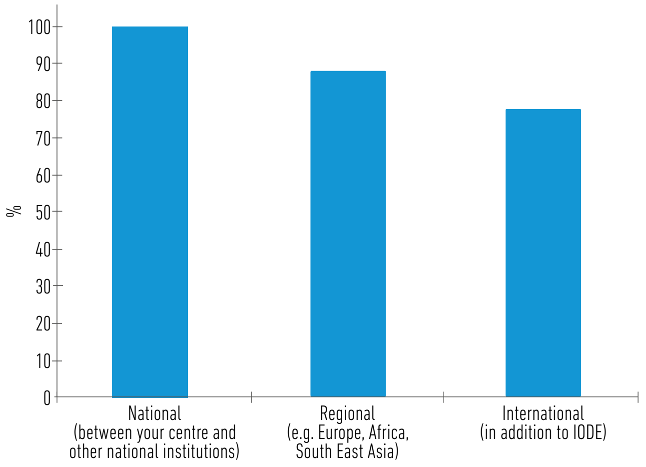


**Figure 7.1.** Proportion (%) of national data centres involved in different types of collaboration (multiple answers possible, 38 respondents).
*Source:* Data based on the GOSR2020 questionnaire.

Overall, ocean science data centres hosted in different countries all over the world mostly manage physical data, followed by chemical data and biological data (Figure 7.2); these results are similar to the ones obtained in the GOSR2017. Data referring to the management of marine pollutants and fisheries are now reported by more than 70% respondents, compared to less than 50% in 2017. Less than half of the assessed data centres collect socio-economic data, even though there is an increasing need for multi- and inter-disciplinary data and information in the light of the UN 2030 Agenda and towards the Ocean Decade.

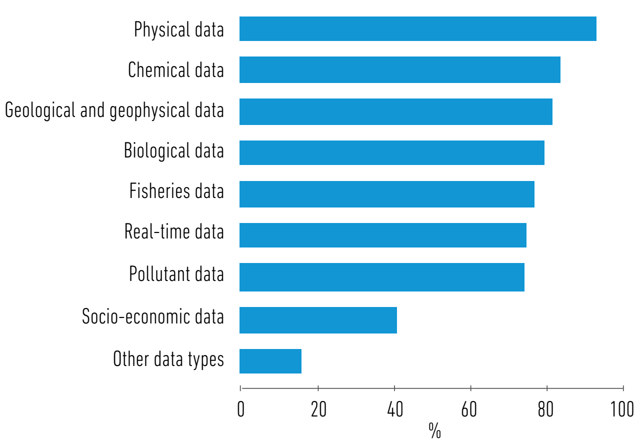


**Figure 7.2.** Proportion (%) of observational data types regularly collected and managed by countries' data centres (multiple answers possible, 44 submissions).
*Source:* Data based on the GOSR2020 questionnaire.[8]

[8] Real-time data is information that is delivered immediately after collection based on the measurements of chemical and physical parameters.

Most data centres concentrate their effort on providing online access to metadata and data, as well as Geographic Information System (GIS) products (Figure 7.3). Compared to the GOSR2017, data centres appear to be increasing their efforts outside of classical data management, with an increased focus on providing data and information, products and services such as e-documents and e-publications, and access to published ocean data and numerical model data. It can be assumed that such recent trends may reflect changing demands by data centre users.

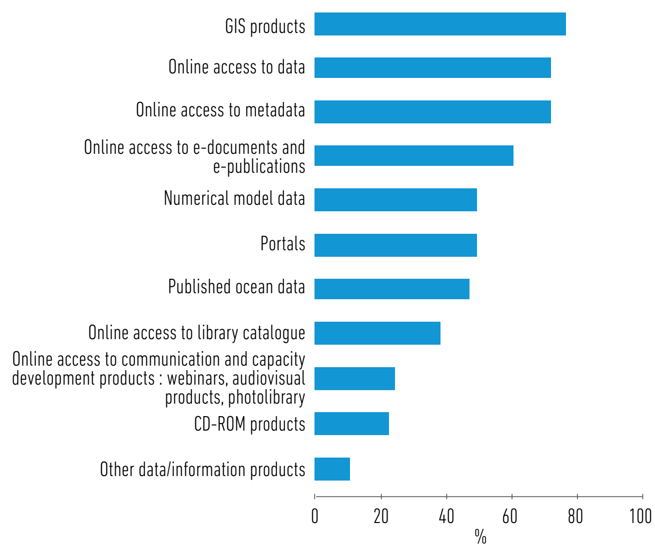


**Figure 7.3.** Proportion (%) of data/information products and services provided by countries' data centre(s) to their clients (multiple answers possible, 44 submissions).
*Source:* Data based on the GOSR2020 questionnaire.

The type of products delivered to the users is mirrored in the type of services data centres provide (Table 7.2). Globally, the top four services offered by data centres to clients are: (i) metadata and data archival; (ii) access to documented methods, standards and guidelines; (iii) data visualization; and (iv) web services (Table 7.2). In 2017, the provision of 'data quality control tools' was in the top four, while web services were seventh. In addition, it seems there is a clear enhancement of web services by the data centres over the last couple of years. The least-provided services include virtual laboratory, data analysis tools and personal data repository. As noted at the beginning of this section, experts responding on behalf of their country were not the same for the GOSR2017 and the GOSR2020, which may explain some of the changes since 2017.

Table 7.2. Proportion (%) of services provided by countries' data centre(s) to their clients.[9]

| Services | Sub-Saharan Africa (9) | Northern Africa and Western Asia (4) | Central and Southern Asia (1) | Eastern and South-Eastern Asia (4) | Latin America and the Caribbean (7) | Oceania (1) | Europe and Northern America (18) | Total (44) |
|---|---|---|---|---|---|---|---|---|
| Virtual research environment | 11% | — | — | — | 14% | — | 17% | 11% |
| Data analysis tools | 11% | — | — | 25% | 14% | 100% | 28% | 20% |
| Personal data repository | 33% | 25% | — | — | 14% | — | 28% | 23% |
| Provision of PIDs[10] | 11% | — | — | — | — | 100% | 44% | 23% |
| Cloud computing facilities | 11% | — | — | 25% | 29% | 100% | 33% | 25% |
| Communication tools | 44% | — | — | — | 14% | — | 44% | 30% |
| Special tools | 11% | — | — | 25% | 14% | 100% | 50% | 30% |
| Data quality control tools | 33% | — | 100% | 25% | 14% | 100% | 44% | 34% |
| Web services | 22% | — | — | — | 29% | 100% | 72% | 41% |
| Data visualization tools | 33% | — | — | 25% | 14% | 100% | 83% | 48% |
| Access to documented methods, standards, guidelines | 33% | 25% | 100% | 25% | 14% | 100% | 78% | 50% |
| Metadata and data archival | 56% | 25% | 100% | 75% | 71% | 100% | 94% | 75% |

*Source:* Data based on the GOSR2020 questionnaire.

The rankings of services provided by data centres in Europe and Northern America are similar to the global pattern, probably because a high number of answers (18) were received from this SDG region (regions defined in Chapter 2). In all regions, metadata and data archival were the major service provided by data centres. Access to documented methods, standards and guidelines is guaranteed throughout regions. In contrast, special data management tools are not sufficiently offered in most regions, especially in Northern Africa and Western Asia or Central and Southern Asia. Furthermore, webservices are not available in many regions. Regional analyses, however, are limited in value due to the low number of responses to the GOSR2020 for some regions, in particular Oceania, and Central and Southern Asia.

## 7.4. Data management policies

Data sharing and open access to data are key components of international, regional and national oceanographic data and information management systems, ensuring that a variety of societal groups have equal and equitable access to data, data products and services. Defined national policies for data storage and sharing can serve as indicators of the priority given to ensuring that oceanographic data and information is stored, shared and used. One main challenge for the sharing and re-using of data and information remains unclear — data licensing, as identified for example by the OECD in 2017, which recommends that governments work towards commonly agreed and enforced legal and ethical frameworks for the sharing of different types of public research data. According to the results of the GOSR2020 questionnaire, more than 80% of the countries apply institutional, national or international data-sharing policies (Table 7.3). The majority of the data centres (58%) stated that they comply with the FAIR criteria for data management (Figure 7.4). Due to the fact that this assessment is not based on the 15 subcriteria as defined by Wilkinson et al. (2016), this might be an over-estimation. Globally, 60% of data centres restrict access to 'certain' data types and 58% during a certain period of time, while 16% apply no restrictions at all (Figure 7.5). These values did not change significantly compared to 2017.

Based on the GOSR2020 questionnaire results, 77% of the national data centres apply the IOC Oceanographic Data Exchange Policy,[11] which was adopted by IOC-UNESCO Member States in 2003, but 23% indicated in the survey that they did not apply it or did not know if their country applies the IOC Oceanographic Data Exchange Policy (Figure 7.6).

9 Multiple answers possible, percentages based on 44 submissions.

10 PID — process identifier.

11 IOC resolution XXII-6: IOC Oceanographic Data Exchange Policy, see http://hdl.handle.net/1834/1747.

**Table 7.3.** List of countries' data centre(s) and the established data policies they apply on the management and sharing of data and information.[12]

| | Yes, institutional | Yes, national | Yes, international | No data policy in place |
|---|---|---|---|---|
| Australia | x | x | | |
| Belgium | x | x | | |
| Brazil | x | x | x | |
| Bulgaria | | | x | |
| Canada | x | | | |
| Chile | | | x | |
| Colombia | x | | | |
| Comoros | x | | | |
| Democratic Republic of the Congo | | | | x |
| Denmark | x | | x | |
| Ecuador | x | | | |
| El Salvador | | | | x |
| France | x | x | x | |
| Germany | | | | x |
| Iran (Islamic Republic of) | x | | | |
| Ireland | x | | x | |
| Italy | | | x | |
| Japan | | | x | |
| Kenya | x | | | |
| Kuwait | | | | x |
| Madagascar | x | | | |
| Mauritius | x | | | |
| Mexico | | | | x |
| Mozambique | | x | | |
| Netherlands | x | x | x | |
| Norway | x | | | |
| Oman | x | x | x | |
| Peru | | x | | |
| Poland | | x | x | |
| Portugal | x | x | x | |
| Republic of Korea | | | x | |
| Russian Federation | | | x | |
| Somalia | | | | x |
| South Africa | | x | | |
| Spain | x | | | |
| Sweden | x | x | x | |
| Turkey | x | x | x | |
| UK | x | x | x | |
| USA | x | x | x | |
| Total countries | 23 | 15 | 18 | 6 |
| % of total respondents | 59 | 38 | 50 | 15 |

*Source:* Data based on the GOSR2020 questionnaire.

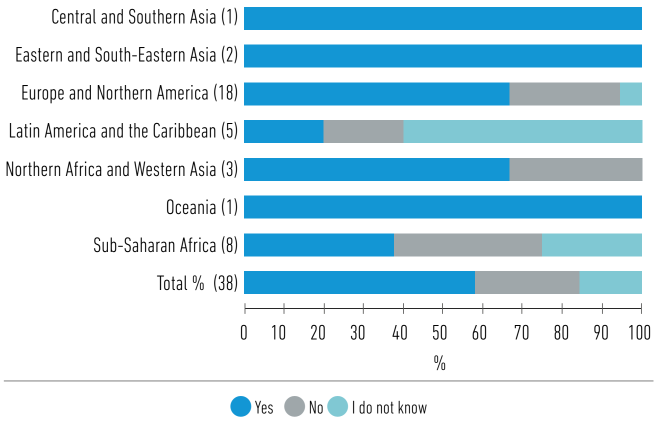


**Figure 7.4.** Compliance of national data centre(s) with the FAIR data management criteria (percentages based on 38 submissions).
*Source:* Data based on the GOSR2020 questionnaire.

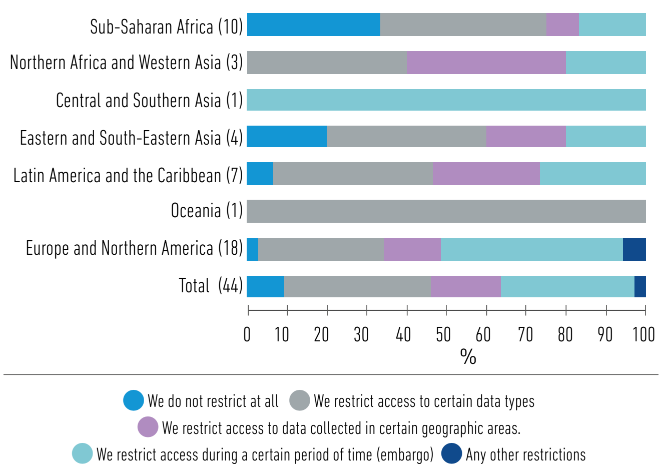


**Figure 7.5.** Proportion (%) of countries' data centre(s) in the different SDG regional groupings applying different restrictions to data and information (based on 44 submissions).
*Source:* Data based on the GOSR2020 questionnaire.

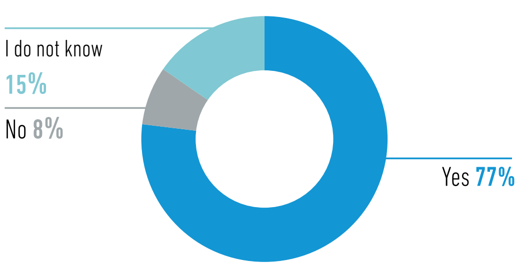


**Figure 7.6.** Percentage of countries' data centre(s) applying the IOC Oceanographic Data Exchange Policy (IOC-XXII-6)[13] (based on 39 submissions).
*Source:* Data based on the GOSR2020 questionnaire.

[12] Multiple answers possible, percentages based on 39 submissions.

[13] IOC resolution XXII-6: IOC Oceanographic Data Exchange Policy, see http://hdl.handle.net/1834/1747.

## 7.5. Applicants and users

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, in particular, to businesses. Globally, the core users of data, products or services are the national and international science community, students and the private sector, followed by the general public and policymakers (Figure 7.7).

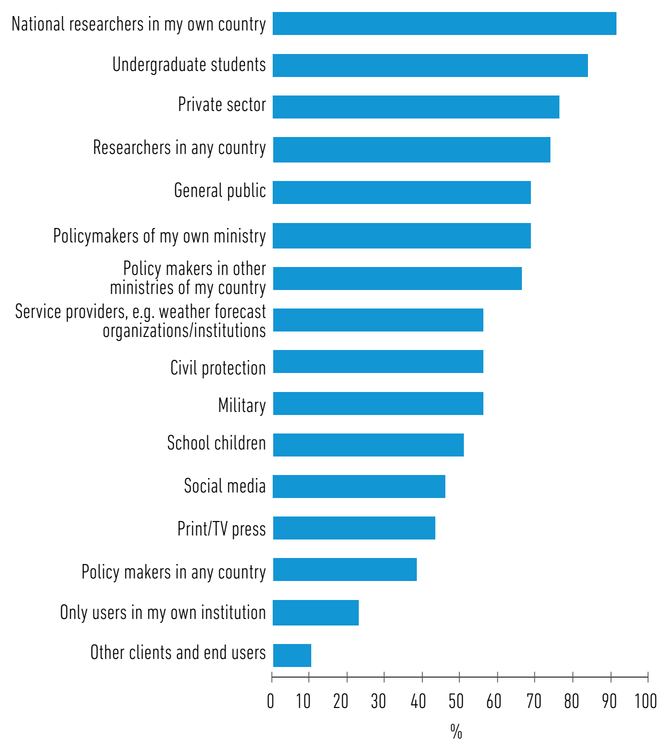


**Figure 7.7.** Percentage of clients and end users of the data, products or services provided by countries' data centre(s) (multiple answers possible, based on 40 submissions).
*Source:* Data based on the GOSR2020 questionnaire.

Furthermore 74% of data centres have established relationships to exchange part of their data and information with other international data systems, which is comparable to results presented in the GOSR2017 (IOC-UNESCO, 2017; Figure 7.8). However, this percentage varies greatly based on the regional comparison, conducted with limited information for a few regions, in particular Oceania and Central and Southern Asia. In Europe and Northern America, for example, more than 90% have this kind of exchange, while in Latin America and the Caribbean, less than 50% (Figure 7.8).

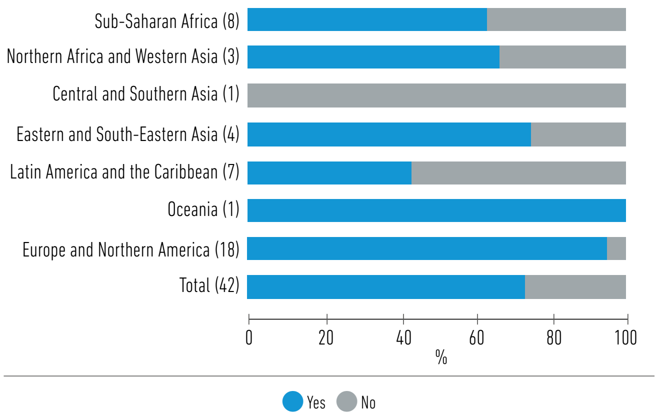


**Figure 7.8.** Percentage of countries' data centre(s) contributing data and information to international systems such as ICS World Data System, GDACs, WMO Global Telecommunication System (GTS), and others (42 submissions).
*Source:* Data based on the GOSR2020 questionnaire.

**Box 7.1.** How the IODE programme supports international data and information management

The IOC was established in 1960 within UNESCO. Its mandate includes the promotion and support of international cooperation and coordinates programmes in ocean science, services and observation systems; hazard mitigation; capacity development; and helping to understand and effectively manage the resources of the ocean and coastal areas. The United Nations recognized IOC-UNESCO as the mechanism for global cooperation in the study of the ocean (UN DOALOS, 2010). Only one year after the establishment of IOC-UNESCO, 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 IODE programme has five main objectives:

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 capacity to manage marine research and observation data and information, and become partners in the IODE network.
V. Support international scientific and operational marine programmes, including the Framework for Ocean Observing (IOC-UNESCO, 2012) 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. As stated above, the IODE data centres have a mandate to manage all ocean-related data variables, including physical oceanography, chemical, biological, etc. From the outset, the IODE programme has focused on building a global community of national data centres, each established and maintained by the individual IOC-UNESCO Member States (Supplementary material 7.1, 7.2, 7.3).

It should be noted that there is currently no formal education related to oceanographic data management. In response, the IODE programme developed an active training programme to address this gap, and since 2002, the IODE's OceanTeacher Global Academy programme14 has provided continuous professional development for staff of the data centres associated with the IODE network (for further information, see Chapter 4). 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, such as SeaDataNet[15] (the European network of national data centres), the Australian Ocean Data Network (AODN)[16] and multinational data portals and services such as the European Marine Observation and Data Network (EMODnet).[17]

#### Ocean Data and Information System (ODIS)

In response to the request by IOC-UNESCO Member States to construct 'a universal information system and ocean data portal' in 2019, the IODE started to establish the 'Ocean Data and Information System' (ODIS), which aims to provide comprehensive 'one-stop' services for global oceanographic data and information.

As the first step, IODE developed the ODIS Catalogue of Sources (ODISCat),[18] which allows users to search a catalogue of existing ocean-related web-based sources/systems of data and information, as well as products and services, through an online browser. The catalogue also provides information on products and enables users to visualize the landscape (entities and their connections) of ocean data and information sources.

As the second step, the Ocean InfoHub project will develop the technology and collaborative culture required to allow these and other resources to interoperate as components of a collective 'e-environment', as specified in the ODIS concept.[19] The ODIS component of the project will provide a 'proof-of-concept reference architecture' (ODIS-Arch), enabling multiple data systems to interoperate with IOC-UNESCO systems and with each other across a wide range of information types, through machine-to-machine interactions. ODIS will initiate a process to improve automated and scalable communication between the hundreds of marine data and information systems globally, where both developers and end users must query and download from each online source, often expending immense resources to contend with a multitude of shifting formats and conventions.

#### Ocean best practices

Given its vast dimensions and internal complexity, the efficient monitoring and predicting of the planet's ocean must be a collaborative effort at both regional and global scales. A fundamental requirement for such observation

[14] See Ocean Teacher Global Academy (OTGA) https://oceanteacher.org.
[15] See SeaDataNet https://www.seadatanet.org.
[16] See Australian Ocean Data Network https://portal.aodn.org.au.
[17] See EMODnet https://emodnet.eu .
[18] See ODISCat https://catalogue.odis.org.
[19] See ODIS Concept Paper https://www.iode.org/index.php?option=com_oe&task=viewDocumentRecord&docID=18703.

and research is to follow well-defined and reproducible methods across activities, from strategies for structuring observing systems, sensor deployment and usage, measurement techniques and guidelines, community-approved quality assurance and control procedures, as well as the generation of data and information products, to aspects of ethics and governance. Thus, methods across all aspects of ocean observing and research should be broadly adopted by the ocean community and, where appropriate, should evolve into 'ocean best practices'. Although many groups have created best practices, they are scattered across various online resources or buried in local repositories and many have yet to be digitized.

To reduce this fragmentation, a new open access, permanent digital repository of best practices documentation was introduced.[20] It comprises a repository archive; a user-friendly web interface; advanced technology, including text mining and semantic tagging; peer-reviewed journals linked to the repository; a training component supported by the Ocean Teacher Global Academy and a community forum. It is maintained by the International Oceanographic Data and Information Exchange (IODE) programme of IOC-UNESCO, and is coordinated in cooperation with GOOS.

Through continued collaboration efforts by ODISCat and the ocean best practice database, and a variety of scientific and other stakeholder groups (e.g. expert groups behind GOOS, GCOS, Group of Earth Observations (GEO) and the General Bathymetric Chart of the Oceans (GEBCO), holding global, local and regional datasets), it is expected that any stakeholders related to the ocean will be able to access data, information and related methodologies in the near future.

## 7.6. Unresolved and emerging issues in the current data debate

### 7.6.1. The big challenge facing us

To be fit for the purpose of managing a sustainable ocean, oceanographic data management must be innovative, efficient and adaptable. The G7 academies in 2015 (Germany), the World Economic Forum (2016), and the recommendation of G20 Academies to the G20 Osaka Summit (2019) all highlight that coastal and marine ecosystems are facing serious threats from rapidly changing ocean conditions, including ocean acidification, deoxygenation, warming, sea-level rise and frequent extreme weather conditions. Land-based pollutions, both inorganic and organic (inclusive of plastics), deteriorate coastal environments. However, global open access data systems to help Member States combat the stressors' impacts are currently in short supply.

[20] See http://www.oceanbestpractices.org.

Recognizing the importance to planners of being able to track, understand and predict ocean conditions, the Ocean Decade calls for a transformation in how we manage ocean data and information, with an emphasis on openness and transparency. While better technology for sharing open data exists, cultural, social political and practical factors result in huge amounts of ocean data, even open data, not being accessible, leaving countries without the information and evidence of the necessity to plan for and sustainably manage their ocean waters.

### 7.6.2. Concrete actions to be taken

In order to meet current and future planning challenges for a sustainable ocean, the flow of data from data provider, to data manager, to data user and finally to stakeholders and decisions-makers, needs to be enforced and made faster, easier and more transparent, in conjunction with action taken at governmental level.

Of the six concrete actions to improve the flow of data, detailed by the G20 Academies of Sciences (Science 20, 2019), two are directly related to data and information:

I. Establishment of an improved data storage and management system that ensures open access for scientists globally; and

II. Sharing of information gained through research activities carried out under extensive and multinational collaboration, to expedite a comprehensive understanding of the global ocean and its dynamics.

The Ocean Decade goes even further in its implementation plan, calling upon the ocean community to collectively co-design and construct a distributed digital system that can present the complex socio-ecological ocean system, at a variety of spatial scales, in order to create a 'digital ocean' and to explore its potential future role in sustainable development pathways and scenarios.

In order to translate this vision into action, experts working within the UN system have begun to develop a strategy on ocean data and information stewardship for the Ocean Decade (IWG-SODIS).[21] These efforts are coordinated with the complementary activities carried out by non-governmental organizations (e.g. Geo Blue Planet), foundations (e.g. the Ocean Data Platform) and regional governments (e.g. the European Union).

[21] See https://www.iode.org/index.php?option=com_content&view=article&id=598&Itemid=100017.

### *7.6.3. Building on existing processes*

When transforming ocean data management, it is not necessary to create the flow of ocean data from zero, as excellent models in terms of data and information sharing already exist. The World Ocean Circulation Experiment (WOCE), for example, brings together data collected under international cooperation and commonly agreed guidelines, in order to harmonize data format and metadata information in its 'WOCE Global Data' product. Similarly, the international Argo programme[22] represents another global effort to manage and share real-time and delayed mode observational data for use by all. Furthermore, there are several community-driven showcases for data sharing, addressing limited public data availability — many started by scientific users (World Ocean Atlas, GLODAP, SOCAT), as well as networks and initiatives such as SeaDataCloud, EMODnet and OBIS, which were supported by agencies. Other up-and-coming initiatives along similar lines focus on data-sharing needs for serious threats, such as ocean acidification through the Global Ocean Acidification Observing Network (GOA-ON) and deoxygenation through the Global Ocean Oxygen Network (GO2NE).

Despite these initial efforts, the availability and sharing of scientific data of the marine environment, especially related biological and socio-economic data, lags far behind what has been achieved for terrestrial areas and the atmosphere. The global assessment report of the Intergovernmental Science-policy Platform for Biodiversity and Ecosystem Service (IPBES) shows that high- and deep-sea biodiversity can be rapidly depleted;[23] data to track changes in marine biodiversity is in short supply, despite efforts to further develop OBIS and other international activities such as the Marine Biodiversity Observation Network.[24]

There remain huge parts of the ocean that are poorly observed, for which reliable data are scarce or absent, and much of the data collected about ocean conditions, including that collected by individual scientists, students and industries, is never shared. In parallel, data remain siloed by disciplines and fields of study. If we are to accomplish the goals of the Ocean Decade, stakeholders and decision-makers need to be able to access data and information across yet another major challenge.

22 See http://www.argo.ucsd.edu.

23 See https://ipbes.net/global-assessment.

24 See https://marinebon.org.

**Box 7.2. Coordination of the global ocean observing networks — metadata and data**

OceanOPS (previously JCOMMOPS[25]) occupies a unique place as the focal point for the coordination of the global ocean observing networks within GOOS. The centre is established in Brest, the French ocean metropolis, within the marine research facility Ifremer, and is approaching its 20th anniversary of support to an increasingly complex and diverse range of ocean observing system implementers.

OceanOPS mission is to monitor and report on the status of the global ocean observing system and networks, to use its central role to support efficient observing system operations, to ensure the transmission and timely exchange of high quality metadata, and to assist free and unrestricted data delivery to users across, operational services, climate and ocean health[26].

The most visible measure of OceanOPS work are the regular authoritative maps of the various observing system components, and an ambitious web based application[27]. These are fueled, in real-time, by metadata from the global ocean observing networks and include a large suit of monitoring tools and services to 'take the pulse' of the network elements, and facilitate and optimize their implementation.

OceanOPS is able to monitor what is operating at sea from first-hand metadata and routinely compares it with data available to users, in order to continuously optimize data flows. Allocating unique 'identifiers' to all marine platforms, harmonizing their metadata and vocabularies, and developing machine to machine services, is a major contribution to the Global ocean Observing System. Supporting a range of benefits, including easing data access, enhancing data usability and interoperability.

Together with the GOOS Observation Coordination Group, OceanOPS produces a yearly report card[28] on the status of the observing system. This is an important annual resource to indicate the status of the global ocean observing system networks, the development of new network elements, the connection with ocean services resulting from the observations, and satellite observing from space, as well as impacts of the COVID-19 pandemic on ocean observation.

OceanOPS has pioneered the cooperation with civil society to deploy instruments through sailing charters or races, explorers, or foundations and his actively developing the concept of citizen involvement in the GOOS with the IOC for operational, communicational, and educational outcomes. Most recently, its real-time monitoring capability has proved invaluable to track and predict the impact of the COVID-19 pandemic across the global ocean observing system. Furthermore, OceanOPS is active in creating coordination opportunities to help maintain critical function across the vital arrays of autonomous observing instruments.

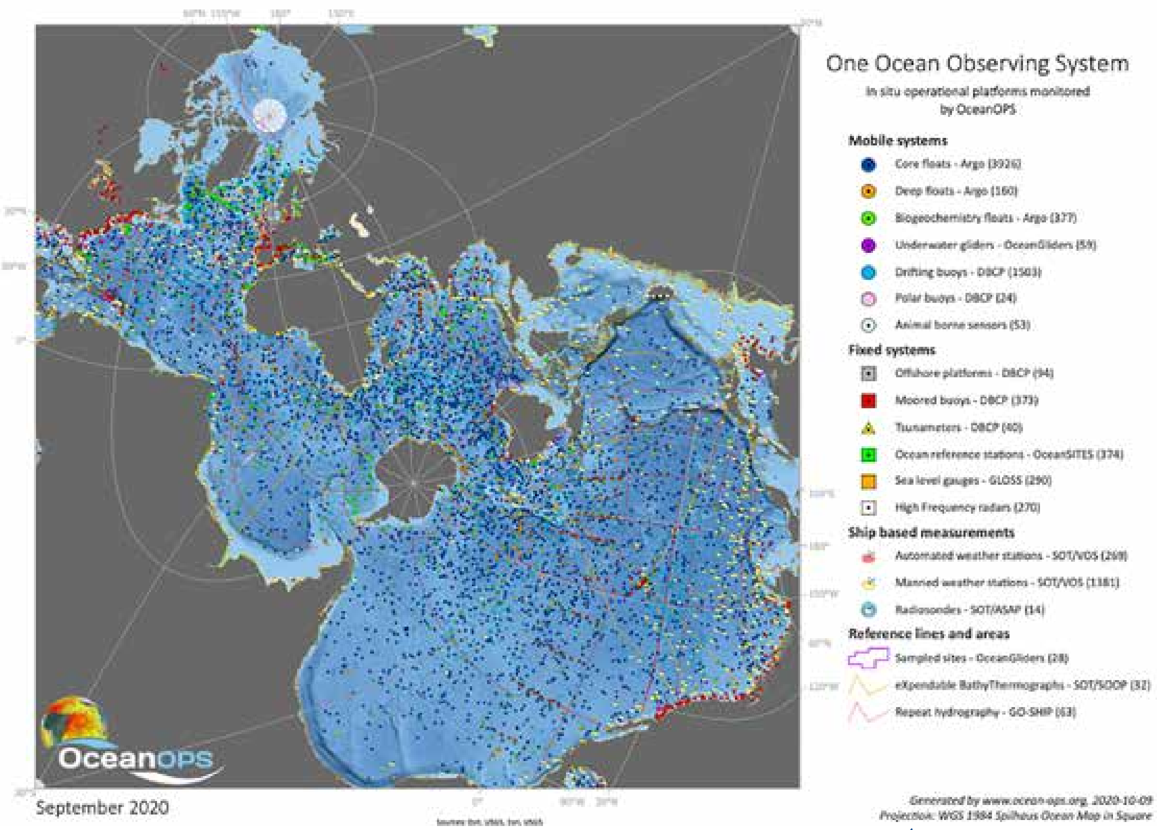


Figure 7.9. One ocean projection indicating the location of approximately 10,000 GOOS network elements (WGS 1984 Spilhaus Ocean Map in Square).
*Source:* OceanOPS.

[25] Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology in situ Observations Programmes Support centre.

[26] See https://ocean-ops.org/strategy.

[27] See https://ocean-ops.org.

[28] See https://ocean-ops.org/reportcard.

Historically focused on supporting the major global ocean observing networks, operating mainly in high seas, OceanOPS is now working towards a greater connection with regional and coastal observing elements to continue to support the emerging diversity of GOOS and the users it serves.

The new OceanOPS 5-year strategic plan[29] provides the roadmap listing major steps towards achieving OceanOPS vision of becoming the international hub and center of excellence, providing vital services in monitoring, coordinating, and integrating data and metadata, across an expanding network of global oceanographic and marine meteorological observing communities.

### 7.6.4. New approaches are needed

While international efforts like ODIS continue to improve data availability and interoperability, new innovative concepts and technologies are required to address current and future data management opportunities as well as challenges. Data from a variety of non-traditional sources and of sometimes differing levels of scientific rigour need to be harnessed to plan for a sustainable ocean. Ocean data collection and management is too expensive to use data just once and throw it away. New data science and engineering approaches create hope that in the future, unlike today, data might be collected for a specific purpose in the first place, but then also used for different assessments from the original, following the notion of 'collect once and use many times'. Bringing together data from various historic and new sources will open up opportunities to apply artificial intelligence approaches, including machine learning, in order to gain new insights into ocean processes. New algorithms have proven to be a powerful and efficient tool for analysing oceanographic and climate data with a high degree of accuracy. The main application of machine learning in oceanography is the prediction of ocean weather and climate, habitat modelling and distribution, species identification, coastal water monitoring, marine resources management, detection of oil spill and pollution and wave modelling. Nevertheless, it is expected that future developments will increase the number of users and lead to its incorporation in daily data management (Ahmad, 2019).

However, these techniques can only be applied if data can be brought together and aligned for use. Efforts to develop a comprehensive and holistic digital representation of the ocean, including a dynamic ocean map, will permit multistakeholder collaboration so that scientists and non-science stakeholders can have free and open access to explore, discover and visualize past, current and future ocean conditions — one of the ten challenges of the Ocean Decade.

Data volumes are constantly rising, due to improvements in technology for making observations and computing ocean data, leading to new demands by the ocean community and to an era of big data for the field of ocean science. The issue of how to store, manage, explore, subset and do science with big data will require new strategies, procedures and workflows. Cloud computing is the best candidate for oceanographic data migration on a distributed and scalable platform, and can help researchers to perform future predictive analysis (Allam et al., 2018). Cloud computing married with the application of artificial intelligence, and in particular machine learning, can increase data flow by bridging, facilitating and even automating the collection, processing and sharing of ocean data.

Nowadays, there are more ways than ever of observing the ocean. New innovative technology is at our disposal to make the resulting data available and useful for those who need it to manage the ocean and its resources. These techniques will be the basis for interdisciplinary work to improve the understanding of the relations across, patterns of and principles in big data, as well as for more efficient access to data and the ability to produce information and knowledge. Action to improve current data access and transparency are indispensable for achieving the objectives of SDG 14 and the 2030 Agenda. It is of the utmost importance to highlight the need for investment, starting by sustained marine observations and research, supported by structured, operational and modern data management for all data in the marine sphere.

Decision makers, however, will only be able to benefit from all of these data and digital advances when the global ocean community overcomes its barriers, be they political, social or cultural, which block the sharing of data for the greater good.

[29] https://ocean-ops.org/strategy.

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7

**Supplementary material 7.1.** List of active National Oceanographic Data Centres (NODCs) in 2020.

| Name | English name (where relevant) | Country | URL |
|---|---|---|---|
| Servicio de Hidrografía Naval | Naval Hydrographic Service | Argentina | http://www.hidro.gov.ar |
| Australian Ocean Data Network | | Australia | http://imos.org.au/aodn_data_management_overview.html |
| Vlaams Instituut voor de Zee, Vlaams Marien Datacentrum (VMDC) | Flanders Marine Institute, Flanders Marine Data Centre (VMDC) | Belgium | www.vliz.be/en/vliz-research-centres |
| Royal Belgian Institute of Natural Sciences, Operational Directorate Natural Environ-ment, Belgian Marine Data Centre | | Belgium | http://www.bmdc.be/NODC/index.xhtml |
| Centre de Recherches Halieutiques et Océanologiques du Bénin | Benin Oceanographic and Fisheries Research Centre | Benin | http://nodc-benin.odinafrica.org |
| Brazilian Navy Hydrographic Center Directorate of Hydrography and Navigation | | Brazil | https://www.marinha.mil.br/dhn/?q=en/node/136 |
| Institute of Oceanology, Bulgarian Academy of Sciences, Varna | | Bulgaria | http://www.io-bas.bg/index_en.html |
| Ministère des Sciences et de l'Innovation, Institut de recherche agricole pour le Développement. Centre de recherche sur les écosystèmes marins (CERECOMA). | Ministry of Scientific Research and Innova-tion, Institute of Agricultural Research for Development. Specialized Research Centre on Marine Ecosystems (CERECOMA) | Cameroon | http://nodc-cameroon.odinafrica.org/a-propos-du-cndo.html |
| Marine Environmental Data Section (MEDS), Oceans Science Branch (DFO-OSB), Fisheries and Oceans Canada | | Canada | http://www.dfo-mpo.gc.ca |
| Servicio Hidrográfico y Oceanográfico de la Armada | Hydrographic and Oceanographic Service of the Chilean Navy | Chile | http://www.shoa.cl |
| National Marine Data and Information Service | | China | http://www.nmdis.org.cn/english/nmdiss-mission |
| Dirección General Marítima Colombia | General Maritime Directorate | Colombia | http://www.dimar.mil.co |
| Centre National de Documentation et de Recherche Scientifique | National Centre for Documentation and Scientific Research | Comoros | http://www.cndrs-comores.org |
| Centre National de Recherches Océanologiques, Abidjan | National Centre for Oceanic Research Abidjan | Côte d'Ivoire | http://www.cro-ci.net |
| Institut za oceanografiju i ribarstvo | Institute of Oceanography and Fisheries | Croatia | http://www.izor.hr |
| Oceanography Centre, University of Cyprus | | Cyprus | http://www.ucy.ac.cy/oceanography/en |
| Instituto Oceanográfico de la Armada del Ecuador (INOCAR) | Oceanographic Institute of the Navy (IN-OCAR) of Ecuador | Ecuador | http://www.inocar.mil.ec/web |
| Institut français de recherche pour l'exploitation de la mer, IFREMER, Centre de Brest | French Institute for the Exploitation of the Sea, IFREMER, Brest Centre | France | http://wwz.ifremer.fr |
| Bundesamt für Seeschifffahrt und Hydrographie (BSH) | Federal Maritime and Hydrographic Agency (BSH) | Germany | http://www.bsh.de |
| Fisheries Scientific Survey Division (FSSD), Ghana Oceanographic Data Centre | | Ghana | http://nodc-ghana.odinafrica.org |
| Hellenic Centre for Marine Research (HCMR), Hellenic National Oceanographic Data Centre (HNODC) | | Greece | http://www.hcmr.gr/en/research-infrastructures/facilities-3/anavyssos |
| Centre de Recherche Scientifique Conakry Rogbané (CERESCOR) | Scientific Research Centre of Conakry Rogbané (CERESCOR) | Guinea | http://www.cerescor.edu.gn |
| Indian National Centre for Ocean Information Services | | India | http://www.incois.gov.in |
| Badan Pengkajian dan Penerapan Teknologi | Agency for the Assessment and Application of Technology | Indonesia | http://www.bppt.go.id/ |
| Iranian National Institute for Oceanography and Atmospheric Science | | Iran (Islamic Republic of) | http://www.inio.ac.ir/Default.aspx?tabid=1204 |
| Marine Institute Headquarters, Galway | | Ireland | https://www.marine.ie/Home/home |
| Israel Oceanographic and Limnological Research | | Israel | https://isramar.ocean.org.il/isramar2009 |

**Supplementary material 7.1.** continued

| Name | English name (where relevant) | Country | URL |
|---|---|---|---|
| Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste | National Institute of Oceanography and Experimental Geophysics | Italy | http://www.ogs.trieste.it |
| Japan Oceanographic Data Center | | Japan | http://www.jodc.go.jp |
| Ministry of Energy, Republic State Enterprise 'Kazhydromet' | | Kazakhstan | http://www.kazhydromet.kz |
| Kenya Marine and Fisheries Research Institute | | Kenya | http://www.kmfri.co.ke |
| Institut Halieutique et des Sciences Marines | Fisheries and Marine Sciences Institute | Madagascar | http://ihsm.mg |
| Ministry of Science, Technology and Innovation, National Oceanography Directorate | | Malaysia | http://www.mynodc.gov.my |
| Institut Mauritanien de Recherche Océanographique et des Pêches (IMROP) | Mauritanian Institute of Oceanographic Research and Fisheries (IMROP) | Mauritania | https://www.imrop.org |
| Mauritius Meteorological Services | | Mauritius | http://metservice.intnet.mu |
| Universidad Autónoma de Baja California (UABC), Instituto de Investigaciones Oceanológicas | Autonomous University of Baja California (UABC), Oceanology Research Institute | Mexico | http://iio.ens.uabc.mx/# |
| Instituto Nacional de Hidrografia e Navegação | National Institute for Hydrography and Navigation | Mozambique | http://www.inahina.gov.mz |
| Koninklijk Nederlands Instituut voor Onderzoek der Zee | Royal Netherlands Institute for Sea Research | Netherlands | http://www.nioz.nl |
| Nigerian Institute for Oceanography and Marine Research | | Nigeria | https://www.niomr.gov.ng |
| Institute of Marine Research | | Norway | http://www.imr.no |
| Marina de Guerra del Perú, Dirección de Hidrografía y Navegación | Navy of Peru, Directorate of Hydrography and Navigation | Peru | https://www.dhn.mil.pe |
| Korea Oceanographic Data Center | | Republic of Korea | http://www.nifs.go.kr/kodc/eng/index.kodc |
| National Institute for Marine Research and Development — Grigore Antipa | | Romania | http://www.rmri.ro/Home/Home.html |
| All-Russian Research Institute Hydrometeorological Information — World Data Center, Obninsk | | Russian Federation | http://www.meteo.ru/nodc/index.html |
| Centre de Recherche Océanographique de Dakar Thiaroye (CRODT-ISRA/ LPAOSF-ESP-UCAD) | Oceanographic Research Centre of Dakar Thiaroye (CRODT-ISRA/ LPAOSF-ESP-UCAD) | Senegal | http://www.isra.sn |
| Seychelles Fishing Authority | | Seychelles | http://www.sfa.sc |
| National Institute of Biology, Marine Biology Station, Piran | | Slovenia | http://www.nib.si/mbp/en |
| Southern African Data Centre for Oceanography (SADCO) | | South Africa | http://sadco.ocean.gov.za |
| Instituto Español de Oceanografía | Spanish Institute of Oceanography (IEO) | Spain | http://www.ieo.es |
| Sveriges meteorologiska och hydrologiska institut | Swedish Meteorological and Hydrological Institute | Sweden | https://www.smhi.se/en |
| Université de Lomé, Centre De Gestion Intégrée du Littoral et de l'environnement | Lomé University, Integrated Management Centre for the Coast and Environment | Togo | http://www.univ-lome.tg |
| Institut National des Sciences et Technologies de la Mer, Salambo | National Institute of Science and Technology of the Sea, Salambo | Tunisia | http://www.instm.agrinet.tn/index.php/fr |
| Turkish Naval Forces, Office of Navigation, Hydrography and Oceanography | | Turkey | http://www.shodb.gov.tr/shodb_esas/index.php/en |
| Ukrainian Scientific Centre of Ecology of the Sea | | Ukraine | http://www.sea.gov.ua/?lang=en |
| National Oceanography Centre, Natural Environment Research Council, Proudman Oceanographic Laboratory | | UK | http://www.pol.ac.uk |
| University of Dar es Salaam, Institute of Marine Sciences | | United Republic of Tanzania | https://ims.udsm.ac.tz |
| NOAA NESDIS National Centers for Environmental Information (NCEI) | | USA | https://www.ncei.noaa.gov |

*Source:* Adapted from IODE https://www.iode.org/index.php?option=com_content&view=article&id=61&Itemid=100057.

**Supplementary material 7.2.** List of active Associate Data Units (ADUs) in 2020.

| Name | English name (where relevant) | Country | URL |
|---|---|---|---|
| Centro para el Estudio de Sistemas Marinos, Centro Nacional Patagónico | Centre for the Study of Marine Systems, National Patagonian Centre | Argentina | http://www.cenpat-conicet.gob.ar/cesimar |
| CSIRO Oceans and Atmosphere (Hobart) | | Australia | https://www.csiro.au/en/Research/OandA |
| Coastal Zone Management Unit | | Barbados | http://www.coastal.gov.bb |
| Long-term Ecological Research Program Coastal Habitats of Espírito Santo (PELD HCES) | | Brazil | http://bentos.ufes.br |
| Ocean Tracking Network | | Canada | http://oceantrackingnetwork.org |
| Instituto de Investigaciones Marinas y Costeras (INVEMAR) | Marine and Coastal Research Institute | Colombia | http://www.invemar.org.co |
| Parques Nacionales Naturales de Colombia | National Natural Parks of Colombia | Colombia | http://www.parquesnacionales.gov.co |
| International Council for the Exploration of the Sea | | Denmark | http://www.ices.dk/Pages/default.aspx |
| Global Biodiversity Information Facility | | Denmark | http://www.gbif.org |
| Comisión Permanente para el Pacífico Sur | Permanent Commission for the South Pacific | Ecuador | http://cpps-int.org |
| Instituto Nacional de Pesca Ecuador | National Fisheries Institute Ecuador | Ecuador | http://www.institutopesca.gob.ec |
| Ivane Javakhishvili Tbilisi State University | | Georgia | https://www.tsu.ge/en |
| Hellenic Centre for Marine Research - Institute of Marine Biology, Biotechnology and Aquaculture | | Greece | http://www.imbbc.hcmr.gr |
| Conservation of Arctic Flora and Fauna | | Iceland | http://www.caff.is |
| Pusat Penelitian Oseanografi. Lemabga Ilmu Pengetahuan | Research Centre for Oceanography, Indonesian Institute of Sciences | Indonesia | http://www.oseanografi.lipi.go.id |
| Marine Science Centre, Basrah University | | Iraq | http://en.uobasrah.edu.iq |
| Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka | | Japan | http://www.jamstec.go.jp/e/index.html |
| Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Global Oceanographic Data Center (GODAC) | | Japan | http://www.godac.jp/en |
| Institute of Oceanography and Environment | | Malaysia | http://inos.umt.edu.my |
| ASEAN Centre for Biodiversity | | Philippines | http://www.aseanbiodiversity.org |
| Quantitative Aquatics | | Philippines | https://www.q-quatics.org |
| SOCIB — Balearic Islands Coastal Observing and Forecasting System | | Spain | http://www.socib.es |
| Ukrainian Scientific Centre of Ecology of the Sea | | Ukraine | http://www.sea.gov.ua/?lang=en |
| The Marine Biological Association of the United Kingdom | | UK | http://www.mba.ac.uk |
| Scientific Committee on Antarctic Research | | UK | http://www.scar.org |
| University of Hull, Oceans Past Initiative | | UK | http://www.hull.ac.uk/hmap |
| Duke University, Nicholas School of the Environment | | USA | https://nicholas.duke.edu/ |
| Tulane University | | USA | http://www.tulane.edu |
| US Geological Survey HQ | | USA | http://www.usgs.gov |
| Woods Hole Oceanographic Institution | | USA | http://www.whoi.edu |
| Universidad Simón Bolívar | Simon Bolivar University | Venezuela (Bolivarian Republic of) | http://www.usb.ve |

*Source:* Adapted from IODE https://www.iode.org/index.php?option=com_content&view=article&id=61&Itemid=100057.

**Supplementary material 7.3.** List of active Associate Information Units (AIUs) in 2020.

| Name | Country | URL |
|---|---|---|
| Flanders Marine Institute (VLIZ) Library | Belgium | VLIZ library catalogue: http://www.vliz.be/en/catalogue<br>Catalogue of the Belgian Marine Bibliography: http://www.vliz.be/en/belgian-marine-bibliography<br>Open Marine Archive: http://www.vliz.be/en/open-marine-archive |
| SPREP Library | Samoa | Collection holdings and repository: https://www.sprep.org/library-information-resource-center/library-home<br>Publications: https://www.sprep.org/publications |
| Institut National des Sciences et Technologies de la Mer (INSTM) Library | Tunisia | OceanDocs (IOC-UNESCO) http:// www.oceandocs.net/handle/1834/138<br>More information and products on http:// www.instm.agrinet.tn/index.php/fr/bibliotheque |
| Dirección Nacional de Recursos Acuáticos (DINARA) Library | Uruguay | DINARA database in SIDALC: http://orton.catie.ac.cr/dinara.htm<br>INVEN database in SIDALC: http://orton.catie.ac.cr/inven.htm<br>ELECTRA database in SIDALC: http://orton.catie.ac.cr/electra.htm<br>DINARA in OceanDocs: https://www.oceandocs.org/handle/1834/2547 |
| Marine Biological Laboratory, Woods Hole Oceanographic Institution (MBLWHOI) Library | USA | DMPTool: https://dmptool.org/get_started<br>Research Information Management (RIM) system, Elements: Public view using VIVO http://vivo.mblwhoilibrary.org |

*Source:* Adapted from IODE https://www.iode.org/index.php?option=com_content&view=article&id=61&Itemid=100057

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# 8

# Charting ocean capacity for sustainable development

# 8. Charting ocean capacity for sustainable development

***Jacqueline Uku, Jan Mees, Salvatore Aricò, Julian Barbière, Alison Clausen***

Uku, J., Mees, J., Aricó, S., Barbière, J. and Clausen, A. 2020. Charting ocean capacity for sustainable development. IOC-UNESCO, *Global Ocean Science Report 2020–Charting Capacity for Ocean Sustainability*. K. Isensee (ed.), Paris, UNESCO Publishing, pp 217-228.

## 8.1. Taking stock of ocean science infrastructures, human resources and capacity development in ocean science

The *Global Ocean Science Report 2020* (GOSR2020) evaluates current capacities and capabilities in ocean science around the world, based on primary data submitted by Member States of the Intergovernmental Oceanographic Commission of UNESCO and bibliometric and technometric data, as well as information provided by relevant scientific organizations. The report also shows how ocean science will continue to provide knowledge for the sustainable use of ocean resources and to contribute to sustainable development in general. But is ocean science capacity heading in the right direction in light of the upcoming UN Decade of Ocean Science for Sustainable Development (the 'Ocean Decade')?

The findings and analyses presented in Chapters 3–7 lead to the following general conclusions: there is a growing understanding of the critical human role in ocean science enterprise and the science-to-management value chain; and there is an emerging recognition of the contribution of ocean science to a sustainable blue economy and sustainable development.

A series of new and increasingly robust metrics and indicators, used to analyse the contents of relevant scientific journals, illustrate an improved understanding of ocean processes and the impacts of human activity on them. This report also demonstrates that the transfer of knowledge to the private sector, generated through ocean research, is flourishing.

The significant increase in scientific publications in all SDG regional groupings since the early 2000s in ocean science, and in all its categories (Chapters 2 and 5), clearly indicates the growing recognition by those who practice ocean science of its societal relevance, and of the need for ocean science to contribute to relevant societal goals. In this regard, the ocean science community is already starting to develop collaborative actions to deliver the goals of the Ocean Decade (IOC-UNESCO, 2020).

These are all very positive developments which call for further investigation into the analysis of the findings presented in this report.

While the primary mission of science is the quest for new knowledge, considering science as a purely neutral field would be reductive and naïve. Science publishing has become a significant emerging economic sector,[1] as reflected in the continuous positive trends in science production in the past 20 years. Moreover, trends in science may reflect geopolitical dynamics as a consequence of strategic investments in science by individual countries, and in the context of dedicated bilateral and multilateral programmes in the areas of science, technology and innovation (UNESCO, 2015; OECD, 2016).

The above considerations also apply to ocean science publications: in the past 18 years — the period covered by the bibliometric analysis in this report — a significant increase in the outputs of ocean science in the Eastern and South-Eastern Asia region and an equivalent decrease in the Europe and Northern America region have been observed. New players in the form of individual countries are emerging on the ocean science production scene, such as Saudi Arabia, Algeria, Iraq and Morocco (Chapter 5).

At the same time, a convergence of interests in ocean research and development (R&D) towards common problems and solutions can be detected. The analysis of global trends in the filing of patents (or 'technometrics') in Chapter 5 shows, for example, that mitigation and adaptation to climate change has emerged as a 'new' area in the application of technologies based on the discoveries of ocean science. This information is very promising: while there is clear evidence that the world's ocean is being impacted by multiple stressors, of which increased $CO_2$ concentrations in the atmosphere and the ocean is only one (e.g. Nagelkerken et al., 2020; Gao et al., 2020; Hurd et al., 2018; Boyd et al., 2015), there is concern about the future capability of the world's ocean to continue acting as a major sink of human-emitted $CO_2$ (Integrated Ocean Carbon Research (IOC-R), in press).

The GOSR2020 shows that ocean science continues to be an open endeavour, attracting scientists from all regions, allowing them to come together around issues of common interest, develop research questions, organize the collection and interpretation of data, analyse the information and develop models for predictions, etc. This finding comes as no surprise, as science has always acted as an instrument of peaceful dialogue among individuals from all countries and cultures.

[1] In 2006, a study commissioned by the Directorate-General for Research of the European Commission reported that the market for science, technology and medicine publishing was estimated between US$7 billion and US$11 billion, while in 2001 OECD countries allocated US$608 billion to R&D (European Commission, 2006). Van Noorden (2013) referred to data from Outsell Consulting, according to which the science publishing industry generated US$9.4 billion in revenues in 2011.

Yet, there is still tremendous scope for further collaboration among nations, especially from the perspective of the transfer of marine technology (TMT).[2] The GOSR2020 illustrates that industrialized nations in the Asia-Pacific, Europe and North America regions continue to act as the main engine of ocean research; moreover, scientists from these regions tend to collaborate closely with each other within the same region (e.g. USA and Canada) or with scientists of another lead region (e.g. USA and China, and USA and Japan). Chinese institutions that are active in ocean science are clearly in the process of establishing ties with the rest of the world. Against this background, it is imperative that ocean scientists recognize their responsibility and, therefore, the leading countries in ocean science acknowledge their role, to help operationalize the provisions of the United Nations Convention on the Law of the Sea with regard to TMT.

Similarly, previous chapters in the report indicate that South-South and North-South cooperation is important to strengthen or develop capacity in ocean science. Indeed, triangular cooperation will be instrumental in the successful implementation of TMT. In this regard, global science programmes, such as those facilitated by IOC-UNESCO and many other players in this area (Chapters 3, 5 and 7), are pivotal to ensure that neutral platforms with an impartial broker role are made available to scientists from all regions in the world. These science platforms help to disperse the strategic and sometimes political dimension of ocean science and to create a neutral environment for science to thrive and use its ingenuity, and for new discoveries to stem from the creative industry that science represents. These types of initiative are more urgent than ever, in light of the continuous and unresolved challenges to ocean sustainability faced by people, societies and the environment.

Given the central services and benefits provided by the world's ocean and the biodiversity therein (IPCC, 2019; IPBES, 2019), it is widely recognized that the ocean plays a pivotal role in achieving sustainable development. Ocean services and benefits encompass regulatory functions in relation to the climate system and provisioning services crucial for food security, etc.; they form the basis for human well-being and for the development of ocean-based economies (fisheries, tourism, transportation, sustainable energy from the ocean). The ocean also provides recreational benefits and contributes to maintaining the cultural and spiritual values of many peoples, communities and nations around the world (Island Press, 2003; Diaz et al., 2015). Yet, the dedicated goal in the 2030 Agenda for Sustainable Development, SDG 14, tends to be seen as the uniquely 'below the water' or ocean-related SDG. This results in a simplified — even distorted — vision of the contribution of the world's ocean to sustainable development and tends to underplay the ocean's essential role in the achievement of numerous other SDGs, including SDG 8: Decent work and economic growth; SDG 2: Zero hunger; SDG 5: Gender equality; and SDG 13: Climate action, among others.

Understanding acquired through science, corroborated by the application of findings by the private sector, as well as traditional knowledge, will continue to act as the basis for developing solutions for ocean sustainability and sustainable development. TMT and innovation will also continue to play a major role in maximizing the societal benefits that the ocean provides.

First and foremost, the ocean science enterprise is a human enterprise: human capacity development in ocean science feeds into a complex web where education, innovation, growth and employment are closely interlinked. There seems to be a clear correlation between the headcount of ocean scientists and science productivity in the countries analysed. The equal participation of female and young ocean scientists deserves continued attention, in order to promote the involvement and engagement of countries in the research agenda on ocean issues in the years to come. Fully accounting for the gender and intergenerational dimensions of ocean science will help to address the specific career needs of women and young scientists, and provide frameworks for succession and renewal of expertise. In turn, ocean science will benefit from the views of these critical stakeholders to identify the changes that it needs to undergo in the next decade to enhance the contribution of ocean science to society.

**Box 8.1.** Efforts towards gender equity in ocean science and governance

The GOSR2020 describes structural inequalities in ocean science (Chapter 4), the ocean science-policy value chain, gendered barriers to access to credit, education, and the gender blindness of ocean policies (Chapter 6). These factors hamper proper access and the participation of women in ocean science and technology, as well their active involvement in ocean governance.

Concrete measures to enhance gender equality in ocean science include: training support for female ocean scientists in the category of ocean technology and observations; the enhancement and development of programmes aimed at the inclusion of women and girls in ocean education and literacy; and the promotion of the participation of women in policy-related processes and governance.

[2] Here, the transfer of marine technology is intended as a whole set of measures going largely beyond the transfer of technology and encompassing, *inter alia*, training courses, participation in oceanographic cruises and expeditions, exchange programmes, opportunities tailored to young scientists and women, and the exchange of data collected through research and systematic observations (IOC-UNESCO, 2005; Aricò, 2015).

Furthermore, actions in the area of ocean science should address the reinforcement of gender equality in the organization of ocean science conferences, symposia, workshops and panels. Such actions may encompass different aspects of gender inequalities, from providing childcare to enable parent-researchers to participate in ocean science, to parity considerations in the makeup of organizing committees, which have proved to lead to a higher number of female featured speakers.

Gender equality is to be mainstreamed in all of the above areas, and such engagement needs to be accompanied by a continuous and expanded collection of sex-disaggregated data. An improved data base will allow the development of targeted strategies to increase female participation in ocean science, taking into consideration regional, cultural and societal conditions. In particular, further information is needed on the evolution of the careers of young female scientists and their dropout rate from ocean science. It is only with this kind of information that the success of the initiatives aimed at empowering women in ocean science in years to come can be measured and evaluated, thereby pursuing not only gender parity but gender equity in ocean science.

## 8.2. Investing in the ocean science capital for the future

The figures and trends highlighted in this report prove that coherent and steady funding for ocean science will be central to delivering an impactful and revolutionary Ocean Decade. Innovative approaches to funding for ocean science involving consortia or partnerships of diverse stakeholders — including business and industry or the financial sector — with a range of aspirations and interests, using the notion of sustainable blue economies as a framework for coordinated planning and actions, appear promising in this respect (Chapter 3) but the impact of such new approaches is yet to be assessed systematically.

When analysing conventional support to ocean science in the form of public funding, it is difficult to comprehend the apparently insignificant proportion of gross domestic expenditure on research and development (GERD) that is used for ocean science, as shown in Chapter 3, when compared to the estimated contribution of the ocean to the global economy — US$1.5 trillion in 2010, according to the OECD (2016) — and its role in critical processes at the planetary scale. The financial efforts in support of ocean science seem largely disproportionate when compared with the outputs of the ocean science value chain, from research and observation to data collection and related infrastructures, science production, and societal and commercial applications of scientific discoveries.

The findings in this report indicate that ocean science acts as an investment for businesses that are required to assess the environmental impacts of their operations. It also generates knowledge that allows industries to improve their operational performance, and thus their competitivity. This may explain the growing trends in funding for ocean science from the private sector, foundations and other philanthropic organizations, as well as an increasing level of innovation in ocean finances (Chapter 3). The A primary objective of the Ocean Decade is to stimulate and boost investments in ocean science whenever required and promote multistakeholder science-based collaborations through co-design and co-delivery of ocean science that assembles generators and users of ocean science in a collective effort. The Ocean Decade will provide a framework for co-design and co-delivery of ocean science between diverse stakeholder groups — including philanthropic Foundations, business and industry or the financial sector, thus allowing them to contribute actively and significantly to the ocean science enterprise throughout the ocean science value chain.

**Box 8.2.** The role of philanthropy in support of the Ocean Decade

Foundations are important partners in the UN Ocean Decade of Ocean Science for Sustainable Development. To gather their views on, and promote their involvement in the Ocean Decade, IOC-UNESCO, in partnership with The VELUX Foundations, organized a Foundations Dialogue Event in Copenhagen in February 2020. The event was attended by 21 foundations, who shared their vision on the role of the Ocean Decade in empowering communities through knowledge, education and the application of the results of ocean science.

Foundations contribute to marine conservation in equal measure to that of official development assistance (ODA),[3] with a strong focus on North America and on interdisciplinary science and global initiatives. However, in comparison to philanthropic support to other SDGs, in 2016, only 0.45% of philanthropic funding was labelled as addressing SDG 14.

Foundations often support innovative programmes and initiatives at the interface of academia, science and society, the business sectors, NGOs, etc. and catalyse knowledge generation and action in support of more established governmental efforts, thus generating synergies for science in action.

The Ocean Decade is multistakeholder by definition, hence it is natural that foundations occupy a clear niche in it, *inter alia* by: actively engaging in the Ocean Decade Alliance — a consortium of multiple stakeholder groups that will support voluntary resource mobilization under the Decade; mobilizing resources and infrastructure to promote the participation of young ocean scientists and professionals in research cruises; encouraging innovative and bold solutions to tackle bottlenecks related to data, technology and innovation for sustainability, including through support to innovation incubators; and advocating for further actors and stakeholders to join the Ocean Decade endeavour. The contribution from foundations will enable us to maximize our collective chances to achieve the relevant SDGs and attain ocean sustainability by 2030

3 See: http://www.oecd.org/development/financing-sustainable-development/development-finance-standards/officialdevelopmentassistancedefinitionandcoverage.htm

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The importance of the ocean cannot be overemphasized; however, evidence to support this in economic terms is difficult to find. Recently, the High-Level Panel for a Sustainable Ocean Economy issued a special report containing an estimate of the world's global net benefits from the ocean by 2050, using the cost-benefit analysis approach (Konar and Ding, 2020). This publication focused on four ocean-based policy interventions to assess and demonstrate the range of benefits obtained from the ocean: conserving and restoring mangrove habitats; scaling up offshore wind production; decarbonizing the international shipping sector; and increasing the production of sustainably sourced ocean-based proteins. The results presented show that sustainable offshore investments generate at least five times more profit than the costs involved in the operations. Investing US$2.0 trillion to US$3.7 trillion globally across the four areas of interventions over 30 years will result in a net benefit of US$8.2 trillion to US$22.8 trillion. When evaluating interventions for each of the four areas, the return on investment is high, with the average economic benefit-cost ratio ranging from 3:1 to 12:1 (Table 8.1).

**Table 8.1.** Summary of benefit-cost ratios for four action areas to reduce $CO_2$ emissions related to ocean/coastal interventions.

| ACTION | AVERAGE BENEFIT- COST RATIO |
|---|---|
| Conserve and restore mangroves[4] | 3:1 |
| Decarbonise international shipping[5] | 4:1 |
| Increase production of sustainably sourced ocean-based proteins | 10:1 |
| Scale up offshore energy production[6] | 12:1 |

*Source:* Konar and Ding, 2020.

At present, a standardized methodology to estimate the value of ocean R&D is lacking. The collection of comparable data on investments in ocean science at the international level remains a priority in order to assess the socio-economic impacts of ocean science. In addition to primary data received through the GOSR questionnaire and portal indicating the level of national investment in ocean science, the next edition of the GOSR should encompass an assessment of the value of ocean services and benefits. The assessment will be based on a combination of economic and non-economic approaches (market factors, citizen and consumer preferences, etc.), attributing values to ocean services and benefits in order to determine more comprehensively, including in quantitative terms, the contribution of the world's ocean to the global economy.

## 8.3. Ocean science and human health

### *8.3.1. Ocean science and the COVID-19 pandemic*

At the time of writing, the COVID-19 pandemic has already had obvious impacts at multiple levels and in many areas of society. A central question that is not dealt with in the previous chapters is how and to what extent will ocean science be affected? What kind of adaptation arrangements will emerge if the sanitary situation persists? Are we going to witness a redeployment of resources to other branches of science such as health research?

The Global Ocean Observing System (GOOS) embarked on an assessment of the impacts of the COVID-19 crisis on sustained observations of the ocean system (Box 8.3).

**Box 8.3.** The impact of the COVID-19 pandemic on the ocean observation system

The Global Ocean Observing System (GOOS) conducted a systematic review of the impact of the COVID-19 pandemic on the Ocean Observing System covering the period between March and June 2020. In the first stage, information from the global networks was gathered; these networks represent the majority of climate and operational services relevant observations of the ocean and consist of implementers at national and regional levels. The immediate impact had been dramatic; almost all research vessels had been called to their home ports. This affected the repeat hydrography of the Global Ocean Ship-based Hydrographic Investigations Program, the servicing of mooring arrays and the re-seeding of autonomous platforms, such as Argo profiling floats (GO-SHIP), the ocean basin scale survey sections, which are important to track climate change measuring multiple variables and to the full depth of the ocean. Four decadal ocean sections had been cancelled. Similarly, almost all work to maintain vital mooring arrays that monitor major ocean currents and critical air-sea exchanges had been cancelled. A number of these are now at risk of failure in the coming months. In June 2020, this situation affected between 30–50% of the 300+ moorings, some of which some had already ceased to send data as batteries ran out. The restrictions meant that 'ship riders' could no longer launch the expendable bathythermography profiling instruments, with the loss of some 90% of data flow from the ships of opportunity (SOOP) network.

Similarly, the deployment and recovery of autonomous underwater gliders had largely been cancelled, with 50% fewer gliders operational in June 2020,

4 The ratio presented is the combined ratio for mangrove conservation and restoration. When assessing specific interventions, the benefit-cost ratio for conservation is estimated 8:1 and for restoration is 2:1

5 The benefit-cost ratio estimated for decarbonising international shipping ranges from 2:1 to 5:1.

6 The benefit-cost ratio estimated for scaling up of global offshore wind production ranges from 2:1 to 17:1.

and many networks had not been able to maintain, calibrate or deploy new instruments.

At the same time a positive result concerning the inherent resilience that now exists in the observing system was also noted: high frequency radar and the Global Sea Level Observing System tide gauges data still flowed at almost 100%. Data flow from autonomous observing platforms and observations form Volunteer Observing Ships (VOS) networks, were also less affected. The VOS network showed an initial 10% reduction of data flow, however it recovered and the network is perhaps at only 5% down on pre-pandemic levels, similarly the surface drifters showed an initial drop as the network was not reseeded, however with strong activity from the observation community this is now also back to operational capacity. The Argo network of profiling floats, observing the top 2,000 m of the water-column, is more reliant on research vessel operations for re-seeding the array of floats and so there are problems in deploying at a normal rate. In April to June 2020 no decline in data flow from the Argo array was detectable however by October 2020, there was a 10% decline, deployment rates in October 2020 suggest that the Argo Array will recover in 2021.

As of a result of the survey, GOOS called for:

- Improved international coordination across observing system networks;
- Ocean observing operations to be prioritized as essential, to allow operators to return to maintenance, calibration and deployment work as soon as possible;
- Careful re-seeding of autonomous arrays;
- Flexibility of operations, e.g. using naval or commercial vessels for operations;
- Future-proofing, as the increased use of autonomous platforms and sensors tends to create resilience.

Up to June 2020, the system showed some resilience, due to an inherent inertia in the system through use of autonomous observing platforms, a well-maintained base, and the swift mitigation action of many observing system operators. Many datasets will have been impacted during the first months of the COVID-19 pandemic, however concerted efforts by many operators, institutes and nations have maintained critical operations. The ocean observation community need to remain vigilant as areas of concern remain, however also use this 'shock' to strengthen the system and the international cooperation on which it depends. (GOOS, 2020; WMO-UNEP-GCP-IOC-Met Office, 2020).[7]

The importance of coordinated global efforts in ocean research has become even more apparent in the current pandemic. This is evidenced, for example, by challenges in accurately determining the consequences of the economic downturn associated with COVID-19 on $CO_2$ emissions. The COVID-19 crisis also provides opportunities, such as scientific and technological developments assisting 'classical' ocean science at a time when manual operations are not possible. These developments include autonomous vehicles and sensors (Chapter 4), advances in global remote sensing and the application of increasingly sophisticated modelling, as well as AI techniques. Future developments will need to go hand in hand with currently coordinated observations on research vessels and VOS, globally curated and accessible high-quality databases, and research and modelling capacities.[8]

The High-Level Panel for a Sustainable Ocean Economy has produced a report entitled *A Sustainable and Equitable Blue Recovery to the COVID-19 Crisis* (Northrop et al., 2020). The report describes in quantitative and qualitative terms the disruption to the ocean economy caused by the pandemic. It was observed that significant impacts relate to specific sectors, namely: the extensive reduction of activities in the coastal and marine sector (estimated to be at least US$30 billion for European coastal areas, US$7.4 billion for SIDS and US$44 billion for the Caribbean); a 25% reduction in marine transportation globally; disruption of aquaculture operations due to shortage of labour; and reduced funding to support marine conservation. These economic impacts were complemented by social impacts in terms of reduced employment, inadequate health and safety for workers on some occasions, and differentiated impacts affecting in particular female workers and vulnerable groups and communities. As with remotely operated ocean observations (GOOS, 2020), largely remotely operated economies and related projections for 2021, e.g. offshore wind production, remained unimpacted. Several countries and the European Commission introduced immediate responses for marine workers and sectors, such as the extension of loans for the tourism sector, financial rescue interventions for the maritime transport sector, and financial compensation for fishers involved in wild capture fisheries and aquaculture. However, the panel noted that the fiscal stimulus packages, which amount to US$10 trillion pledged by several countries around the world to compensate for the adverse effects of the COVID-19 pandemic and rebuild economies, do not take into full account the ocean dimension of the global economy.

There is a need to assess the potential long-term impacts of the COVID-19 pandemic on the international ocean science landscape, in terms of reduced funding for research (laboratory operations, field campaigns, infrastructures, job opportunities for researchers) and for sustained observations. It is possible that funding for ocean science may suffer from being redirected towards other branches of science. The sanitary crisis might change the future interactions of those operating in the area of ocean science, with fewer and smaller physical scientific gatherings taking place alongside an increase in remote interactions. However, such possible impacts of the COVID-19 pandemics on ocean research and ocean science gatherings, as well as funding for ocean science, would have to be assessed

[7] Tanhua, T., Co-Chair of the Global Ocean Observing System (GOOS). SBSTA Chair information event with the scientific community, 8 June 2020 .

[8] Wanninkhof, R., Co-Chair of the Integrated Ocean Carbon Research (IOC-R) initiative. SBSTA Chair information event with the scientific community, 8 June 2020.

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in a systematic manner. Other than assessing the impacts of the pandemic on manual ocean observations, it is too early to be able to do so.

Evaluating the impacts of COVID-19 on ocean research will require a different approach to the way in which impacts on ocean research have been assessed and described to date. The data contained in the GOSR2020 are pre-COVID-19, while the next edition of the report will allow the full impact of the pandemic to be measured on ocean science infrastructure, human and technical capacities, including core funding, investments by the private sector, scientific production, conferences, observations, trends in R&D, employment and the gender dimension of ocean science. It is anticipated that an intermediary study will be undertaken, based on the methodology of the GOSR2020, and adapted to reflect the specificity of the COVID-19 crisis, using tailored variables and indicators. This report, due in 2022, will also contain recommendations on how to redesign the ocean science enterprise in a time of COVID-19, so that new knowledge on the state of the world ocean can continue to be generated at a time of global health crises, and the multiple societal applications stemming from such knowledge can continue to be developed.

### *8.3.2. The contribution of ocean science to human health*

At the time of publishing (December 2020), during which the COVID-19 pandemic is still unfolding, there is a need to step back and look more generally at the clear evidence that we have on the contribution of ocean science to important research and discoveries relevant to human health. The analysis in this report examines key trends emerging from the technometrics analysis (Chapter 5), highlighting the need to expand the scope of how ocean science is defined (see the eight categories of ocean science, Chapter 2) and for the need to add an additional high-level theme in national and international ocean research strategy and policy: ocean and human health.

It is gradually accepted that, as much as humans affect ocean health, the ocean also affects human health and well-being, both in terms of risks (e.g. pollution, ocean hazards) and solutions (e.g. pharmaceuticals from the ocean, proteins, recreation). An increasingly recognized subject in academia, the theme 'ocean and human health' is still in its infancy and requires further articulation in a policy context (European Marine Board, 2020). The European Commission project on Seas, Oceans and Public Health in Europe (SOPHIE) has developed a strategic agenda for mainstreaming ocean issues into human health, through the pursuit of actions linking ocean and health research in the following areas: sustainable seafood for healthy people; blue spaces, tourism and well-being; marine biodiversity, medicine and biotechnology; and enabling trans-disciplinary and trans-sectoral collaborations (H2020 SOPHIE Consortium, 2020). As the emerging 'ocean and human health' interdisciplinary science unfolds, SOPHIE recommends that 'medical, public health, marine, environmental science need to work together; that co-creation and engagement with communities, business, NGOs and government is essential; and that transdisciplinary training must be offered'.[9]

The High-Level Panel for a Sustainable Ocean Economy reports that advances in sequencing technology and bioinformatics have increased our understanding of the ocean genome; these new insights are likely to lead to, and in some cases have already led to, improvements in marine conservation planning and management, marine protected area designation, and a variety of commercial-based biotechnology products such as new medicines from marine natural products, cosmetics and industrial chemicals (Blasiak et al., 2020).

Current science-policy efforts in ocean and human health were first triggered by a group of experts from multiple disciplines that convened spontaneously in Bedruthan, UK, in 2014[10] (see also Fleming et al., 2014). At the intergovernmental level, IOC-UNESCO has focused on the linkages between ocean and human health through its Harmful Algal Blooms programme (Young et al., 2020).

There is an opportunity with the Ocean Decade to expand the scope of current science-policy initiatives on ocean and human health beyond a risk framework; as a first step, this will need to fully capture the true benefits, value and importance of ocean resources (Fleming et al., 2019).

[9] Presentation by L. Fleming at the UN Decade of Ocean Science for Sustainable Development Webinar on Ocean and Human Health, 9 October 2020.

[10] Message from Bedruthan, see: https://marineboard.eu/sites/marineboard.eu/files/public/images/Message_from_Bedruthan_March2014_FNL.pdf.

## 8.4. Charting ocean science in the next decade

### *8.4.1. Breaking down the data barriers via the Ocean Decade*

Enhanced ocean data management is a priority theme of the Ocean Decade. The Decade looks at the management, sharing and use of relevant ocean data, information and knowledge as a key area for transformative action with which it will assist. The Ocean Decade aims to create a multistakeholder, multicomponent 'digital ocean ecosystem' that will be comprised of interoperable data infrastructures, both existing and newly developed. The creation of this ecosystem will be a dynamic and continuous process, incorporating established approaches and technologies, as well as those that are only just emerging. Capacity development, including TMT, will be essential to ensure that there is open and equitable access to data, information and knowledge and to facilitate the linkages to non-digitized knowledge, for example local and indigenous knowledge. Ocean Decade Challenges No. 8 (Creating a digital representation of the ocean) and No. 9 (Ensuring comprehensive capacity development and equitable access to data) explicitly reflect the importance of data management and related capacity development throughout the Ocean Decade.

The fields of application for the findings of ocean science are numerous and, in principle, limitless. One of the rules of practice of science is never to predict where science will lead, as scientific discoveries are often unforeseen and characterized by ingenuity, both in the underpinning research questions and also in the methods that make the discovery possible.

As mentioned previously in this chapter, ocean science is first and foremost a human endeavour and, as such, is faced with limitations such as barriers in the sharing of data and information. This is a stumbling block in the free pursuit of knowledge through ocean science into the next decade.

The GOSR2020 and the Ocean Decade both concur on the urgent need for new approaches in accessing data and information to overcome critical barriers hampering knowledge generation through science, in order to contribute to actions towards a sustainably managed ocean, and sustainable development in general (Chapter 7). A new, constructively disruptive approach to data is unfolding, building on the growing use of social media and the advances in AI technologies. Pendleton et al. (2019) recognized that significant advances have taken place to enhance the interoperability and transparency of data but that these represent small steps in light of the huge challenge the ocean community faces: to make all data feasibly and openly accessible, as and when needed. A number of measures leading to a technical and cultural step change were proposed. These solutions entail and reflect a combination of dimensions, including the processing of natural language, automatic data translation, incentives in the form of 'digital currencies' and data impact factors, and social networking solutions.

At present, ocean science is far from such a needed data revolution. The findings presented in Chapter 7 show that, globally, 60% of data centres limit the access to certain types of their data. The data centres that do not apply any restrictions are the exception to the rule, even though more than 60% of the data centres claim to manage in a 'FAIR' way — findable, accessible, interoperable and reusable. Data centres are connected through relevant international platforms, but this situation varies significantly on a regional basis. We are far from an open access ocean data reality.

On the other hand, the GOSR2020 concludes that the types of users of ocean data continue to increase in diversity, which demonstrates both the relevance of ocean data for the operations of multiple stakeholders and a positive trend in their increasing demand for more data in the future.

In addition to a much-needed cultural revolution in our approach to ocean data, there remains a need to gather data for entire portions of the world ocean which continue to be poorly observed. Ultimately, data collection in the next decade, and the underpinning human and infrastructural and financial resources needed to support this endeavour, will follow the vision of a comprehensive and holistic digital representation of the ocean, including a dynamic ocean map, allowing the matching of data to needs by multiple stakeholders, thus fostering collaboration as foreseen in the Ocean Decade.[11]

[11] The High-Level Panel for a Sustainable Ocean Economy (Leape et al., 2020) reported that the sharing of ocean-related data, real-time information acquisition and automation, and investment for innovation should be supported by an open, viable and equitable digital ecosystem for the ocean. The paper suggested six critical steps to realize the vision of a digital ocean, namely: capitalize on the Ocean Decade; liberate ocean data; create an 'Internet of Things' for the ocean; automate ocean management based on near real-time data on ocean conditions and resource use; create incentives for innovation; and mobilize capital for technologies for under-served markets.

### 8.4.2. Coordination of ocean science activities towards the Ocean Decade

A substantial increase in country-level ocean science productivity, including via adequate capacity enabling measures, coupled with a significant increase in the uptake and use of that science by diverse actors, will be essential to achieving the ambitious and transformative outcomes of the Ocean Decade. The next decade must benefit from a balanced approach between national positional aspirations in ocean science and competitiveness, and the need to enhance opportunities for scientific collaboration through co-design of research agendas and joint data-gathering programmes, co-production of knowledge through science, cross-fertilization in the practice of science by academia and the private sector, and the recognition and valorization of relevant indigenous and local knowledge. It is only through such an approach, balancing the interests of specific stakeholder groups with a collective vision of ocean sustainability, that knowledge generated through ocean science will be transferable into practical solutions to ocean problems.

The Ocean Decade shall unify actions based on co-design of the ocean research and observation agenda, co-production of knowledge, and co-delivery of ocean solutions; mobilize interest and resources to develop further capacity in ocean science and for transferring knowledge and technical know-how, so that nations of the world can collectively contribute to and benefit from a sustainable ocean; further link ocean sustainability with sustainable blue economies; and deliver on a set of shared societal goals relative to a clean, data transparent and safe ocean (IOC-UNESCO, 2020).

In more concrete terms, future actions fed by ocean science will contribute to meeting the Ocean Decade Challenges and to achieving the Decade Objectives. When analysing the Decade Challenges, it is clear that ocean science will have a central role in mobilizing and generating further scientific knowledge around Challenge 1 (Pollution and contaminants, and questions related to ocean and human health), Challenge 2 (Multiple ocean stressors), Challenge 3 (Food security), Challenge 4 (Sustainable ocean economy), Challenge 5 (Ocean-Climate nexus), Challenge 6 (Ocean hazards), Challenge 7 (Ocean observations), Challenge 8 (Data), Challenge 9 (Capacity development) and Challenge 10 (Inciting behaviour change). Important criteria to develop the actions will be co-designed by knowledge generators and users; provision of all resulting data will be in an open access, shared, discoverable manner (section 8.4.1); and the promotion of gender, generational and geographic equity and diversity will be interwoven across all areas.

Furthermore, the GOSR is the recognized method and repository of related data to measure progress towards the achievement of SDG target 14.a: 'Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the IOC-UNESCO 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'. Reporting in a transparent and timely manner on efforts in the area of ocean sciences and related capacity is a major task. Importantly, the GOSR will continue to act as a platform for collaborative actions to boost ocean science capacity in the next decade; it is expected that the current and upcoming editions of the GOSR will constitute an integral element of the monitoring and evaluation framework to track the achievements and outcomes of the Ocean Decade, thus allowing Ocean Decade actions and priorities to be adapted to respond to emerging needs and contexts.

However, science productivity — as measured by publication rates — does not provide a full picture of the trends in the use and uptake of this new knowledge by society for decision making, awareness raising, resource management or corporate planning, in order to contribute to sustainable development. In the context of the upcoming Ocean Decade, there will be a need for a new battery of tools to assess and track the rate of societal uptake of science and knowledge, and to measure the capacity of different stakeholders to access and use science. Such tools will be developed as part of the monitoring and evaluation framework for the Ocean Decade and will inform and be informed by future editions of the GOSR.

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# Annexes

# Annex A

# Biographies of authors and members of the editorial board

### Salvatore Aricò

Salvatore Aricò is Head of the Ocean Science Section at the Intergovernmental Oceanographic Commission of UNESCO, where he contributes to shaping the ocean science agenda in the next decade. Previously, he was Executive Secretary of the United Nations Secretary-General's Scientific Advisory Board; coordinator of UNESCO's intersectoral Biodiversity Programme; a senior researcher at the United Nations University Institute of Advanced Studies; Chief of the Marine and Coastal Biodiversity Programme of the Convention on Biological Diversity; and a researcher at the University of Delaware, USA. He obtained his PhD at the Stazione Zoologica di Napoli. He has authored 85+ publications on biodiversity, the ocean, global change and science and technology, including *Ocean Sustainability in the 21st Century* (CUP). He is the Director of IOC-UNESCO's *Global Ocean Science Report*. Among Salvatore Aricò's achievements are building the scholarly evidence demonstrating the need for a BBNJ agreement and contributing to the creation of the Intergovernmental Panel on Biodiversity and Ecosystem Services.

### Julian Barbière

Julian Barbière heads the Marine Policy and Regional Coordination Section at the Intergovernmental Oceanographic Commission of UNESCO. Educated as an environmental scientist, he has approximately 25 years of experience at the international level in the field of ocean sustainability, science-policy interface ocean governance and the implementation of ecosystem-based management approaches in a multi-stakeholder context. Since 2017, he has been leading the preparation phase of the UN Decade of Ocean Science for Sustainable Development (2021-2030).

### Alexandre Bédard-Vallée

Alexandre Bédard-Vallée joined Science-Metrix in January 2019 as a research analyst. Since mid-2019, he has produced the majority of the bibliometric and technometric indicators for multiple bibliometrics projects. He is also a main contributor to ongoing work on a suite of automated tools that will enable automated bibliometric indicator computation and visualization. Alexandre Bédard-Vallée holds an MSc in Physics from Université de Sherbrooke with a specialization in experimental quantum computing. During his master's degree project, he was able to gain substantial experience in data analysis, problem solving and programming. This experience also allowed him to build a solid understanding of academic research and funding.

### Mathieu Belbéoch

Mathieu Belbéoch is the lead of the joint IOC-WMO Centre OceanOPS. He has 20 years of experience at international level in ocean observation systems implementation and governance. With a mathematical engineer background, applied to numerical modelling in oceanography, and after a short experience leading web development projects, he has supported the development of the Argo programme as Technical Coordinator, and made OceanOPS into a firm operational centre to support key *in situ* ocean observing systems. He has been the architect of an ambitious web-based information system to monitor the GOOS and deliver tools and services essential to its implementers. He has pioneered the 'citizen scientist' concept by using sailing ships and NGOs to help sustain the global arrays and raise greater public awareness of ocean observations

### Sergey Belov

Sergey Belov is Deputy Director of the All-Russian Research Institute of Hydrometeorological Information-World Data Center (RIHMI-WDC). He holds a PhD in system analysis from the Russian Academy of Science. Sergey Belov graduated from Obninsk State University in 2003 with an MSc in industrial information systems. He has worked at RIHMI-WDC since 2001. He has been involved in international cooperation activities as an expert at IOC-UNESCO and WMO levels since 2005. Since 2019, he has co-chaired the International Oceanographic Data Exchange (IODE) programme of IOC-UNESCO.

### John Bemiasa

John Bemiasa is Vice-Chair of the IOCAFRICA in charge of the East African Countries and Adjacent Islands. He graduated from the Fishery Institute and Marine Sciences (University of Toliara, Madagascar) with a PhD in oceanography. He is a senior lecturer and worked for the Madagascar National Oceanographic Data Centre (MD NODC) as Scientific Ocean Data Manager for 22 years. He has been the National IODE Coordinator for Madagascar since 2010 and has been engaged as a member in several regional/international groups of experts, in particular in the African Marine Spatial Planning initiative and the 2nd International Indian Ocean Expedition (IIOE-2). John Bemiasa was also the national technical focal point for the SWIOFP (South Western Indian Ocean Fishery Project): component 4, monitoring pelagic fish in the South West Indian Ocean (2007–2013) and the GMES & Africa Project (Global Monitoring of Environment and Security) (2010–2020).

## Alison Clausen

Alison Clausen joined the Intergovernmental Oceanographic Commission of UNESCO as a programme specialist in 2019 with over twenty years' professional experience in programme and project development and management in the areas of marine conservation, marine policy and climate change adaptation. Before joining IOC-UNESCO she was based in Madagascar, where she worked throughout the Western Indian Ocean region for the World Bank and most recently as the Regional Director for the Madagascar and Western Indian Ocean programme of the Wildlife Conservation Society. Prior to that she was based in Vietnam where she worked through South-East Asia for a range of development banks, UN agencies and NGO partners. She is currently working on diverse ocean and marine policy issues including support to the coordination of the preparation of the UN Decade of Ocean Science for Sustainable Development.

## Roberto de Pinho

Roberto de Pinho holds a PhD in computer science and computational maths from the Universidade de São Paulo (USP) and an MSc in energy industry regulation. He is a senior science and technology analyst at the Brazilian Ministry of Science, Technology and Innovation, currently working in the department for General Coordination for the Ocean and Antarctica. He was Head of Section, Science, Culture and Communication at the UNESCO Institute of Statistics, Deputy Secretary at the Secretariat of Science, Technology and Innovation, State of Bahia, Brazil, and delegate to the OECD's National Experts on Science and Technology Indicators Working Party (NESTI). He is an acknowledged contributor to the *Frascati Manual 2015* and has published in collaboration with experts from institutions such as the OECD, UNESCO and IBGE (Brazil's national statistics office). As a data scientist and STI policy and indicators expert, he has worked on relevant projects in data mining and visualization, bibliometrics, and STI policy and indicators definition and analysis.

## Itahisa Déniz González

Itahisa Déniz González is a project specialist at the Intergovernmental Oceanographic Commission of UNESCO, where she has worked since 2013. Her work is mainly focused on ocean science capacity, in particular its enhancement in developing countries of North-West Africa. She has ten years of experience in the management of international cooperation projects that promote the divulgation and sharing of scientific information and knowledge. She holds a degree in marine science and an MSc in coastal management from the University of Las Palmas de Gran Canaria, Spain, where she carried out research on coastal geological heritage.

## Henrik Enevoldsen

Henrik Enevoldsen is Head of the IOC-UNESCO Science and Communication Centre on Harmful Algae, which is hosted by the University of Copenhagen, Denmark. He has a background in aquatic ecology and has worked for more than 25 years in the development and implementation of international research and capacity building in marine science. He has published on harmful algae ecology, international capacity building and programme development. He coordinates several international scientific working groups and regional networks in marine science, including the joint IOC-SCOR international research programme GlobalHAB and the IOC Intergovernmental Panel on Harmful Algal Blooms (IPHAB). He is the IOC-UNESCO Technical Secretary of GESAMP. He was a contributing author and part of the report team for the first *Global Ocean Science Report* (2017), contributing author to the 2nd edition to be released in 2020, and is actively involved in the preparations for the UN Decade for Ocean Science for Sustainable Development 2021–2030.

## Elva Escobar Briones

Elva Escobar received her PhD in biological oceanography from the Univerisdad Nacional Autonoma de México (UNAM) and is a full-time professor engaged in deep sea benthic macroecology, biodiversity conservation and sustainable use at Instituto de Ciencias del Mar y Limnología (ICML) UNAM. Together with her students, she conducts fieldwork on board UNAM's research vessels and contributes to the long-term research observations in the Gulf of Mexico. Her research in collaboration with national and international institutions, describing biodiversity patterns in the abyssal oceanic regions of Mexico, has been widely published. These results have been used to define policies, and to design conservation networks and programmes in the deep ocean. She has also engaged with capacity building programmes in biological oceanography and is a lead member of the Deep Ocean Stewardship Initiative (DOSI).

## Emma Heslop

Emma Heslop is a physical oceanographer with significant strategic and business development expertise. She completed a PhD in physical oceanography and is passionate about the need for sustained monitoring of the oceans and the utility of ocean data for science, government and industry applications, now and into the future. Her experience in oceanography encompasses circulation variability, new technology such as gliders, model validation, multi-platform ocean observing systems, the economics of ocean data and ocean data products. She has proven leadership of research projects, international collaborations and a successful record of applying business practice to help bridge the gap between ocean science and societal applications. In 2018, she joined the Intergovernmental Oceanographic Commission of UNESCO to support the development of the Global Ocean Observing System (GOOS), in particular the development of a Global Ocean Observing System 2030 Strategy. She is now focused on energizing the community, nations and partners towards the implementation of this ambitious vision.

### Kirsten Isensee

Kirsten Isensee has been a programme 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 in support of the 2030 Agenda for Sustainable Development. She provides technical assistance to activities promoting women in ocean science and facilitates collaboration between scientists, policymakers and stakeholders, via networks such as the Global Ocean Acidification Observing Network, the International Blue Carbon Initiative and the Global Ocean Oxygen Network. She received her diploma and her PhD in marine biology from the University of Rostock, Germany.

### Claire Jolly

Claire Jolly is Head of Unit in the Directorate for Science, Technology and Innovation (STI) in the Organisation for Economic Co-operation and Development (OECD). She is in charge of the OECD research and analysis on the economics and innovation dimensions of two important frontier domains: the ocean and the space environment. Many science, research and development, innovation and economic activities are now linked to the exploration and sustainable uses of the ocean and of the space environment. Claire Jolly had over 20 years of experience in business and policy analysis, supporting decision-making and strategic planning in public and private organizations in Europe and North America, before joining the OECD in 2003. She has authored and contributed to over 40 publications (books, reports, articles) focusing on the evolution and impacts of science- and technology-intensive sectors (e.g. space, ocean, defence). Her background is in international economics (MA University of Versailles, Cornell University), engineering (ENSTA, Paris), with a special interest in the space sector (MSc ISU in Strasbourg) and international security studies (alumna of the French Institute for Higher National Defence Studies in Paris — Institut des hautes études de défense nationale, IHEDN).

### Kwame A. Koranteng

Kwame Koranteng is a fisheries scientist, statistician and marine ecosystems analyst. He received his PhD from the University of Warwick, UK. He worked for the Food and Agriculture Organization of the United Nations, is a former Eastern Africa Regional Representative of WWF — the global conservation organization; and former staff member and Director of the Marine Fisheries Research Division, Ministry of Food and Agriculture (Ghana). He has over 40 years' experience of working in aquatic biodiversity assessments, management and conservation. Kwame Koranteng has provided scientific advice to local communities, governments and non-governmental organizations. He also served as Chairman of the Africa Coordinating Committee of the Global Ocean Observing System (GOOS-Africa), member of the GOOS Living Marine Resources Panel and Capacity Development Panel, Co-Chairman of the Global Marine Assessment Group of Experts, Vice-Chairman of the FAO Advisory Committee on Fishery Research, and member of the Ghana National Commission for UNESCO's Natural Science Committee.

### Ana Lara-Lopez

Ana Lara-Lopez is a marine scientist with over 20 years' experience in marine ecology and applied (laboratory and field-based) research. Her expertise includes environmental and fisheries science in estuarine, coastal and oceanic ecosystems, both tropical and temperate. She has been working in science coordination in marine observatories in Australia over the last six years to improve the integration and coordination of multidisciplinary observing systems. She chaired the Australian Coastal and Oceans Modelling and Observations workshop, led the creation of the Marine Science and Data MOOC at the University of Tasmania and established the IMOS Larval Fish Observing facility in Australia. Ana completed her BSc and MSc in marine biology at the National University of Mexico and her PhD at the University of Tasmania in 2006. She also worked as a postdoctoral research scholar at the Scripps Institution of Oceanography in California. She is currently working in science coordination for EuroGOOS in Brussels and is an adjunct researcher at the Institute for Marine and Antarctic Studies at the University of Tasmania.

### Youn-Ho Lee

Youn-Ho Lee is Vice-President and a professor at the Korea Institute of Ocean Science and Technology (KIOST). He graduated from Seoul National University and received his PhD in marine biology at the Scripps Institution of Oceanography of University of California, San Diego, in 1994. Before he joined KIOST, he worked as a research and a senior researcher at the California Institute of Technology from 1994 to 1998. His research interest covers molecular ecology, population genetics and molecular evolution of diverse groups of marine organisms. He served as an advisory committee member of the Ministry of Education, Science and Technology, National Science and Technology Commission, and as a member of the National Committee for Sustainable Development of the Korean Government. He also served as Vice-Chair of the IOC-UNESCO Sub-Commission for the Western Pacific (WESTPAC) from 2012 to 2017. Youn-Ho Lee is currently a member of the Advisory Committee for the Ministry of Oceans and Fisheries, and a member of IOC's Executive Planning Group for the UN Decade of Ocean Science for Sustainable Development.

### Jan Mees

Jan Mees has been General Director of the Flanders Marine Institute (VLIZ, Oostende, Belgium) since its establishment in 1999. Trained as a marine biologist and ecologist, he holds an MSc in zoology, an MSc in environmental sanitation and a PhD in marine biology, all from Ghent University, Belgium, where he is a part-time professor. Jan Mees served as elected chair of the European Marine Board from 2014 to 2019 and represents Flanders in the Belgian delegation to the Executive Council and General Assembly of the IOC of UNESCO. His research interests include marine biodiversity, ecology and taxonomy and he is the author of close to 100 scientific publications.

### Yutaka Michida

Yutaka Michida is currently a professor at the Atmosphere and Ocean Research Institute (AORI) at the University of Tokyo, Japan. He received his PhD in physical oceanography from the University of Tokyo. He served as a research officer for the Japan Coast Guard in its Hydrographic Department for 1984–2000, then moved to the Ocean Research Institute (currently AORI) in 2000. He has been contributing to oceanographic data management for more than 30 years, as Deputy Director of the Japan Oceanographic Data Center (JODC) from 1997–1999, and was Co-Chair of the International Oceanographic Data and Information Exchange Programme (IODE) of IOC-UNESCO from 2015 to 2019. Yutaka Michida was also one of the vice chairs of IOC from 2011–2015, and Chair of the Japanese National Committee for the IOC since 2018. In addition to physical oceanography, his major research field, he has recently extended his research interests to include marine pollution and marine policy.

### Leonard A. Nurse

Leonard A. Nurse was the first Director of the Coastal Zone Management Unit, Barbados. He retired in 2018 as Professor, Integrated Coastal Management and Climate Change Adaptation, University of the West Indies, Barbados. He was Chairman of the Board of Governors, Caribbean Community Climate Change Centre, Belize for almost 15 years. He was a coordinating lead author for the IPCC third, fourth and fifth assessments. He served as Vice-Chair of the IOC Sub-Commission for the Caribbean and Adjacent Regions, and from 2002–2004 he was a member of the Scientific and Technical Advisory Panel of the Global Environmental Facility. His work focuses on coastal and nearshore dynamics under a changing climate, and assessment of risk, vulnerability and adaptation on small islands, subjects on which he has published widely in various scientific journals. Leonard A. Nurse is a graduate of the University of the West Indies, Mona Campus, Jamaica, Memorial University of Newfoundland, and McGill University, Canada.

### Ntahondi Mcheche Nyandwi

Ntahondi Mcheche Nyandwi works with the University of Dar es Salaam at the Institute of Marine Sciences, Zanzibar. He was Deputy Director of the Institute for 12 years, from 2001 to 2012. He was responsible for research coordination and ensuring research quality control by overseeing oceanographic deployments. Ntahondi Mcheche Nyandwi graduated with a BA in geology at the University of Dar es Salaam, Tanzania in 1984 and later undertook an MSc in marine geotechniques at the University College of North Wales, Bangor, UK. During his PhD, he stayed at the Senckenberg Institute in Wilhelmshaven, Germany where he gained vast experience with marine operations and worked on sedimentation processes in the German Wadden Sea. He coordinates Tanzania's activities related to the Second International Indian Ocean Expedition initiatives. Ntahondi Mcheche Nyandwi has served in a number of positions including the Climate Change National Adaptation

Plan (NAP) and as leader of a team of experts undertaking the stocktaking exercise for the preparation of the NAP document for Tanzania. He has contributed to and published over 60 publications in the form of journal papers and conference proceedings.

### Mattia Olivari

Mattia Olivari is an economist working in the OECD's Directorate for Science, Technology and Innovation (STI). He is contributing to the development of original economic and innovation indicators related to science- and technology-intensive sectors, as well as conducting specific research on the socio-economic impacts of institutional investments in space programmes. Mattia Olivari contributed to and authored several reports published by the OECD, and papers in scientific journals. Before joining the Directorate for STI in 2016, Mattia Olivari worked at the OECD Development Centre (from 2013), conducting policy assessments in the fields of social capital, rural development and poverty reduction. He holds a BA and an MSc in economics and social sciences with a major in quantitative methods from Bocconi University in Milan, Italy.

### Linwood H. Pendleton

Linwood Pendleton is Senior Vice-President for Science at the Centre for the 4th Industrial Revolution — Ocean in Oslo, Norway. He also holds the International Chair of Excellence at the European Institute for Marine Studies (France), a senior fellowship at Duke's Nicholas Institute for Environmental Policy Solutions (USA), and an honorary professorship at the University of Queensland's Global Change Institute (Australia). Linwood lives just 500 m from the Iroise Sea Marine Natural Park in Finistère, France. Linwood has broad experience in marine conservation science with degrees in biology (William and Mary), ecology/evolution/behaviour (Princeton), public administration (Harvard) and environmental economics (Yale). His work, both in academia and the real world, incorporates all of these fields and more. Linwood served as Acting Chief Economist for the National Oceanic and Atmospheric Administration from 2011–2013, and is an adjunct associate professor at the Duke University Marine Laboratory. He has also collaborated with conservation organizations worldwide, including the WWF, the Nature Conservancy, Environmental Defense Fund, NRDC, and he served for nearly ten years on the Board of the Conservation Strategy Fund. He currently serves on the Executive Planning Group of the United Nations Decade of Ocean Science for Sustainable Development, the MarineGeo Advisory Council, the GEO Blue Planet steering committee and the Marine GEOBON RCN.

### Benjamin Pfeil

Benjamin Pfeil is Head of the Bjerknes Climate Data Centre at the University of Bergen and was Acting and Deputy Director of the Ocean Thematic Centre of RI ICOS. He has been involved in major international data management efforts in the field of marine biogeochemistry (SOCAT and GLODAP) and has been responsible for the data management of more than 25 EU- and NFR-funded projects. He has a strong link to the international scientific marine biogeochemistry and data management community through various networks. He is Co-Chair of the Data Sub-Committee for the Southern Ocean Observing System (SOOS), a member of the Scientific Steering Group of IOC-UNESCO/SCOR's International Ocean Carbon Coordination Project (IOCCP), the Research Infrastructure Committee of RI ICOS, the Executive Council for IOC-UNESCO/IAEA's Global Ocean Acidification Observing Network (GOA-ON), IOC-UNESCO's Global Ocean Surface Underway Data Project (GOSUD), a Scientific Committee member for the H2020 infrastructure project SeaDataCloud, a Steering Committee member of CMEMS INSTAC and has been a member of the OECD Global Science Forum Expert Group on International Coordination of Cyber-infrastructures for Open Science. His group is leading marine data activities such as the ICOS OTC and the Norwegian EMSO.

### Susan Roberts

Susan Roberts is Director of the Ocean Studies Board at the US National Academies of Sciences, Engineering and Medicine, a position she has held since 2004. 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. Susan Roberts received her PhD 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. Susan Roberts is an elected Fellow of the American Association for the Advancement of Science (AAAS) and the Washington Academy of Sciences.

### Juana Magdalena Santana-Casiano

Juana Magdalena Santana Casiano holds a PhD in marine science and is a full professor in chemical oceanography at the Faculty of Marine Sciences at the University of Las Palmas de Gran Canaria, ULPGC. She is the principal investigator on marine trace metal research in the QUIMA group at the Institute of Oceanography and Global Change. She served as the Director of the PhD programme in oceanography from 2001 to 2011 and as Vice Dean of postgraduate studies on marine science from 2010 to 2017 at the ULPGC. Her work is dedicated to the study of the effect of acidification, global warming and the presence of organic matter on the biogeochemical cycle of iron in the marine environment. From 1995, she has participated in the study of the CO2 system and its effect on ocean acidification in the ESTOC oceanic time series station in the North-East Atlantic Ocean. Juana Magdalena Santana Casiano has also participated in oceanographic cruises in the Sub-Arctic, Antarctic and Atlantic regions in collaboration with international institutions.

### Karina von Schuckmann

Karina von Schuckmann is an expert in physical oceanography. Her work focusses on the ocean's role in the earth energy budget and for sustainable development, ocean heat storage and ocean warming, the global ocean observing system and ocean reanalyses. She has a long list of scientific publications, including *Nature Climate Change* and many other international journals, contributes as lead author to the sixth assessment cycle of IPCC, and has been elected as a member of the European Academy of Science. She has contributed to major advancements in climate science on the topic of the earth energy imbalance, due in particular to her leadership in international initiatives at WCRP and GCOS level. Since she joined Mercator Ocean International, she has built up the reporting activity of the Copernicus Marine Service, including as the lead of the annual Ocean State Report. She is a member of the GOOS/GCOS physics and climate panel.

### Margareth Serapio Kyewalyanga

Margareth Serapio Kyewalyanga is a senior lecturer and Director of the Institute of Marine Sciences (IMS), University of Dar es Salaam (UDSM). She completed her MSc and PhD in biological oceanography at Dalhousie University in Nova Scotia, Canada, and graduated in 1991 and 1997, respectively. She has extensive sea-going and research experience. Her research interests include phytoplankton ecology and primary production in the marine environment, and physiological aspects of phytoplankton. She is also interested in remote sensing and modelling of primary production, as well as the monitoring of harmful micro-algae in coastal waters. She maintains strong international and regional collaborations. For example, she is the IOC focal point, representing Tanzania, at the IOC statutory meetings; she is a member of the SCOR Capacity Development Committee; and she represents UDSM-IMS at many international and regional forums. Margareth Serapio Kyewalyanga is involved in several national, regional and international research projects, and teaches and supervises post-graduate students.

### Yoshihisa Shirayama

Yoshihisa Shirayama was born in in Tokyo in 1955 and obtained his PhD from the Graduate School of Science, University of Tokyo (UT), in 1982. He then served as an assistant and associate professor at the Ocean Research Institute, UT. In 1997, he became a professor at the Seto Marine Biological Laboratory, Faculty of Science, Kyoto University. In 2003, the laboratory moved to the Field Science Education and Research Center. He served as Director of the centre from 2007, following which he worked as the Executive Director of Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) for seven years from April 2011, and served as both the Associate Executive Director and the Director of Global Oceanographic Data Center (GODAC) of JAMSTEC from April 2018 onwards. His major research field is marine biology, especially taxonomy and ecology of deep-sea meiobenthos. He also investigates marine biodiversity and how this is impacted by ocean acidification. He was awarded the 'Oceanic State Promotion Contributors Award', one of the Prime Minister's Awards, in Japan, August 2018.

### Paula Cristina Sierra-Correa

Since 2000, Paula Cristina Sierra-Correa has been Head of Research and Information for Marine and Coastal Management at the Marine and Coastal Research Institute (INVEMAR). A Colombian, she holds a PhD in marine ecosystem-based adaptation to climate change and received her MSc on geo-informatics and coastal zone management from ITC-University of Twente, Netherlands. She has worked at INVEMAR since 1996. She was part of the team that elaborated the coastal zone policy in Colombia. She has participated in the elaboration, execution and coordination of more than 25 research projects (including at least 5 international projects). She was a leader of the GEF project 'Design and Implementation of Marine Protected Areas Subsystem in Colombia'. Currently, Paula Cristina Sierra-Correa is a leader of the European Union Action on mangroves, seagrasses and local communities in the Caribbean (MAPCO). Since 2015, she has been responsible for coordinating the Regional Training Center for Latin America with the OTGA strategy of IODE-IOC-UNESCO, and for active research at Caribbean Marine Atlas linked with CLME+ following the state of the marine environment in the Caribbean Region. She has expertise in coastal planning and policy options, climate change issues (impacts, vulnerability, adaptation and mitigation). She has authored more than 20 scientific publications and leads a research team of over 35 people.

## Jacqueline Uku

Jacqueline Uku is a senior research scientist and research coordinator at the Kenya Marine and Fisheries Research Institute (KMFRI). She is currently President of the Western Indian Ocean Marine Science Association (WIOMSA). She is also a co-opted member of the Scientific Committee on Oceanic Research (SCOR). She holds a PhD in plant physiology from Stockholm University and an MSc in biology of conservation from the University of Nairobi. In the recent past, she was also the project coordinator of the World Bank-funded Kenya Coastal Development Project (KCDP). Her work is focused on strengthening the contribution of ocean science to Blue Economic growth, fostering linkages between scientists and policymakers and enhancing ocean literacy in the Western Indian Ocean region. Along with Jan Mees, Jacqueline Uku has served as Co-Chair of the GOSR2020 Editorial Board. In 2019, Jacqueline Uku was awarded the NK Pannikar Award by the IOC Assembly for her efforts in supporting capacity building in marine science in the Western Indian Ocean Region.

## Luis Valdés

Luis Valdés is Research Professor and Coordinator of International Affairs at the Instituto Español de Oceanografía (IEO). He was Head of Ocean Sciences at the Intergovernmental Oceanographic Commission of UNESCO from 2009 to 2015, and formerly (2000–2008) served as Director of the Centro Oceanográfico de Gijón-IEO. In the period 2002–2008, he was appointed as Spanish delegate for both IOC-UNESCO and the International Council for the Exploration of the Sea (ICES). With more than 35 years of experience in marine research and field studies related to marine ecology and climate change, he established the time series programme in 1990, which is based on ocean sampling sites and marine observatories, and maintained by Spain in the North Atlantic. He has a long experience in science management and has advised governmental, intergovernmental and international organizations, as well as research funding agencies. He has also chaired several working groups and committees, including the ICES Oceanographic Committee.

## Christian Wexels Riser

Christian Wexels Riser is a special adviser at the Department for Ocean and Polar Research at the Research Council of Norway, a position he has held since 2012. Christian Wexels Riser is coordinator for the research programme 'Marine Resources and the Environment', the Research Council's most important thematic initiative in the field of marine ecological research. It is designed to provide the government administration with a sound knowledge base and promote increased value creation based on marine resources, with sustainability as an underlying principle throughout. Christian Wexels Riser is a biologist by training and received his PhD in marine ecology from the Arctic University of Tromsø, Norway. As a scientist, Christian Wexels Riser has worked extensively on various questions related to carbon cycling in different seas, including the Arctic, Antarctic, North Atlantic, Mediterranean and the Adriatic, with a special focus on the role of lower trophic levels. He has been a member of the Norwegian delegation to the IOC venues since 2016.

## Dongho Youm

Dongho Youm has been a senior researcher at KIMST (Korea Institute of Marine Science and Technology Promotion) since 2010. His work mainly focuses on the managing and planning of marine science R&D programmes in the Republic of Korea. He also takes part in the management of international cooperation programmes, such as the US-Korea Sea Grant Collaboration, and in establishing the basis for international cooperation on ocean science programmes in the Republic of Korea. For the period 2019 to 2021, he has been seconded to the Intergovernmental Oceanographic Commission of UNESCO as a GOSR project officer. He holds an MSc in systematic biology with marine invertebrates from Seoul National University, Republic of Korea.

# Annex B

## Acronyms and abbreviations

B

## A

| | |
|---|---|
| **AAD** | Australian Antarctic Division |
| **AANChOR** | All Atlantic Cooperation for Ocean Research and innovation |
| **ADCP** | Acoustic doppler current profilers |
| **ADUs** | Associate Data Units |
| **AIUs** | Associate Information Units |
| **AMLC** | Association of Marine Laboratories of the Caribbean |
| **AODN** | Australian Ocean Data Network |
| **AR** | Argentina |
| **ARC** | Average of Relative Citations |
| **ARIF** | Average of Relative Impact Factors |
| **ASCLME** | Agulhas and Somali Current Large Marine Ecosystems |
| **AT** | Austria |
| **AU** | Australia |
| **AUV** | Autonomous Underwater Vessel |
| **AWI** | Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research |

## B

| | |
|---|---|
| **BBNJ** | Biodiversity Beyond National Jurisdiction |
| **BCLME** | Benguela Current Large Marine Ecosystem |
| **BE** | Belgium |
| **BEIS** | Department for Business, Energy & Industrial Strategy, United Kingdom |
| **BIOPAMA** | Biodiversity and Protected Areas Management Project |
| **BMBF** | Federal Ministry of Education and Research [Original German: Bundesministerium für Bildung und Forschung] |
| **BR** | Brazil |

## C

| | |
|---|---|
| **CA** | Canada |
| **CA$** | Canadian dollar |
| **CARICOM** | Caribbean Community |
| **CCCCC** | Caribbean Community Climate Change Centre |
| **CCLME** | Canary Current Large Marine Ecosystem |
| **CCRF** | Code of Conduct for Responsible Fisheries |
| **CD** | Capacity Development |
| **CH** | Switzerland |
| **CHM** | Clearing house mechanism |
| **CIA** | Central Intelligence Agency |
| **CIESM** | International Commission for the Scientific Exploration of the Mediterranean |
| **CIRM** | [Original Portuguese Comissão Interministerial para os Recursos do Mar, Brazil] |
| **CL** | Chile |
| **CLIVAR** | Climate and Ocean Variability, Predictability and Change core project of WCRP |
| **CMA** | Caribbean Marine Atlas |
| **CN** | China |
| **CNIPA** | China National Intellectual Property Administration (Chinese Patent Office) |
| **CNR** | National Research Council, Italy [Original Italian: Consiglio Nazionale delle Ricerche] |
| **CNRS** | French National Centre for Scientific Research |
| **$CO_2$** | Carbon dioxide |
| **COFASP** | Cooperation in Fisheries, Aquaculture and Seafood Processing |
| **COI** | Indian Ocean Commission |
| **CONISMA** | National Inter-University Consortium for Marine Sciences, Italy [Original Italian: Consorzio Nazionale Interuniversitario per le Scienze del Mare] |
| **COST** | Cooperation in Science and Technology |
| **COVID-19** | Corona Virus Disease 19 |
| **CPC** | Cooperative Patent Classification |
| **CPI** | Consumer Price Indexes |
| **CREWS** | Coral Reef Early Warning Stations |
| **CROP** | Council of Regional Organisations in the Pacific |
| **CSMZAE** | Department for Continental Shelf, Maritime Zones Administration & Exploration, Mauritius |
| **CSW** | Catalogue Service - Web |
| **CZ** | Czechia |

## D

| | |
|---|---|
| **D. Rep. Congo** | Democratic Republic of the Congo |
| **DBCP** | Data Buoy Cooperation Panel |
| **DE** | Germany |
| **Defra** | Department for Environment, Food and Rural Affairs, United Kingdom |
| **DFO** | Department of Fisheries and Oceans Canada |
| **DK** | Denmark |
| **DOAJ** | Directory of Open Access Journals |
| **DOALOS** | Division for Ocean Affairs and the Law of the Sea |
| **DOCDB** | Document database which is the main bibliographic database of the EPO. Data from PATSTAT comes partly from DOCDB. |
| **DoEE** | Department of Environment & Energy |
| **DOI** | Digital Object Identifier |
| **DST** | Department of Science and Technology, South Africa |

## E

| | |
|---|---|
| **EAF** | Ecosystem Approach to Fisheries |
| **ECV** | Essential Climate Variable |
| **EEZ** | Exclusive Economic Zones |
| **EG** | Egypt |
| **EGU** | European Geosciences Union |
| **ENEA** | Italian National Agency for New Technologies, Energy and Sustainable Economic Development [Original Italian: Agenzia Nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile] |
| **EOV** | Essential Ocean Variable |
| **EPO** | European Patent Office |
| **ERA** | European Research Area |
| **ES** | Spain |
| **EU** | European Union |

## F

| | |
|---|---|
| **FAIR** | Findable, Accessible, Interoperable and Reusable |
| **FAO** | Food and Agriculture Organization of the United Nations |
| **FI** | Finland |
| **FR** | France |
| **FTE** | Full Time Equivalents |
| **FUST** | Flanders UNESCO Trust Fund |

## G

| | |
|---|---|
| **G20** | Group of Twenty |
| **G7** | Group of Seven |
| **GCOS** | Global Climate Observing System |
| **GDACs** | Global Data Assembly Centres |
| **GDP** | Gross Domestic Product |
| **GEBCO** | General Bathymetric Chart of the Oceans |
| **GEF** | Global Environment Facility |
| **GEM** | Global Economic Monitor |
| **GEO** | Group on Earth Observations |
| **GEOHAB** | Marine Geological and Biological Habitat Mapping |
| **GEOTRACES** | International Study of the Marine Biogeochemical Cycles of Trace Elements and Isotopes |
| **GERD** | Gross Domestic Expenditure on Research and Development |
| **GEUS** | Geological Survey of Denmark and Greenland [Original Danish: De Nationale Geologiske Undersøgelser for Danmark og Grønland] |
| **GIS** | Geographic Information System |
| **GlobalHAB** | Global Ecology and Oceanography of Harmful Algal Blooms |
| **GLOBEC** | Global Ocean Ecosystem Dynamics |
| **GODAR** | Global Oceanographic Data Archaeology and Rescue |
| **GOOS** | Global Ocean Observing System |
| **GOSR** | Global Ocean Science Report |
| **GOSR2017** | First edition of the Global Ocean Science Report |
| **GOSR2020** | Global Ocean Science Report 2020 |
| **GOSUD** | Underway Sea Surface Salinity Data Archiving Project |
| **GR** | Growth Ratio |
| **GR** | Greece |
| **GTSPP** | Global Temperature and Salinity Profile Programme |

## H

| | |
|---|---|
| **HC** | Headcounts |
| **HF** | High frequency |
| **HFR** | High frequency radar |
| **HK** | China Hong Kong SAR |
| **HUGO** | Human Genome Organization |

## I

| | |
|---|---|
| **IAEG-SDGs** | Inter-agency and Expert Group on Sustainable Development Goal Indicators |
| **IASC** | International Arctic Science Committee |
| **ICES** | International Council for the Exploration of the Sea |
| **ICMB-X** | 10th International Conference on Marine Bioinvasions |
| **ICR** | International co-publication rate, International collaboration rate |
| **ICSU** | International Council for Science |
| **IE** | Ireland |
| **IEO** | Spanish Institute of Oceanography [Original Spanish: Instituto Español de Oceanografía] |
| **IF** | Impact factor |
| **IGBP** | International Geosphere-Biosphere Programme |
| **IGOs** | Intergovernmental organizations |
| **IIP** | National Institute of Fisheries Research, Mozambique [Original Portuguese Instituto Nacional de Investigação Pesqueira] |
| **IL** | Israel |
| **IMROP** | Mauritanian Institute of Oceanographic and Fisheries Research [Original French: Institut Mauritanien de Recherches Océanographique et des Pêches] |
| **IN** | India |
| **INAHINA** | National Institute for Hydrography and Navigation, Mozambique |
| **INAMAR** | National Marine Institute, Mozambique |
| **INGOs** | Internationanl Non-governmental organizations |
| **INPADOC** | International Patent Documentation Center |
| **INVEMAR** | Marine and Coastal Research Institute [Original Spanish: Instituto de Investigaciones Marinas y Costeras] |
| **IOC** | Intergovernmental Oceanographic Commission |
| **IOCaribe** | IOC Sub-Commission for the Caribbean and Adjacent States |
| **IOCCP** | International Ocean Carbon Coordination Project |
| **IODE** | International Oceanographic Data and Information Exchange |
| **IODP** | International Ocean Discovery Program |
| **IPBES** | Intergovernmental Platform on Biodiversity and Ecosystem Services |
| **IPC** | International Patent Classification |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IQuOD** | International Quality Controlled Ocean Database |
| **IR** | Iran (Islamic Republic of) |
| **ISCED** | International Standard Classification of Education |
| **ISI** | Institute for Scientific Information |
| **ISO** | International Organization for Standardization |
| **ISPRA** | Italian Institute for Environmental Protection and Research [Original Italian: Instituto Superiore per la Protezione e la Ricerca Ambientale] |
| **IT** | Italy |
| **IUU** | Illegal, unreported and unregulated |
| **IYAFA** | International Year of Artisanal Fisheries and Aquaculture |

B

## J

| | |
|---|---|
| **JCOMM** | WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology |
| **JP** | Japan |
| **JPI Oceans** | Joint Programming Initiative Healthy and Productive Seas and Oceans |
| **JPO** | Japan Patent Office |

## K

| | |
|---|---|
| **KIOST** | Korea Institute of Ocean Science and Technology |
| **KIPO** | Korean Intellectual Property Office |
| **KMA** | Korea Meteorological Administration |
| **KR** | Republic of Korea |

## L

| | |
|---|---|
| **LAC** | Latin America and the Caribbean |
| **LDCs** | Least Developed Countries |
| **LLDC** | Landlocked Developing Countries |
| **LME** | Large Marine Ecosystem |
| **LMMAs** | Locally Managed Marine Areas |

## M

| | |
|---|---|
| **MAFF** | Ministry of Agriculture, Forestry and Fisheries, Japan |
| **MARG** | Marine Research Grant Programme |
| **MASMA** | Marine and Coastal Science for Management |
| **MATTM** | Ministry for Environment, Land and Sea Protection of Italy |
| **MCDS** | the Marine Climate Data System |
| **MEDAs** | Marine Ecosystem Diagnostic Analyses |
| **MESRI** | Ministry of Higher Education, Research and Innovation [Original French: Ministère de l'Enseignement Supérieur, de la Recherche et de l'Innovation] |
| **METI** | Ministry of Economy, Trade and Industry, Japan |
| **MEXT** | Ministry of Education, Culture, Sports, Science and Technology, Japan |
| **MinLNV** | Ministry of Agriculture, Nature and Food Quality, Netherlands |
| **MISE** | Ministry of Economic Development, Italy |
| **MIUR** | Ministry of Education, University and Research, Italy |
| **MLIT** | Ministry of Land, Infrastructure, Transport and Tourism, Japan |
| **MMS** | Mauritius Meteorological Services |
| **MOE** | Ministry of the Environment, Japan |
| **MOI** | Mauritius Oceanography Institute |
| **MPAs** | Marine Protected Areas |
| **MSP** | Marine Spatial Planning |
| **MSTIC** | Ministry of Science, Technology, Innovation and Communication of Brazil |
| **MTS** | Marine Technology Society |
| **MX** | Mexico |
| **MY** | Malaysia |

## N

| | |
|---|---|
| **NASA** | National Aeronautics and Space Administration |
| **NDCs** | Nationally-determined contributions |
| **NGOs** | Non-governmental organizations |
| **NIFS** | National Institute of Fisheries Science |
| **NIOZ** | Royal Netherlands Institute for Sea Research |
| **NIVA** | Norwegian Institute for Water Research |
| **NL** | Netherlands |
| **NO** | Norway |
| **NOAA** | National Oceanic and Atmospheric Administration, USA |
| **NODCs** | National Oceanographic Data Centres |
| **NOK** | Norwegian Krone |
| **NSF** | National Science Foundation |
| **NZ** | New Zealand |

## O

| | |
|---|---|
| **OBIS** | Ocean Biodiversity Information System |
| **OCW** | Ministry of Education, Culture and Science , Netherlands |
| **ODIS** | Ocean Data and Information System |
| **ODISCat** | ODIS Catalogue of Sources |
| **OECD** | Organisation for Economic Co-operation and Development |
| **OGS** | National Institute of Oceanography and Applied Geophysics, Italy [ Original Italian: Istituto Nazionale di Oceanografia e Geofisica Sperimentale] |
| **ORCID** | Open Researcher and Contributor ID |
| **OSJ** | Oceanographic Society of Japan |
| **OT e-LP** | OceanTeacher e-Learning Platform |
| **OTGA** | OceanTeacher Global Academy |

## P

| | |
|---|---|
| **PATSTAT** | EPO Worldwide Patent Statistical Database |
| **PCBs** | Polychlorinated biphenyls |
| **PEBACC** | Pacific Ecosystem-Based Adaptation to Climate Change |
| **PEMSEA** | Partnerships in Environmental Management for the Seas of East Asia |
| **PhD** | Doctor of Philosophy |
| **PICES** | North Pacific Marine Science Organization |
| **PL** | Poland |
| **POGO** | Partnership for Observation of the Global Oceans |
| **PPOA** | New Zealand-Pacific Partnership on Ocean Acidification |
| **PPP** | Purchasing Power Parity |
| **PT** | Portugal |
| **PUC** | Pontifical Catholic University of Chile |

## R

| | |
|---|---|
| **R&D** | Research and Development |
| **RAS** | Recirculating aquaculture systems |
| **RCN** | Research Council of Norway |
| **RIF** | Relative impact factor |
| **ROV** | Remotely operated vehicle |

| | |
|---|---|
| **RTC** | Regional training centre |
| **RU** | Russian Federation |
| **RV** | Research vessel |

## S

| | |
|---|---|
| **S20** | Science 20 |
| **SAMOA** | SIDS Accelerated Modalities of Action |
| **SCAR** | Scientific Committee on Antarctic Research |
| **SCOR** | Scientific Committee on Oceanic Research |
| **SDG** | Sustainable Development Goal |
| **SE** | Sweden |
| **SFI** | Centres for Research-Based Innovation, Norway |
| **SG** | Singapore |
| **SHOA** | Chilean Navy Hydrographic and Oceanographic Service [Original Spanish: Servicio Hidrográfico y Oceanográfico de la Armada] |
| **SI** | Specialization index |
| **SIDS** | Small Island Developing States |
| **SJR** | Scimago Journal Ranking |
| **SOLAS** | Surface Ocean - Lower Atmosphere Study |
| **SPEC** | South Pacific Bureau for Economic Cooperation |
| **SPU** | Pacific Commission |
| **SQU** | Sultan Qaboos University |
| **SPREP** | Secretariat of the Pacific Regional Environment Programme |
| **SRIA** | Strategic Research and Innovation Agenda |
| **SSF Guidelines** | Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries |
| **STC** | Specialized training centre |
| **SUT** | Society for Underwater Technology |
| **SUV** | Surface unmanned vessel |
| **SZN** | Zoological Station Anton Dohrne [Original Italian: Stazione Zoologica Anton Dohrn Napoli] |

## T

| | |
|---|---|
| **TH** | Thailand |
| **TMT** | Transfer of Marine Technology |
| **TR** | Turkey |

## U

| | |
|---|---|
| **UCSC** | Catholic University of the Most Holy Conception |
| **UIS** | UNESCO Institute for Statistics |
| **UK** | United Kingdom |
| **UN** | United Nations |
| **UN ESCAP** | United Nations Economic and Social Commission for Asia and the Pacific |
| **UNCLOS** | United Nations Convention on the Law of the Sea |
| **UNDFF** | United Nations Decade of Family Farming |
| **UNDP** | United Nations Development Programme |
| **UNEP** | United Nations Environmental Programme |
| **UNESCAP** | United Nations Economic and Social Commission for Asia and the Pacific |
| **UNESCO** | United Nations Educational, Scientific and Cultural Organization |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **UNGA** | United Nations General Assembly |
| **UoM** | University of Mauritius |
| **US/USA** | United States of America |
| **USAID** | United States Agency for International Development |
| **USPTO** | United States Patent and Trademark Office |
| **US$** | United States Dollars |
| **UV** | University of Valparaiso |

## W

| | |
|---|---|
| **WCRP** | World Climate Research Programme |
| **WiMS** | Women in Marine Science Network |
| **WIO** | Western Indian Ocean |
| **WIO LME SAPPHIRE** | Western Indian Ocean Large Marine Ecosystems Strategic Action Programme Policy Harmonisation and Institutional Reforms |
| **WIO-ECSN** | Western Indian Ocean Early Career Scientists Network |
| **WIOMSA** | Western Indian Ocean Marine Science Association |
| **WIPO** | World Intellectual Property Organization |
| **WMO** | World Meteorological Organization |
| **WMO GTS** | World Meteorological Organization Global Telecommunication System |
| **WMR** | Wageningen Marine Research |
| **WOCE** | World Ocean Circulation Experiment |
| **WOD** | World Ocean Database |
| **WWF** | World Wildlife Fund |

## Z

| | |
|---|---|
| **ZA** | South Africa |

# Global Ocean Science Report 2020

## Charting Capacity for Ocean Sustainability

The world ocean is a life-supporting system for humanity, yet it remains largely unknown. Based on data collected from around the world, the Global Ocean Science Report 2020 (GOSR2020) offers a global record of how, where and by whom ocean science is conducted. By analysing the workforce, infrastructures, equipment, funding, investments, publications, data flow and exchange policies, as well as national strategies, the GOSR monitors our capacity to understand the ocean and seize new opportunities. In its second edition, the GOSR2020 addresses four additional topics: contribution of ocean science to sustainable development; blue patent applications; extended gender analysis; and capacity development in ocean science.

The GOSR2020 is a resource for policymakers, academics and other stakeholders seeking to assess progress towards the sustainable development goals of the UN 2030 Agenda, in particular SDG target 14.a on scientific knowledge, research capacity and transfer of marine technology. The GOSR provides the information for the indicator for target 14.a as the proportion of total research budget allocated to research in the field of ocean science. GOSR2020 not only provides consistent reference information at the start of the UN Decade of Ocean Science for Sustainable Development 2021–2030, it evolves as a living product. The global community is given the online facility to submit and update data on the GOSR portal and consult data to regularly assess progress on the efficiency and impact of policies to develop ocean science capacity.

For more information:
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