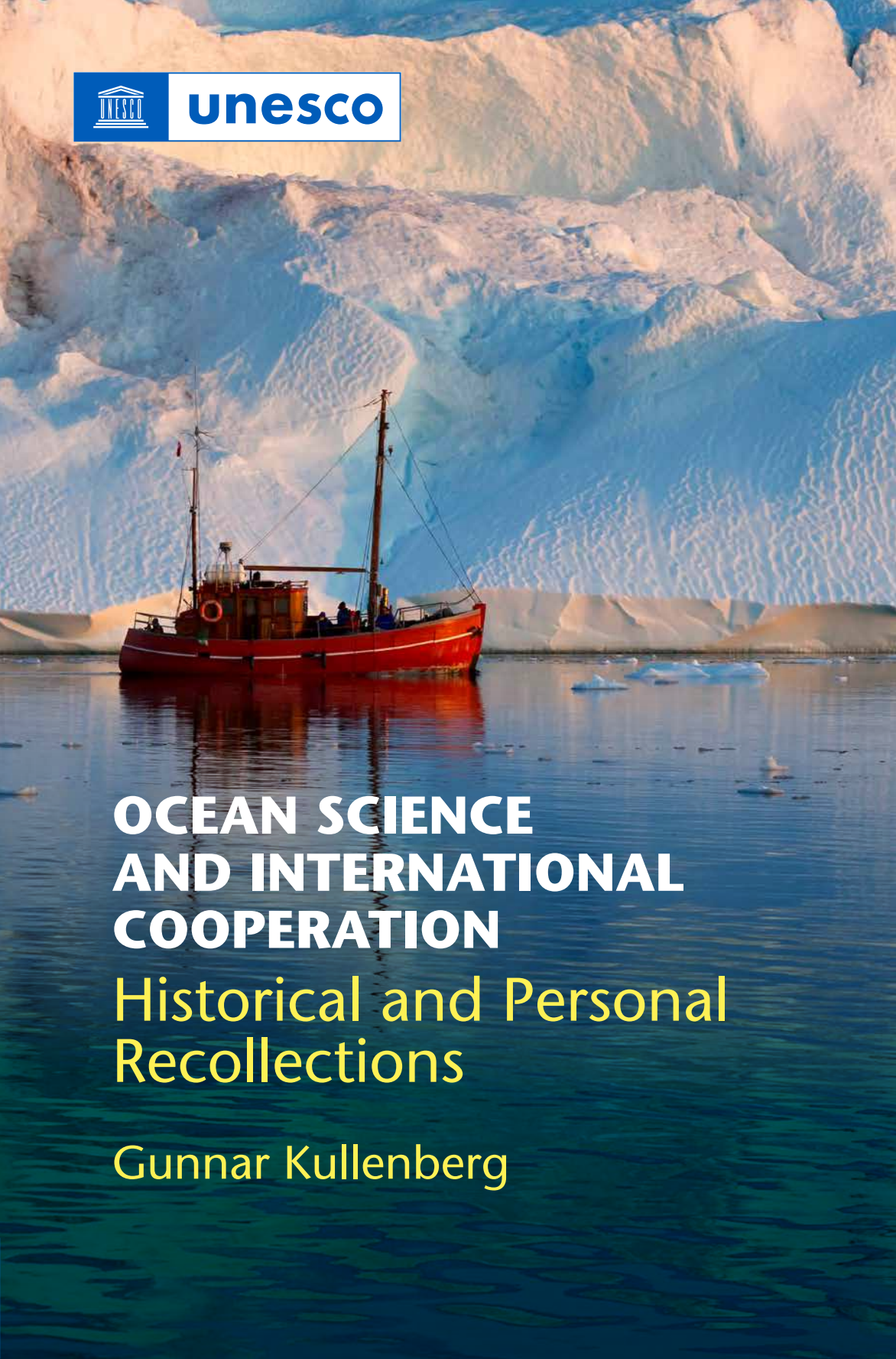

OCEAN SCIENCE AND INTERNATIONAL COOPERATION

Historical and Personal Recollections

Gunnar Kullenberg

Gunnar Kullenberg, a citizen of Sweden and Denmark, was trained in the Royal Swedish Navy from 1958 to 1961, where he became an officer in the voluntary reserve. He holds degrees from the University of Gothenburg in physical oceanography and the University of Copenhagen (doctorate in oceanography), becoming professor at both institutions. His professional life as an oceanographer involved research, teaching and training, and long periods of time at sea on research vessels from different countries. He also served in international organizations for many years. He was appointed Senior Assistant Secretary of the Intergovernmental Oceanographic Commission (IOC) of UNESCO in 1985–1988, and Secretary (later Executive Secretary) in 1989–1998. After the IOC, he served as Executive Director of the International Ocean Institute (IOI) from 1998 to 2003, was visiting scientist at the Nippon Foundation during 2003 and 2004, and leader of the evaluation teams for the Global Environmental Facility (GEF) supported programmes PEMSEA 2005–2006 and the Yellow Sea LME 2010–2011. He led workshops on ocean and human security at the UN Institute for Training and Research (UNITAR) Hiroshima Office in 2007, 2008 and 2009, and contributed to IOC Programme developments in 2014–2017. As Executive Secretary of the IOC, following the directives of Member States, he enhanced cooperation between the IOC and several organizations within and outside the UN system, including by initiating the development of the Global Ocean Observing System in 1989; ensuring active participation of the IOC in the Second World Climate Conference (1990), the World Climate Research Programme, the UN Conference on Environment and Development (1992) and related contributions to the preparation of Agenda 21 and the 'Rio Conventions' on climate change and biodiversity; jointly organizing the Oceanographic Conference in 1994 on the occasion of the entering into force of the UN Convention on the Law of the Sea (UNCLOS); and initiating the preparations for the International Year of the Ocean (1998).

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SHORT SUMMARY

International scientific cooperation is fundamental to the pursuit of knowledge on the ocean, its condition and related sustainable development issues

This book presents the personal insight on the evolution of modern oceanography of Gunnar Kullenberg, a distinguished ocean scientist and former Executive Secretary of the Intergovernmental Oceanographic Commission of UNESCO. It leads us through the transition from IOC-UNESCO serving as a platform for cooperation among leading nations in operational oceanography in the 1960s to its role as a facilitator for the sharing of oceanographic knowledge and technology for the benefit of all nations in the 1980s and 1990s.

Through this dual perspective, Kullenberg describes how the practice of oceanography has evolved, from physical exploration to relying largely on computer modelling together with analysis of remote observations, both from satellites and *in situ* moored and drifting profiling recording instruments, and now artificial intelligence. It reflects how the growing awareness on ocean issues at all levels of society and the engagement of marine actors are crucial to address sustainable development. In a quickly changing word, Kullenberg's testimony reminds the new generation of oceanographers of the equal importance for them to keep developing a robust retrospective knowledge of their subject.

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Member States have engaged with the **Intergovernmental Oceanographic Commission** of UNESCO since its creation in 1960

unesco

"Since wars begin in the minds of men and women it is in the minds of men and women that the defences of peace must be constructed"

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Foreword

From its foundation in 1960 until its 60th anniversary in 2020, the Intergovernmental Oceanographic Commission (IOC) had nine executive secretaries. Gunnar Kullenberg served as the sixth Executive Secretary, from 1989 to 1998. During his term, the initial title of 'IOC Secretary' was upgraded to 'IOC Executive Secretary' in the rank of Assistant Director-General of UNESCO.

The IOC shapes the world's oceanography. The needs of the world shape the IOC. One cannot really govern ocean science (because it is *science*), but one may affect the direction and pace of its evolution by certain actions. As a result, IOC Executive Secretaries and Chairs are constantly analysing how ocean science is evolving, and where it needs to be gently steered. They act as facilitators, striving to stimulate interest and to engage the brightest minds in the co-design of future activities through collective brainstorming. Such decisions involve major responsibilities, especially towards IOC Member States.

Gunnar Kullenberg has exerted his influence on oceanography. This book reflects his deepest mental immersion in the processes that comprise the progress of science, evoking memories of key programmes, events and decisions that have taken ocean science to where it is now.

In 2015, after my appointment as IOC Executive Secretary, I felt compelled to cordially invite Gunnar Kullenberg for strategic consultations on the future of the IOC. He responded with dedication and energy. The brainstorming was intense and exciting. One of the strategic retreats in which Gunnar Kullenberg actively participated was led by IOC Chair Prof. Peter Haugan on 5 and 6 January 2016 in Gilleleje, a small coastal town in Denmark. It resulted in the idea of designing a UN ocean decade and paved the way for the United Nations Decade of Ocean Science for Sustainable Development, 2021–2030. This was history in the making. I hope that the Ocean Decade will take ocean science to a new level of delivery and will help all of us to live better and in harmony with a healthy ocean.

This book by Gunnar Kullenberg reminds me of the famous quote by George Santayana (1905): 'Those who cannot remember the past are condemned to repeat it'. Dr Kullenberg does remember the history of ocean science, because he lived through it. The reading is very interesting and educative and may be particularly useful for understanding how intergovernmental processes can help

to develop the capacity of ocean science and turn its power towards sustainable development.

The seventh and concluding expected societal outcome of the Ocean Decade is 'an inspiring and engaging ocean'. Gunnar Kullenberg's book is the result of his life-long love of the ocean and oceanography, and I hope that you too will feel inspired by reading it.

Vladimir Ryabinin
IOC Executive Secretary

Paris, 4 October 2021

Preface

Since the mid-nineteenth century, the development of oceanography through exploration and scientific observation has been coupled with industrialization and is indivisible from scientific, technological and social change. It has been driven by revolutions and world wars – in particular the Second World War – as well as globalization, reflecting developments in trade and economic growth, all of which have increased the need of governments and industry for greater knowledge of the ocean's conditions and resources. Such scientific knowledge encompasses an understanding of physical, chemical and biological functions, living and non-living resources, the impact on the environment from human uses and abuses, natural and human-induced changes and environmental responses, which include consequences for human security. Over the last five decades or so, quantifying the assimilative capacity of the ocean has been an important research theme, notably with respect to the uptake of carbon dioxide and additional heat, as well as pollution. Results of the research have provided the basis for an integrated interpretation in a number of assessments with respect to the conditions in the ocean, including shelf seas.

Cooperation is fundamental to the pursuit of knowledge. The aim of this book is to highlight the role of international cooperation, together with social and environmental developments and needs, in our endeavour to understand the most important realm of our planet: the ocean. With this objective in mind, the following chapters present the development and role of cooperation in ocean exploration and science, coupled with new technology, over more than two centuries. Regional divisions and motivations for specific actions, including social needs and environmental concerns, are examined to demonstrate this development. These reflections are also linked to the creation, development and strengthening of the IOC of UNESCO and its role in facilitating cooperation.

The overview of the book in the Introduction, although not strictly sequential, highlights the development of international cooperation at the regional and global level in ocean science over about 250 years, and blends historical content with my own perspectives.[1] Personal experiences from expeditions and

1 Many additional examples of cooperation in ocean exploration and research, particularly from the Asian region, can be found in Morcos et al. (2004).

international cooperation are presented in boxes throughout the narrative. Most of the text was drafted from 2015 to 2017, with some amendments in 2018–19, and editing in 2020.

Gunnar Kullenberg

Grundsund, 1 July 2020

Executive messages

1. The ocean imperative

We could not survive without the ocean; therefore, it is imperative that we maintain it in a healthy condition. The ocean constitutes the source of protein for approximately a third of the world's human population. It controls our climate and weather, functions as a primary means of transport and communications, and provides rich resources, notably for coastal regions worldwide. In a global context, its value as a source not only of food but also non-living resources, such as gas and oil, can also make the ocean a site of competition and conflict between nations. Ongoing abuse and over-exploitation of the ocean and marine resources have made clear the need for internationally agreed management arrangements. Collaboration and cooperation in marine research and observations is the only available means to develop the scientific basis for international agreements and conventions to ensure the sharing of resources and the responsible utilization of the ocean.

2. Governance

The international nature of the ocean and marine resources has led inexorably to global legal arrangements, embodied most clearly in the development of the United Nations Convention on the Law of the Sea (UNCLOS) of 1982, which came into force in November 1994. The law is wide-ranging, stipulating that the ocean and marine resources should be shared equally, used for peaceful purposes only, and protected and managed effectively as a whole, together with living marine resources. The law defines the extent of the territorial sea and adjacent area, and introduces the Exclusive Economic Zone (EEZ) concept, which represents a substantial transfer of resources and related responsibilities to coastal states. The law also includes a section on marine research and observations, emphasizing the imperative for cooperation and sharing data and results. Stipulations regarding fisheries and migrating species are also included, along with provisions relating to the transportation of various goods, marine pollution and the special open ocean areas of the sea bed, which are also subject to several other dedicated agreements and conventions. Implementation of UNCLOS and its associated agreements, together with the results of the United Nations Conference on Environment and

Development (UNCED) 1992 and associated agreements,[2] provides the basis for adequate governance of the ocean and coastal seas. The associated governance requirements have led to the establishment of several intergovernmental and non-governmental organizations to address new findings, emerging problems and potential conflicts.

3. Knowledge, understanding and cooperation

Endangering the health of the ocean threatens the health of life on Earth. Ocean science and observations play a vital role in understanding the processes and conditions necessary to help ensure a healthy ocean. These tasks depend on infrastructure such as ships, data recording instruments and satellites to undertake the collection of information on currents, environmental parameters, fish migration and the tracing of contaminants such as radioactive substances, trace metals and pesticides. Knowledge of fluxes between the ocean, the atmosphere, land and ice masses, including gases such as carbon dioxide, sulphides and oxygen, are also essential. This wide range of activity demands international cooperation and collaboration across institutions with the necessary equipment and resources, as well as scientists and technical staff covering the requisite disciplines. It also necessitates international agreement on programmes, and the sharing of outcomes and their interpretations.

Initially, cooperation focused on fisheries management, the protection of living resources, safer shipping and the saving of lives in coastal zones and at sea. Over time, cooperation was extended to include research and data collection on other resources, leading to the building of a Global Ocean Observing System (GOOS) to track long-term changes in environmental conditions, including organic production and interannual changes, sea level rise and natural hazards. From about 1850, oceanography and its associated technologies have developed into a broad international cooperative science, providing knowledge of ocean circulation, ocean interior and bottom conditions, submarine volcanism and plate tectonics, all of which are crucial for submarine cabling and pipelines. Over the decades, ocean science has also expanded to provide an understanding of the role of the ocean in our climate system and for our health and nutrition. Marine research and technology have facilitated fisheries management and biodiversity preservation, as well as the discovery and exploitation of mineral resources, and have provided clues to past climate changes through the study of sediment cores. More recently, the development of high-powered computers has facilitated the

2 These are the Rio Declaration of Principles and its annexed Plan of Action, Agenda 21 and the Rio Conventions on Biodiversity, Climate Change and Desertification, which were opened for signature in 1992.

use of observational data in dynamic models for forecasting cyclones, strong storm events and climate-related seasonal and interannual variations of environmental conditions. This has led to operational modelling and forecasting of great potential for the management of agriculture, among others. Nowadays, artificial intelligence is increasingly used in optical measurements of marine life on a routine basis.

Despite these technological advances, however, there remain significant gaps in our knowledge of deep ocean circulation, sea bed conditions and interior processes, as well as quantification of deep water formation, upwelling and fluxes of gases and other material across the sea bed and sea surface. Greater understanding of the polar regions with respect to ice and climate changes, and their interactions with the adjacent ocean system, have stimulated much cooperative research, but concerns for ecosystem disruptions and consequential national and territorial disputes still prevail. The relative impacts of human actions, as opposed to natural processes, are also not well defined, leading to uncertainties in our understanding and management of environmental change. In particular, the impact of multistress factors, coupled to climate change, acidification and de-oxygenation, as well as pollution from land-based sources, including nutrients and plastics, needs much better understanding and adaptive management for the preservation of the ocean and human health, and for economic and safety reasons. These are sensitive areas, where in the past there has been some reluctance to share information. However, the imperatives of a healthy ocean and healthy coastal zones have led to improvements in cooperation between the marine research community, the social sciences and the developers of ocean economies. This trend needs to be encouraged and enhanced through agreed programmes and a common platform and framework. The UN Decade of Ocean Science for Sustainable Development 2021–2030, together with the 2030 Agenda for Sustainable Development, should provide direction and stimulation in this regard.

4. Funding requirements

In earlier times, oceanography was driven mainly by curiosity, funded largely by private donations and supported with infrastructure provided by national navies, concerned primarily with charting and hydrography. However, increasing recognition of the economic and environmental importance of the ocean has encouraged greater government involvement, generating regional cooperation and pooling of resources through national agencies. In turn, this led to the formation of intergovernmental organizations funded by Member States. This increased activity, along with relevant advances in technology,

led to enhanced applications of marine research, as described earlier, and concomitant increases in funding. The research community recognized the need for government involvement to provide infrastructure, institutions and human resources to capitalize on research findings. As for weather services, an adequate and reliable GOOS cannot be certified without support from governments. In parallel, concerns about overfishing, marine pollution and coastal zone pressures became more prevalent, resulting in the strengthening of national institutions for ocean and coastal seas research and training, together with related authorities and agencies. Geopolitical interests drove national navies to both cooperation and competition, resulting in the provision of directed funding for some oceanographic research.

In the 1960s and 1970s, favourable economic conditions provided sufficient funding for oceanographic infrastructure and research, subsequently bolstered by interest generated in many countries as a result of negotiations on UNCLOS and the International Decade of Ocean Exploration 1971–1980. In addition, some funding became available from national donor agencies for the development of marine research in developing countries. However, this enhanced interest also created strong competition for programme support among Member States and research agencies, and has complicated and overshadowed the funding process. There was also infighting between different UN bodies, to some extent reflecting the structure and conditions in national governments, undermining the obvious need for cooperation and trust. One example of the inadequacy of available funding is the training and mutual assistance programme of the Intergovernmental Oceanographic Commission (IOC) of UNESCO, which was expected to facilitate the global development of institutions and human resources in developing countries with annual seed funding of about US$100,000. A similar amount was provided during the 1990s for the development of GOOS. These numbers speak for themselves.

5. Institutional development needs

Oceanography has matured over time and now provides important, often essential, services to our society. However, the number and diversity of institutions whose mandate encompasses some aspect of marine affairs has resulted in the absence of an agreed dedicated, trusted and accountable leading international institution with responsibility for coordinating, integrating and reporting marine science-related activities. Practically all ocean regions have their own regional fisheries and marine environmental intergovernmental organization – in some cases, several. At the global level, in principle, all UN agencies play a role in ocean and marine affairs. In the case of scientific, technical and observational inputs

to evaluations of marine pollution problems, this is demonstrated through the advisory mechanism GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), where all participating UN agencies are, or can be, represented by independent experts. The outcome is a complicated, time-consuming, competitive and sometimes politically infected process.

This situation contrasts markedly with that of the science of meteorology and, to some extent, hydrology. The World Meteorological Organization (WMO), created in 1950, originates from the International Meteorological Organization (IMO), which dates back to 1873. It became a specialized agency of the United Nations in 1951 and is now the recognized focal agency for weather and water services, marine meteorology and atmospheric climatic conditions. The WMO enjoys extensive cooperation with the IOC, created in 1960. The IOC also cooperates closely with other agencies in the UN system. However, this cooperation is based on a much weaker institutional and funding basis than that of WMO and other bodies. The IOC is not an independent organization, even though it has been granted what is referred to as 'functional autonomy' within UNESCO. It is still confined and constrained by the institutional boundaries, conditions, directives and governance of its mother organization. Unlike the WMO, the IOC does not benefit from a strong policy-enabling environment, such as that provided by a convention. In the opinion of the author, this is unsatisfactory, given the size and imperative of our ocean environment. Marine research and ocean observations, together with mutual assistance, training and transfer of marine technology, have matured and demonstrated their ability to provide important services to society. It is time to recognize this and create an independent intergovernmental organization, of an equivalent status to the WMO, to serve as the focal point for governments and Member States, with the objective of directing and supporting programmes and outcomes on most aspects of ocean conditions and services to society, all of which are based on marine research and sustained ocean observations. The organization must be able to respond to the directives of its Member States, free of other constraints. This could be a prime goal of the United Nations Decade of Ocean Science for Sustainable Development.

UNESCO drafted the agreement that led to the creation of the IOC, which has since matured. It is hereby proposed that the IOC be given the task of establishing a small expert panel, comprised of senior members with experience from positions in governments and international bodies, to outline the design and possible constitutional agreement for such an organization.

List of boxes

List of acronyms

AOSIS	Alliance of Small Island States
APEC	Asia Pacific Economic Cooperation
BOD	Biochemical oxygen demand
CBD	Convention on Biological Diversity
CCIW	Canada Centre for Inland Waters
CICAR	Cooperative Investigations in the Caribbean
CIDA	Canadian International Development Agency
CIESM	Mediterranean Science Commission
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTD	Conductivity-temperature-depth
CUEA	Coastal Upwelling Ecosystem Analysis
DANIDA	Danish International Development Agency
DDT	Dichlorodiphenyltrichloroethane
DNAs	Designated National Agencies
EEC	European Economic Community
EEZ	Exclusive Economic Zone
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GEF	Global Environment Facility
GELTSPAP	Group of Experts on Long-term Scientific Policy and Planning
GEOHAB	Global Ecology and Oceanography of Harmful Algal Blooms
GEOSECS	Geochemical Ocean Sections Study
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GIPME	Global Investigation of Pollution in the Marine Environment
GOOS	Global Ocean Observing System
GSF	General Framework for the Study of the World Ocean
HAB	Harmful algal bloom
HELCOM	Baltic Marine Environment Protection Commission (Helsinki Commission)
HMS	His/Her Majesty's Ship
IAEA	International Atomic Energy Agency
IAMAP	International Association of Meteorology and Atmospheric Physics
IAPO	International Association for Physical Oceanography (currently IAPSO)
IAPSO	International Association for the Physical Sciences of the Oceans (formerly IAPO)

ICAM/ICM	Integrated Coastal Area Management/Integrated Coastal Management
ICES	International Council for the Exploration of the Sea
ICSPRO	Inter-Secretariat Committee on Scientific Programmes Relating to Oceanography
ICSU	International Council for Science
IDNDR	International Decade of Natural Disaster Reduction
IDOE	International Decade of Ocean Exploration
IGBP	International Geosphere-Biosphere Programme
IGOSS	Integrated Global Ocean Services System
IGPP	Institute of Geophysics and Planetary Physics
IGY	International Geophysical Year
IMCO	Inter-Governmental Maritime Consultative Organization
IMO	International Maritime Organization
IOC	Intergovernmental Oceanographic Commission
IOCCP	International Ocean Carbon Coordination Project
IODE	International Oceanographic Data and Information Exchange
IOI	International Ocean Institute
IPCC	Intergovernmental Panel on Climate Change
ISA	International Sea Bed Authority
ISOS	International Southern Ocean Studies
IUBS	International Union of Biological Sciences
IUCN	International Union for Conservation of Nature
IUGG	International Union of Geodesy and Geophysics
IW	International Waters
JASIN	Joint Air Sea Interaction
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
LEPOR	Long-term and Expanded Programme of Ocean Exploration and Research
LME	Large Marine Ecosystem
MoU	Memorandum of understanding
MPA	Marine Protected Area
NATO	North Atlantic Treaty Organization
NCPO	Nordic Council for Physical Oceanography
NGO	Non-governmental organization
NOAA	National Oceanic and Atmospheric Administration (of USA)
NODCs	National Oceanographic Data Centres
OBIS	Ocean Biodiversity Information System (formerly Ocean Biogeographic Information System)
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PCB	Polychlorinated biphenyl
PEMSEA	Partnerships in Environmental Management for the Seas of East Asia

PIM	Pacem in Maribus
POPs	Persistent Organic Pollutants
PVC	Polyvinyl chloride
RNODC	Responsible National Oceanographic Data Centres
RRS	Royal Research Ship
R/V	Research Vessel
SAREC	Swedish Agency for Research Cooperation
SOCA	Subcommittee on Oceans and Coastal Areas of the Administrative Committee on Coordination
SCOR	Scientific Committee on Oceanic Research
SDG	Sustainable Development Goal
SDS-SEA	Sustainable Development Strategy for the Seas of East Asia
SIDA	Swedish International Development Cooperation Agency
SIDS	Small Island Developing States
SOLAS	International Convention for the Safety of Life at Sea
SOPAC	South Pacific Geosciences Commission
SPREP	Secretariat of the Pacific Regional Environment Programme
TEMA	Training, Education and Mutual Assistance
TDA/SAP	Transboundary Diagnostic Analysis/Strategic Action Programme
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNCLOS	United Nations Convention on the Law of the Sea
UN-DESA	United Nations Department of Economic and Social Affairs
UN-DOALOS	United Nations Office of Legal Affairs/Division for Ocean Affairs and the Law of the Sea
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
UNITAR	United Nations Institute for Training and Research
UNU	United Nations University
USA	United States of America
UV	Ultraviolet
WCRP	World Climate Research Programme
WDC	World Data Centres
WESTPAC	IOC Sub-Commission for the Western Pacific
WHO	World Health Organization
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WMU	World Maritime University
WSSD	World Summit on Sustainable Development
XBT	Expendable bathythermograph

Introduction

The background to this work is my personal experience, first in the Royal Swedish Navy from 1958 to 1961, with regular periods of service until 1978 as an officer in the voluntary reserve, followed by studies at the University of Gothenburg, Sweden, where I obtained a degree in physical oceanography. Subsequently, my professional life as an oceanographer involved working at universities and other scientific institutions, research with teaching and training, and a great deal of time at sea on research vessels from different countries, together with experience of serving in international organizations.

My interest in the sea developed during school days and summers on the west coast of Sweden, expeditions at sea during holidays with my father and a period serving on the research vessel *Skagerrak*. This interest was fuelled by studies of naval history and a somewhat romantic fascination in the context of sea battles, the development of empires, and naval exploration during the eighteenth and nineteenth centuries. This led to my entering the Swedish Navy, where my education, training and service further stimulated my interest in the sea and desire to know and understand the ocean. My early training on the sea and exploratory expeditions over a six-month period took me across the Atlantic, through the Caribbean and Panama Canal to the Galapagos, and from there north along the North American coast up to Vancouver, returning by Key West and Dover in early 1959.

After my university studies, I obtained a position at the University of Copenhagen and worked as an oceanographer, participating actively in numerous expeditions at sea. I travelled from the Arctic to the Antarctic, exploring the Atlantic and Pacific Oceans and the associated regional seas, in particular the Baltic, the North and Norwegian Seas, as well as the Mediterranean Sea.

My responsibilities grew with seniority, first as a full professor at the University of Gothenburg (1977–78) and then at the University of Copenhagen (1979–85). In addition to teaching and research, I became involved in various national and international organizations, including intergovernmental UN agencies and non-

governmental organizations (NGOs).[3] My interest and responsibilities gradually increased to the point where I decided to become an international civil servant. In 1985, I joined the IOC, where my scientific and capacity development work initially focused on the Global Investigation of Pollution in the Marine Environment programme, including workshops, symposia and programmes resulting from the International Decade for Ocean Exploration 1971–80, regional activities and the work of the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), which focused on the health of the ocean. From 1989 until May 1998, I served as Secretary of the IOC (from May 1995, Executive Secretary) with overall responsibility for the organization under the direction of the IOC Member States and the Director-General of UNESCO.

Overview of the book

Chapter 1 looks at scientific data collection through systematic, agreed, regular observations from ships, on basin-wide scales, with regular data exchange – a process that involves international and intergovernmental cooperation, motivated by support for shipping, commerce, security and transport controls. It focuses in particular on the efforts of one individual: Mathew F. Maury, exploring the development of formal cooperation agreements through intergovernmental conferences, the first of which took place in 1853, and the contributions of this cooperation and stability to ocean observations and science. It also examines major technological developments at the time, including the ability to measure wind and wave conditions according to an agreed scale, and data transfer through telegraphy.

Chapters 2 and 3 examine the collection of material, samples and data on ocean and terrestrial conditions, as well as exploration and colonization, including by Captain Cook (1768–79). They discuss the participation of scientists from several countries, the Little Ice Age (1350–1850), early exploratory expeditions in East and South Asia by China, and Russian expeditions to study conditions in the Pacific, which began as early as the 1630s. The chapters also trace the

3 The intergovernmental organization in question was the International Council for the Exploration of the Sea (ICES). United Nations organizations included the IOC of UNESCO, the United Nations Environment Programme (UNEP), the International Atomic Energy Agency (IAEA) through its Marine Environmental Studies Laboratory in Monaco, the Food and Agriculture Organization of the United Nations (FAO) and the International Maritime Organization (IMO) through the Joint Group of Experts on Scientific Aspects of Marine Pollution (GESAMP). NGOs included the International Council for Science (ICSU) with the Scientific Committee on Oceanic Research (SCOR), as well as the International Association for the Physical Sciences of the Oceans (IAPSO) and the International Association of Meteorology and Atmospheric Physics (IAMAP).

scientific-technological developments of surveys, charting, the mapping of tides and currents, biological samples from land and sea, and the invention of the chronometer, which contributed vastly to safe navigation.

Chapter 4 explores the period of relative peace and stability after the Crimean War and the wars of unification in Europe, regarding Germany and Italy, against a backdrop of major technological and infrastructure developments, the emerging industrial revolution and support for science and exploration. The chapter traces the mounting of global ocean scientific expeditions planned by the Royal Society to gather observations and collect material and samples, and highlights the *Challenger* expedition of 1872, which was fundamental to the development of oceanography. The chapter also refers to major technological developments – including the steam engine and propeller – which enabled ships to remain on station, the emergence of photography, and explores the advent of broad cooperation for analyses and interpretation of data and samples, which pooled scientific capabilities, minds and knowledge.

Chapter 5 discusses concerns about limited fisheries resources, with related possible conflicts and lack of control at the regional level. It explores how this situation generated cooperation proposed and driven by the scientific community with the support of governments, based on the realization that proper management of fisheries requires a scientific understanding of the regional conditions influencing fish survival, migration and yearly fluctuations. The chapter also traces the gradual development, through persistence among the scientific community, of regional cooperation at the intergovernmental level, with the formation of agreements on controls, regulations, limitations and norms. It examines the establishment of the International Council for the Exploration of the Sea (ICES) in 1902, and major technological developments, which have led gradually to local and regional overfishing, increased ocean cabling, and the clarification of topography and sea floor conditions.

Chapters 6, 7 and 8 examine technological developments and further scientific exploratory expeditions in parts of the northern North Atlantic from the 1860s onwards – a long period that was interrupted by the First World War and then reinitiated with regional support for research cooperation up to 1940, including observations, data exchange and the pooling of resources for scientific exploration of European seas and large parts of the Atlantic.

Chapters 9, 10 and 11 cover the period after the Second World War when scientific cooperation was motivated by a desire to bring technologies developed during the war into the arena of ocean science and to attract leading scientists from other disciplines into ocean research. These developments were stimulated

by global ocean expeditions which led ocean science into a new phase. The chapters also examine developments in ocean observing technology, current recording meters, satellite navigation and diving technology. This period also saw the emergence of a formalized structure for scientific cooperation from a more holistic approach, encompassing hydrology, geology, the atmosphere and ice. The chapters trace the establishment of key intergovernmental organizations, the first large multiship regional study of the North Atlantic, the development of training and mutual assistance programmes, and the advent of new observing, recording and communication technologies.

Chapters 12 and 13 examine extensions of national jurisdictions leading to colonization of the ocean floor beyond coastlines, including reference to the Truman Proclamation of 1945 (which led to the three UN conferences on the Law of the Sea in 1958, 1960 and 1973–82) and the development of the International Decade of Ocean Exploration 1971–1980, which enabled scientific cooperation at the global, regional and subregional level. This cooperation resulted in fundamental discoveries of conditions on and below the ocean floor, regional projects with the Nordic Council for Physical Oceanography, International Southern Ocean Studies, and global studies of fluxes between the ocean and the atmosphere. The chapters examine major technological developments, including refined sampling, analytical technologies and the storage of samples and modelling, all of which were rooted in interdisciplinary cooperation. In parallel, they discuss the negotiations at the Third United Nations Conference on the Law of the Sea leading to the development of the United Nations Convention on the Law of the Sea (UNCLOS) of 1982, as well as its impact on cooperative ocean research and observations, in particular through the introduction of the Exclusive Economic Zone (EEZ).

Chapters 14–22 explore increasing concerns relating to degradation of the marine environment, overfishing and coastal erosion, increasing levels of waste disposal, pollution, and global changes in demography, population and nutrition, as well as political tensions. The chapters also refer to the 1972 United Nations Conference on the Human Environment in Stockholm, the creation of the United Nations Environment Programme (UNEP) and GESAMP, and present examples of related regional cooperation. They discuss the emergence of concerns for human health related to seafood contaminated by pollution, which highlighted the need for specific interdisciplinary and multidisciplinary research with an integrated approach. The chapters present the development of the Large Marine Ecosystem (LME) model for such studies, and the Integrated Coastal Area Management (ICAM) paradigm, which was used from the 1970s onwards. They also track the rise in concern for marine pollution, debris and

algal blooms, with consequent impacts on seafood security and human health. On the technological front, the chapters describe the gradual establishment of GOOS during the 1990s, the development of models to forecast seasonal events and changes, the use of warning systems for hazards such as tsunamis, typhoons, tropical cyclones and flooding, and various risk reduction efforts. They also recount cooperation approaches in research and observations at the intergovernmental level, as well as major technological breakthroughs in ocean observations, recording and surveillance using satellite observations and mapping, and forecasting of seasonal fluctuations, including El Niño and monsoons.

Chapters 23, 24 and 25 trace the evolution of the sustainable development paradigm, climate change and multistressor issues, including ocean acidification, ocean warming, plastic pollution of coastal waters and the open ocean, and sea level rise. The new millennium saw an increased focus on the need for sustained, coherent, consolidated and coordinated efforts over time, leading to the proposal and creation of a United Nations Decade of Ocean Science for Sustainable Development (2021–2030). The chapters examine these developments, as well as major concerns for resource limitations, freshwater security, comprehensive human security, nutrition and health, and population developments.

Chapters 26–30 examine developments up to about 2015, including modalities of interdisciplinary cooperation and the increasing need for integration, including in the social and economic sciences, as well as collaboration between different sectors of society towards developing the ocean economy and enhancing public participation and understanding. They provide an overview of changes in the ocean and offer some results of research, observations and ongoing ocean service programmes, which demonstrate great potential for further developments in service of society, including in relation to climate and global change. The chapters also discuss some related trends in ocean research with industrial applications, as well as further technological developments in observations, modelling and training. The final chapter provides some concluding remarks and an outlook for the future.

1 A breakthrough in visionary cooperation serving commerce and safety at sea

Early efforts in the mid-nineteenth century to establish international and multinational cooperation for ocean observations, together with the exchange, sharing and use of the resulting data for the common good, can be traced to the singular vision and drive of one individual, Matthew F. Maury, who served in the US Navy and was Head of the US Naval Observatory. His persistent efforts led to the creation of an internationally coordinated system of regular physical observations of the surface layer currents (drift), temperature, wind and cloud cover. The system was established with the participation of several Western maritime nations, in particular Belgium, England, France, Holland and the United States (Maury, 1874), and relied on mariners and commercial shipping.

Among the outcomes of this coordinated regional effort were wind and current charts, which drew on the logbooks kept by navigators. These charts, which were initially prepared by Maury on the basis of these meteorological data and records of sea surface temperature during the 1840s, were greatly appreciated by American navigators. As a result, Maury extended the charting and routing endeavour geographically and involved several nations in the process, pursuing the creation of a uniform global network based on agreed standard procedures of observation and reporting. He initially wanted to include observations from land as well as the sea, but ran into resistance despite obtaining scientific support.

The ocean charts significantly improved navigation, and thus the safety of shipping, and could also potentially aid weather forecasting. They significantly shortened the time of passage of sailing vessels between continents, decreasing the travel time between Europe and the west coast of the United States from 185 days to 135 days, and a round trip of Europe, Asia and Australia from 280 days to 160 days. Regular observations were noted in dedicated ship logs and reported to receiving stations at the end of each voyage. The charts gradually came to cover all areas of the ocean subject to regular navigation, and included information on winds, currents, magnetic variations – of singular importance for safe navigation – surface temperatures and, in some cases, hydrography,

with depths and tidal ranges. Such a system of physical research and its useful results attracted the interest not only of mariners but also of commerce and governments.

Ships providing logged observations to institutions, such as the National Observatory in Washington, received the wind and current charts for free. Accordingly, it did not take long to build a network of voluntary observers, with more than a thousand navigators engaged in the endeavour, covering large parts of the ocean and making and recording their observations according to a uniform plan developed by Maury. Indeed, the venture drew the interest of most users of the sea. The Government of the United States, in cooperation with Belgium, invited interested nations to a conference to adopt a uniform system for the observations and their reporting. The conference owed much to the cooperation between Maury and Adolphe Quetelet, the Director of the Royal Observatory in Brussels and Secretary of the Royal Academy of Belgium (Houvenaghel, 1990). It was held, after considerable preparations, in Brussels in August 1853, with the participation of delegations from Belgium, Denmark, England, France, Holland, Norway, Portugal, Russia, Sweden and the United States (Maury, 1874). It resulted in a recommended plan of observations to be followed on board the vessels of all friendly nations, in particular those attending the conference. Shortly after the conference, several other nations joined the cooperative effort, including Austria, Brazil, China and Spain.

The 1853 conference in Brussels and the implementation of a network of regular observations with an agreed reporting procedure, designed to achieve a global understanding of surface layer phenomena through standardized basic tools, represented the first international cooperative effort towards the creation of a worldwide oceanographic and meteorological databank – a necessary step towards modern oceanography (Houvenaghel, 1990). They also demonstrated the necessity of global cooperation to achieve important goals in this field. Together, Maury and Quetelet had laid the foundation for modern oceanography, and their initial idea of incorporating observations from land with a view to creating a world meteorological network was initiated 20 years later at the first International Meteorological Conference, held in Vienna in 1873.

This global effort could be seen as a precursor to the creation of a law of the sea initiated about 100 years later. This is reflected in Maury's conclusion: 'Thus the sea has been brought regularly within the domains of philosophical research and covered with observations'. According to Maury, Alexander von Humboldt, the renowned German naturalist and explorer, agreed that a new field of science had been born, which the latter named the 'Physical Geography of the Sea'. Maury also noted that the system as it stood covered only the ocean and not

the land. Data from the latter would need to be included to broaden knowledge and increase the possibilities of forecasting weather and other conditions. This vision was gradually pursued and strengthened through international and intergovernmental cooperation, notably through the same conference in Vienna in 1873, which initiated the creation of the International Meteorological Organization. This was finally established by the International Meteorological Congress in Rome 1879. The organization survived two world wars and in 1947 was transformed into the World Meteorological Organization (WMO) through the adoption of the Convention for WMO by Congress in Washington DC. The Convention was ratified in 1950 and the IMO formally became the WMO, which in 1951 became a Specialized United Nations Agency.

It is worth noting, however, that the ocean and the seas led the way. Indeed, the nature of the ocean made cooperation inevitable. The ocean became the great integrator as well as the moderator, in some ways due to the hazards and dangers it presented, together with open access, which invited free use as well as abuse. These problems were addressed 100 years after the Vienna Conference at the negotiations for the United Nations Convention on the Law of the Sea (UNCLOS).

Maury also took note of a particular technological advance in the exchange of information: the telegraph. This innovation would make possible the exchange of observations on a daily basis, in near-real time. This system of weather information came into operation in 1860. While lesser known than the chronometer 100 years before, the telegraph in fact represented a technological achievement of great importance for navigation, safety at sea and ocean research. Seafarers and navigators soon realized that the system of international cooperation which had been put in place would have an important educational impact – scientifically as well as culturally. It would increase understanding between nations and provide for enhanced awareness and readiness with respect to the hazards of the sea and the need to extend help to those in danger. The mere availability of information beyond immediate reach would stimulate seafarers to explore and become interested in learning more, possibly with the aim of achieving a greater understanding of interactions between the sea, the atmosphere, the ice, land and human society. However, despite the availability of the new means of communication, it took a major disaster to agree on a global norm for the safety of lives at sea. Following the loss of the *Titanic* in 1913, the SOLAS treaty was passed in 1914. The International Convention for the Safety of Life at Sea (SOLAS) was adopted in its present form in November 1974 and entered into force in May 1980.

For the cooperation and services envisioned by Maury to come to fruition, there was a need for reasonably precise navigation and technology for the positioning of ships. Both of these needs were fulfilled, but their achievement built on the successes of another earlier navigator and explorer with a diligently scientific approach to his work, for whom we need to travel back in time about 100 years.

2 Exploration: Navigators, practitioners and scientists

The development of oceanography would not have been possible without practitioners in the form of seafarers, navigators and explorers, with open and scientific minds, willing to share their findings and cooperate with others. Many great explorers fit this description, but one in particular is worthy of mention: Captain James Cook. As an explorer, Cook also contributed substantially to the development of safe navigation and positioning in the open ocean, and initiated and participated in scientific cooperation, including through charting his voyages, recording observations, and collecting and preserving samples.

Captain Cook was born in 1728, about 100 years before Matthew F. Maury. His contributions to exploration and science span the years 1760–79 during the period known as 'the Enlightenment'. They cover exploration, surveying, astronomy and navigation, human health in the context of long voyages, and contributions to natural sciences in cooperation with scientists from several countries. He also collected natural materials, which were preserved and recently used in a DNA (deoxyribonucleic acid) study to trace the movement of the sweet potato across the Pacific.[4]

Captain Cook's voyages ranged from the Arctic to the Antarctic, covered the Atlantic and Pacific Oceans and also included the Indian Ocean. He first came to the attention of the Royal Society due to his detailed work on a solar eclipse observed in Newfoundland in 1766 (e.g. Freuchen, 1957; Low, 1878). As a result, he was chosen by the Royal Society and the Admiralty to lead an expedition to the South Sea to observe the eclipse of Venus across the sun. This first expedition on the H.M.S. *Endeavour* sailed from England in August 1768. Cook brought with him several leading scientists, including the Swedish botanist Daniel Solander, who had worked with Carl Linnaeus and Joseph Banks, and artists

4 The referred research suggested that the sweet potato found by Cook was different from other sweet potatoes; it is nevertheless suggested by the research team that it may have been brought to the Polynesian islands from South America by voyaging islanders. Let the link remind us of the important role of Tahiti and the Polynesian people for the explorations of Captain Cook (Moore, 2018; Thompson, 2019); see also Zimmer (2018).

to make illustrations and maps. Livestock and fruit were stored on board to provide fresh food to help prevent outbreaks of scurvy.

Daniel Solander was at that time living in London, organizing collections at the British Museum. It was there that he had met and made friends with Joseph Banks, who had studied at Oxford University but was nevertheless a self-educated botanist. Banks had accepted and was applying the classification system and new taxonomy developed and published by Linnaeus. The new taxonomy had stimulated much discussion and led to botany becoming a leading natural science subject. Banks and Solander worked together with Cook during the expedition, collecting samples of plants and other organisms from the ocean surface using a small boat tugged by the *Endeavour* (see Moore, 2018). The *Endeavour* became a scientific laboratory and a base for ocean studies, with catching nets gathering samples that were then analysed on the ship, sketched in detail by the artists, and preserved as far as possible for the return home. This process represented a new approach in scientific sampling, making the expedition a point of reference in the development of ocean science. Cook circumnavigated the globe on the *Endeavour* on a number of expeditions between 1768 and 1771. The ship was uncommonly strong and is commemorated in the many names of bays and straits (Moore, 2018). The initial expedition was both an exploratory and scientific undertaking, and in many respects symbolized the advent of ocean research.

In May 1769, the Cook expedition reached Tahiti, which provided an ideal platform for the observation and astronomical study of the transit of Venus. The research also afforded the scientific group an opportunity to study the habits and lives of the indigenous people inhabiting the islands – with respect and without interference. The expedition studied the botany and collected samples, and surveyed and mapped the entire group of islands. Cook chose to maintain the native geographical names on the maps in a remarkable display of scientific diplomacy. In this decision he was influenced by the islanders, notably a Tahitian islander, Tupaia, who had a wide knowledge of the islands and the Pacific, including charts, which he shared with Cook. These led to a wider understanding of the Pacific Ocean (Thompson, 2019), and greatly assisted Cook in his further exploration and discovery of other Pacific islands. A remarkable cross-cultural friendship developed between Cook and Tupaia, who became a member of the crew and travelled with Cook on the *Endeavour*. On one occasion, he averted hostilities with a group of Maoris on a New Zealand shoreline by speaking with them in Tahitian. This trans-Pacific understanding of the language was confirmed during further expeditions by Cook (Thompson, 2019). It should be noted that the first European to sight New Zealand was the Dutch explorer Abel Tasman

in 1642 – an expedition that culminated in hostilities with the native islanders and many deaths. Captain Cook was the first European to circumnavigate and map the country and land there without incident, thanks to the intervention of his friend Tupaia.

Captain Cook's skills as a natural surveyor resulted in highly precise maps. Much information was collected by the scientists on the *Endeavour* about the nature of the region and the ethnology of the people, which provided a baseline for local conditions. However, these expeditions also opened up these lands to other European explorers and conquerors – a process which led to colonization and hindered the free sailing and trade of the Polynesians across the Southern Seas (Thompson, 2019). The changes were noted about 150 years after Cook's voyages by another famous scientist, Prof. Johannes Schmidt of Denmark, who visited Tahiti with his wife in 1925–26 (Poulsen, 2016). Schmidt was studying the eel population of the island group as part of global in-depth research into this species, while his wife explored the local culture and living conditions. Colonization had gradually eradicated many, if not yet all, indigenous customs, and the Schmidts came to refer to Tahiti as 'Paradise Lost'.

On the way back, the Cook expedition followed the coast of Australia, then called New Holland, stopping at a bay that was home to so many unknown plants that the scientists named it Botany Bay. The expedition collected many specimens and set sail, finally reaching London in July 1771 after several further adventures, including outbreaks of scurvy. The scientific results of this first expedition proved to be of global interest and greatly stimulated the natural sciences. This led to a decision to launch a new expedition with the support of the British Government, under the leadership of Captain Cook, this time with two ships. The destination was Antarctica and the hypothesized *Terra Australis Incognita*, whose existence had already been conceived by Greek geographers, due to the balance of land mass on this rotating sphere requiring a continent in the South Seas.

Setting sail in July 1772, H.M.S. *Resolution*, captained by Cook, and H.M.S. *Adventure*, captained by Tobias Furneaux, stopped first at Cape Town, where several scientists joined the expedition, including another botanical apostle of Carl Linnaeus, Anders Sparrman. The expedition continued southwards, reaching 50° S before being stopped by ice flows and dense fog. With course adjustments and care, it reached 67° S in January 1773, thus being the first expedition to pass the Antarctic South Polar Circle at 60° S. This was during the period of the Little Ice Age, which lasted from about 1350 to 1850, with temperatures on average up to at least 3 °C cooler than the present day, and likely even colder at polar latitudes. After passing the Southern Polar Front, the

ships became separated by fog and ice. They did not manage to make contact again. The *Adventure* turned northwards, returning to New Zealand, while the *Resolution* pushed on towards Antarctica before having to turn back.

After spending the southern winter in Tahiti, the *Resolution* made another attempt to venture further, but was stopped at 71° S. Following further efforts to locate a southern landmass, Cook's ship rested at Easter Island, studying the place in detail. From there, they sailed once more to Tahiti. Continuing westwards in 1774, they found an unknown group of islands, inhabited by Melanesian populations; these became the Cook Islands. Despite continuing eastwards across the Pacific, passing by Cape Horn, and sailing around the South Pole, Captain Cook was unable to catch sight of the fabled continent although on his last attempt he came within 75 miles of the coast but had to retreat due to field ice. On its return, the expedition brought home more scientific results and geographical information than any previous expedition. Cook was hailed a national hero and elected a member of the Royal Society. Another 50 years were to pass before two Russian sloops, the *Vostok* and the *Mirnyi*, under the command of Fabian Gottlieb von Bellingshausen and Mikhail Lazarev, respectively, were to succeed in exploring the Antarctic Region. The expedition lasted from 1819 to 1821, retrieving data on ice barriers, as well as currents and the physical characteristics of the water (see Rostov, 2004).

Cook's third, and ultimately his last, expedition aimed to locate a passage between the Atlantic and the Pacific north of America. The expedition set out with two ships in July 1776, a week after the signing of the Declaration of Independence between England and the United States of America. Sailing by the Cape of Good Hope, onwards south of Australia and Tasmania by New Zealand, Cook reached Tahiti a year later in July 1777. After several months, Cook proceeded across the Pacific, reaching an island inhabited by turtles. The island had been found three years earlier by the French explorer Rocheguide in January 1774, and was previously sighted on Christmas Day in 1615 by Captain William Mynors, who gave it the name Christmas Island (see, for example, Treguer, 2018). On continuing the voyage, the expedition rediscovered an archipelago which Cook named the Sandwich Islands, today known as the Hawaiian Islands. The marks of previous European visitors from Spain could be found among the population there, in the form of organized farming and iron tools.

After overhauling his ships on Vancouver Island, in April 1778 Cook proceeded along the coast to Alaska and into the Bering Strait – in so doing becoming the first navigator-scientist-explorer to cross both the southern and the northern Polar circles. Heavy ice, however, prevented the expedition from progressing further north. Instead, Cook turned south again to Hawaii, thereby avoiding the

fate of another explorer, Sir John Franklin, whose crew perished of hypothermia, starvation and scurvy in 1847 while pursuing the same route. Setting out from Hawaii in February 1779, Captain Cook was forced to return to seek repair for his ships after heavy storms. There followed a dispute with the islanders which ended Captain Cook's life on 14 February. However, his crew followed Cook's training and refrained from retaliation. The expedition departed without its Captain, once more in an effort to locate the north-west passage, but without success.

The *Endeavour* had been scuttled the year before Cook's death. Linnaeus passed away the same year and Solander died in 1782. A remarkable couple of decades had passed. This period had witnessed the publication of Linnaeus' natural classification system, and the invention of Watts' steam engine in 1769, followed by the spinning jenny in 1770. The United States of America was founded in 1776 in the same year that Adam Smith published *The Wealth of Nations*. A period that had shaped much of Western society came to an end, only to be followed by the terror of revolution, which caused the European nations to turn inwards (Moore, 2018).

Joseph Banks lived through this period of revolution and was elected president of the Royal Society in 1778, finally passing away in 1820. The cooperation between Banks, who had great admiration for Linnaeus and Solander, as well as Anders Sparrman, during the expedition on the *Endeavour* under Captain Cook – and the great number of samples brought home – gave rise to the Royal Navy tradition of carrying a naturalist on board naval expeditions to make biological collections and observations. The expeditions of the so-called Apostles of Linnaeus in the eighteenth century thus led to those of Darwin, Huxley and J. D. Hooker in the nineteenth century and, ultimately, to the acceptance of the theory of the evolution of plants and animals (Blunt, 1971). However, over 100 years was still to pass before oceanography became a science in its own right – also this time through cooperation between academia and the military, represented by the Royal Navy.

Captain Cook stands out among sailors, navigators and scientifically minded explorers for his courage and honour, as well as his ability to inspire other explorers, including scientists, and to generate cooperation among them on both a national and international scale. Combined with this was a respect for other cultures, indigenous peoples and their rights. A commemorative tablet in the church complex where his wife and two sons are buried (Low, 1878) reads as follows: 'In Memory of *CAPTAIN* JAMES COOK, of the Royal Navy, one of the most celebrated Navigators, that this, or former Ages can boast of; who

was killed by the Natives of *Owyhee*, in the *Pacific Ocean*, on the 14th Day of February, 1779; in the 51st Year of his Age.'

There are, of course, outstanding navigators and explorers from former ages who may be compared to Captain Cook. One such example is the Chinese navigator and explorer Zheng He. Between 1405 and 1433, his expeditions reached most of the countries of South-East Asia, Southern Asia and the Indian Ocean (Yang, 2004). His efforts received the strong support of the Chinese Emperor, and included up to 27,000 men, scores of large ships and over 100 smaller ones. They explored the seas and coasts of Japan, Viet Nam, Indonesia and Malaysia, and came to control the Malacca Strait into the South Asian Seas and the Indian Ocean. They accomplished reaching the Gulf of Aden, Hormuz and the Red Sea, the coasts of Somalia, Mogadishu and Kenya. In all, Zheng He completed seven expeditions, covering an area which is home today to over 30 countries.

The main purposes of these expeditions were pacification, alleviating conflicts, maintaining stability, demonstrating strength and showing the flag of the Chinese Empire, which at the time was very powerful and prosperous. Countries were encouraged to endorse the sovereignty of China and pay regular tribute (Yang, 2004). Zheng's demonstrations of power included the defeat of pirates based around Sumatra, Indonesia during his first voyage in 1407. A similar show of strength took place in 1411 in Sri Lanka. Following an attack by the local king, Zheng He deployed his forces decisively in a surprise attack, capturing the king and queen.

Each expedition took gifts and information about China and Chinese culture to the places they visited, and on their return they brought back spices, textiles and precious stones, all of which were highly valued in China. Indeed, the huge, loaded ships came to be regarded as 'treasure ships'. The expeditions also provided a wealth of information about these countries – their customs, values, resources and military strengths. Zheng He himself, according to the biographer, was deemed a man of wisdom and courage, experienced in military affairs; he was diligent, polite and noted for his understanding of other people and cultures. He was much praised by later generations (Zhang, 1997).

Among early explorers and surveyors, the expeditions mounted from Russia from the 1630s onwards are also of note (Rostov, 2004). The initial expeditions in particular contributed to scientific understanding and knowledge of the northern Pacific Ocean coasts and straits. In 1648, a Russian expedition navigated a route from the Arctic to the Pacific, thereby confirming the existence of a strait between North America and Asia. The strait was later named after Vitus Bering who explored the coast of Siberia and parts of the Bering Sea from 1725 to 1730.

Several Russian expeditions from the 1740s to the 1770s also provided a basis for reasonably accurate geographic maps of the Far East and the northern Pacific (Rostov, 2004). These maps were extended to cover more of the northern Pacific through expeditions undertaken during 1785–94, including joint Russian-American surveys of these northern areas. This period marked the beginning of regular navigation, observations, mapping and hydrographic investigations in the northern Pacific. These continued and were extended over the period 1803–66, encompassing the Pacific Ocean, and included a first expedition to circumnavigate the world, mounted by the Russian Navy.

This work contributed to the emergence of oceanography and climatology. Findings included the system of equatorial currents, the Kuroshio Current, observations of temperature distributions in surface and subsurface waters, water transparency, and delimitations of ice and tidal regimes (Esakov et al., 1964). The Imperial Russian Navy performed regular hydrographic and oceanographic observations during this same period. The first expedition around the world, with two sloops, was undertaken by the Russian Navy during 1803–06 and included observations of tides, currents, temperature, salinity and vertical temperature profiles to 360 m.[5] Another expedition in 1819–21 with two sloops explored the Antarctic regions, retrieving data on ice barriers, as well as currents and the physical characteristics of the water. This was the first voyage to visit the regions since the second expedition of Captain Cook about 50 years earlier.[6]

The Russian contributions marked the beginning of systematic observations, laying a foundation for oceanography and marine meteorology, several decades before the initiative of Maury, and leading up to the *Challenger* expedition (see Chapter 4). The Russian expeditions were in many cases also rooted in international exchanges and cooperation: Vitus Bering was of Danish origin and Joseph Billings, one of the leaders of the expeditions, who provided detailed mapping and hydrographic studies of the northern Pacific in 1785–94, was a British navigator who had served with Captain Cook on his third and last voyage (Suzyumov, 2004).

The life of Captain Cook was part of the Enlightenment epoch, from approximately 1740–1800, following the Scientific Revolution of the seventeenth century from 1600 onwards. The Enlightenment period sought an understanding of the human condition more aligned with the Scientific Revolution and the

5 Published by the leader Kruzenshtern (1812), in Russian.

6 In 1815–18, a few years earlier, another circumnavigating research-oriented expedition had retrieved observations of surface layer transparency by measuring the depth of visual disappearance of a white plate lowered into the water – a method later named the Secchi disk after the Italian Father Pietro Angelo Secchi, who applied the technique in the Mediterranean in 1865.

Age of Reason than the views of the Middle Ages, and comprised four main themes: reason, science, humanism and progress (Pinker, 2018). These qualities and characters were all demonstrated by Captain Cook, an outstanding representative of the eighteenth-century Enlightenment. The Enlightenment has remained central to our thinking over the 270 years since its inception and represents the foundation for our present democratic system. Captain Cook was a practitioner of its core tenets, combining knowledge and cooperation to generate progress based on reason, science and human cooperation towards a vision of better ways of living.

BOX 1. Personal student experiences from ocean expeditions on the *Helland Hansen*: from the Baltic and the Skagerrak to the North Atlantic in 1963

I participated in many expeditions, initially as a student in 1963 and later as an oceanographer, until I joined the Intergovernmental Oceanographic Commission (IOC) in 1985. The majority of these expeditions were ventures in cooperation or partnership with other projects and groups of scientists on board research vessels from different nations.[7]

My first oceanographic experiences as a student at the Oceanographic Institute of the University of Gothenburg were obtained during the summer of 1963 on the research vessel *Helland Hansen*. The ship was provided by the Geophysical Institute in Bergen, Norway with financial support from the Oceanographic Institute. These experiences laid the foundation for my continued oceanographic fieldwork. Students from the institute were given the possibility to participate in expeditions covering parts of the southern and central Baltic, and the Kattegat and Skagerrak areas. The work included piston coring for sediment studies in the Baltic, hydrographic sections of the area using standard water bottles attached to a wire lowered by a hydrographic winch, and water current measurements. For the uninitiated, 'sections' consist of multiple stations – positions, normally predetermined, where the ship stops with the bow facing the wind and waves and its engines and propellers going, allowing it to drift with the water current and wind without making speed, while keeping the wire with the bottles vertical. This allows the ship to remain in the same relative place so instruments can be lowered over the side to take samples.

The *Helland Hansen* was a small ship, weighing about 200 tonnes, with a standard crew of seven to eight supplemented by a scientific crew of eight to ten. Equipment included a laboratory and winches for heavy oceanographic equipment (e.g. hydrographic casts, bathythermographs, oceanographic buoys and piston coring).

Having been educated at the Swedish Naval Academy, the conditions on a crowded ship and the requirements for personal conduct and

7 Several formed part of large-scale regional or global ocean research programmes, organized through international bodies – ICES, SCOR and IAPSO of ICSU or IOC-UNESCO and other UN partners – and some were programmes of the International Decade for Ocean Exploration 1971–1980.

management were not new to me. In fact, my naval experience proved to be highly useful, especially my training in navigation by radio, radar and astronomy. My objective was to learn how to undertake oceanographic work on a ship. In this regard, the teachers from the Oceanographic Institute and the crew were of enormous help. The overall spirit was positive, typified by cooperation, mutual trust and a willingness to share knowledge and practical experience. I got along very well with the crew and was sorry to leave the ship in Gothenburg once the summer was over.

From the crew of the *Helland Hansen*, however, I had learnt of an upcoming international expedition that the ship was due to make to Iceland and Greenland in September 1963, to study conditions in the Denmark Strait with a focus on overflow from the Greenland Sea to the North Atlantic. The work was to include current measurements, moorings and hydrographic sections across the Strait. I made several attempts to join the expedition through the Oceanographic Institutes in Gothenburg and Bergen, only to hear that the ship's complement was full. At the last moment a place opened up and I was accepted, and took a train from Gothenburg to Bergen in early September.

The joint Icelandic-Norwegian expedition to the area between Iceland and Greenland in September 1963 – of which I was now a member – formed part of a large-scale Irminger Sea programme, which was supported by the NATO Subcommittee on Oceanographic Research. As stated above, a key area of focus was the overflow through the Denmark Strait between Iceland and Greenland.[8] The programme aimed to measure currents using anchored recording current meters recently developed in Bergen. On the ship, we measured the current at several depths using the Ekman repeating current meter, which can be used to observe the current at several preselected depths in one lowering while the ship was at the station. We also obtained sections in lines across the Strait at a predetermined number of stations where the ship stopped to lower water bottles attached to the hydrographic winch for water sampling.

We sailed on the *Helland Hansen* from Bergen in early September for Reykjavik, verifying the position of a current meter buoy close to Shetland en route. The weather was reasonably good and we saw the newly formed volcanic island close to Iceland, named Surtsey, with

8 See Gade and Malmberg (1965) for more details.

eruptions of water and hot air. After a brief stopover in Reykjavik, we continued into the Denmark Strait. The area is known for bad weather, and this reputation turned out to be well-earned: the weather deteriorated quickly. We managed to stop at a few hydrographic stations to lower water-sampling bottles by means of a hydrographic winch. At one of these stops, while operating the wire with the water bottles, I was almost swept overboard, only to be saved by Dr Herman G. Gade, the cruise leader.

During the passage, we maintained contact with other ships participating in the Irminger Sea programme, in particular the *Harald Sverdrup* of the Norwegian Polar Institute. We obtained regular information on the progress of the overall project, the weather in other parts of the sea and, crucially, the ice conditions in the western parts of the Strait. We had an experienced ice pilot on board, and it became clear that he would earn his salary.

My training and education developed considerably through the work and exchanges with graduate students, scientists and, not least, technical staff from the Geophysical Institute of Bergen, who formed part of the scientific crew. The chief scientist, Dr Herman Gade, became a good friend, as did the crew of the ship. I had the opportunity to navigate with radio beacons and even use a classical sextant to measure the height of the sun in order to determine our latitude.

After crossing the Strait, the plan was to meet with several ships in the port of Angmagssalik on the east coast of Greenland. However, the weather and ice conditions prevented our ship from entering the harbour. The ice pilot advised against passing through the ice belt in such weather and ice conditions, which hindered free movement of the ship. Furthermore, the propeller of the ship was unprotected. The wind force reached storm level with gusts well above 30 m/s and drifting ice streaks formed at regular distances apart, similar to the streaks of foam formed by the wind that can be seen when sailing in calmer conditions. A decision was taken to heave to behind a grounded iceberg at a suitable distance until conditions improved.

The storm continued for several days with wind speeds of around 30–35 m/s, and rising seas. Standing on the bridge house, I was unable to see the horizon, which indicated waves of the order of 6–10 m in height. Drifting ice flakes formed distinct and persistent streaks on the sea surface. It was the responsibility of the bridge watch to avoid these, as

many of the flakes were quite substantial in size. I was asked to replace the mate for several watches – a sign of the trust the crew and acting captain had placed in me. However, keeping watch was demanding and tiring. Each watch period lasted six hours and required constant attention to the ice and waves, ensuring that the ship was positioned correctly against the waves. This was achieved through the use of a Kamewa propeller and, of course, the rudder, with communication passing rapidly between the two watchers positioned on the bridge and the engine room. However, on my first watch, the bridge was filled with others wondering at the spectacle of the sea and watching my professional ability to handle the ship.

After five days, the storm gradually calmed, the seas reverted to gentler swells and the captain took the ship out of the area. We had done what we could and it was decided to return to Iceland, stopping at hydrographic stations en route for sampling. The sea was still rough, however, and the ship pitched and rolled heavily. After stopping off once more at Reykjavik we turned towards Bergen. The whole experience had been remarkable. On our return I received a request to meet with the director of the Geophysical Institute, the renowned Prof. Håkon Mosby. This was an experience in itself, particularly as he personally paid me several hundred Norwegian kroner as a compensation for my watchkeeping on the bridge. These were spent with several of the crew drinking beer on the mountain top overlooking Bergen.

This expedition was my first real test of genuine responsibility on a research vessel under rough weather conditions. The experience was much to my liking and I came to understand the extent of the ocean research still to be done. I also had the opportunity to familiarize myself with some of the emerging new technologies for ocean observation which the expedition deployed. I realized that the international cooperation underpinning the project was clearly essential for regional and basin-wide ocean research – from the perspective of best use of available resources by pooling of infrastructure and human resources. The cruise had also provided a thorough demonstration of the hazards of working in hard weather in northern waters on a rather small ship. I did not know then that I would participate in many more expeditions on the *Helland Hansen* for over a decade. These would take me to the northern seas outside Norway and the fjords, to the Skagerrak and Kattegat, and down to the western Mediterranean and the Strait of Gibraltar. These expeditions would often last several weeks. My respect

for the crew and the ship grew, due to the many, different and sometimes complex experiments and associated operations carried out in very varied conditions.

Several of these cruises were the result of Nordic cooperation involving several Nordic institutes, as well as institutes and scientists from other countries, including the United States. Our joint scientific results provided contributions to the increasing understanding of the ocean and its coastal zones. The statement at the opening of the Oceanographic Conference in Scotland in 1976, that the *Helland Hansen* had been lost at sea outside Norway, came as a great shock, and a personal loss. The captain whom I met first in 1963 and one technician were lost. Apparently, the ship had sunk fast, but thanks to the quick action of the captain, who managed to send a May Day signal, the rest of the company on board were saved. This was a testament to the very high level of professionalism, competence, sense of duty and responsibility of the captain and crew, which I had experienced, greatly appreciated and learnt from since my first expedition in the summer of 1963.

True to its tradition and dedication to exploration and ocean research, as well as international cooperation, Norway launched a new ship for the University of Bergen. This was given the name of *Håkon Mosby*, named after the Norwegian oceanographer referred to above. In May 1985, I would undertake my final expedition with the same cruise leader, now Prof. Herman G. Gade of the University of Bergen, Norway, on this same ship.

3 Longitude: The role of cooperation in a technological, scientific breakthrough

Captain Cook made one more very important scientific-technological contribution to the field of ocean exploration – his contribution to the long-standing navigational issues around determining longitude, a challenge that required a precise and accurate means of determining time. The efforts involved in tackling this problem lasted more than 200 years before a satisfactory solution was found. Several prizes were announced to stimulate these efforts by the King of Spain in 1598 and the Dutch Government some decades later, culminating in a prize of £20,000 offered by the British Government in 1714 (Andrewes, 1996). Three main approaches were considered feasible: terrestrial, celestial and mechanical. The terrestrial methods for longitude were based on knowing the magnetic fields of the Earth and making observations of their variations through the deviations of the compass needle. However, changes in the Earth's magnetic fields resulted in this approach being discarded.[9] The celestial method was based on determining lunar distances and had long been considered the preferred method. The moon served as a celestial clock, combined with selected related stars, and the distance between the moon and the selected stars was measured. However, the approach that finally paid off was a mechanical solution: the time-keeper. The key requirement of a satisfactory time-keeper was the ability to keep time to within two seconds per day – on a moving ship. Most leading scientists at the time considered this to be unattainable. In 1775, Captain Cook returned from his second expedition during which he had used both the lunar distance and the time-keeper methods to determine longitude over a period of three years.

Cook had brought with him four time-keepers. One of them, made by L. Kendall, was a copy of Harrison's original which had won the prize awarded by the British

9 There remains, of course, navigation relying on land observations, also referred to as 'terrestrial navigation'. This was used by navigators following the coast, for instance, in trade across the Baltic and North Seas, as well as by open ocean navigators sighting ocean islands, including the Vikings travelling from Scandinavia via the Faroe Islands, Iceland and Greenland to North America; by Portuguese and Spanish explorers crossing the Atlantic via Cabo Verde, the Canary Islands, the Azores, Bermuda and into the Caribbean, where they found many islands which they used as references; and by Pacific islanders crossing the Pacific.

Government (e.g. Freuchen, 1957; Andrewes, 1996). It performed so well that Cook and his chief astronomer came to rely on it rather than the recommended lunar distance method, which was more complicated and time-consuming. This version of the time-keeper was further developed and tested over subsequent decades. By 1790, it had evolved into what is known as the maritime chronometer, and was in general use. This marked 500 years since the introduction of the compass in sea faring in Europe in about 1280, a development which greatly increased navigation, shipping and commerce with global implications, as well as generating great wealth in many European nations (Aczel, 2002).

John Harrison, who developed the first successful maritime time-keeper, which evolved into the chronometer, was a self-made inventor without any formal university education. His story mirrors that of Cook, who was also a self-educated man with no university or other formal education. It was Cook's praise of the Harrison time-keeper that led to its recognition, acceptance and popularity on the basis of reliability and ease of use. This scientific development had global implications for navigation, exploration and the natural sciences. In our context, however, the chronometer was a basic requirement for the establishment of a network of cooperative systematic observations at sea, instituted through the work of Maury.

The longitude problem was scientific in nature, and its solution involved many specialized disciplines and cooperation, as well as much competition (Andrewes, 1996). A large number of proposals were submitted soon after the announcement of the prize by the British Parliament in 1699. The great importance attached to the problem was also evidenced by the careful protection of charts and maps, which had been gathered over time, in particular by Portuguese and Spanish explorers, and remained a closely guarded secret (see, for example, Landes, 1996). The solution to the longitude problem also formed part of a wide set of social interests related to trade, exploration, politics, competition to find new products for commercial exploitation, and the creation of trade monopolies, colonies and empires by the Europeans. Safe passage across the ocean was of vital importance, as shown by the mounting of cannons on ships.

Technological developments in navigation have continued, as we well know. As of the last decade of the previous century, the Global Positioning System (GPS) has allowed us to establish our position simply by means of our mobile phones. As with the development of the naval chronometer 200 years earlier, this technology was triggered by national and practical needs in the context of security, and potential and real conflicts.

4 The *Challenger* expedition and international cooperation: The foundation of oceanography as a science in its own right

Oceanography as a scientific discipline is considered to have been born with the British *Challenger* expedition of 1872–76, which took place 100 years after Captain Cook's second expedition and two decades after the first international ocean conference in 1853. In his book *The Voyage of the Challenger*, Eric Linklater concludes that 'The voyage of the Challenger made oceanography a science in its own right' (Linklater, 1972).

The *Challenger* expedition, as well as regional expeditions in the North Atlantic during subsequent decades, benefited from a warmer climate. The shift from a cold climate to a warmer period, beginning around 1850, facilitated further exploration of the seas at higher latitudes. This gradual warming by several degrees Celsius made expeditions to reach high latitudes considerably less hazardous than during the period of Captain Cook.

The *Challenger* sailed from England in early December 1872 and returned in May 1876. The vessel crossed the Atlantic four times and the Pacific once, travelling south along the African continent before turning westwards across the Atlantic close to the Equator, then on towards South America. It turned south and east towards the central South Atlantic, before turning south-west towards Cape Horn and heading into the Pacific, continuing westwards then north across the Equator. It then turned westwards to Asia, Indonesia and southwards into the South Pacific, westwards to Australia, across the Indian Ocean south of Africa into central South Atlantic, then along West Africa to Europe and England. The route covered many interesting parts of the ocean, and sampled and mapped the oceanographic conditions of many regions.

The organizers of the expedition followed the example of Captain Cook, drawing on cooperation between national institutions, including the Royal Navy, the Royal Society and universities. Indeed, the important contributions of the national navies of most maritime nations to the development of ocean research should be noted. Without cooperation between civil societies, private donors,

scientific leaders and national defence, oceanography would not have developed at such a rapid pace. My own limited experience in the Swedish Navy and at the University of Copenhagen supports this observation, as our institute received strong support from the Royal Danish Navy for investigations in Danish waters and the southern Baltic through the provision of time on small ships suitable for the Danish waters and the Kattegat.[10]

The team on board the *Challenger* included a number of scientists from different countries and institutions, making the expedition an international undertaking and concern. The scientific staff were under the leadership of Charles Wyville Thomson, who had a broad scientific background (e.g. Cowen, 1960), with experience from several smaller regional scientific expeditions in the North Atlantic. His research was concerned with confirming life at depth, below the euphotic zone which constitutes the upper layer where light penetrates to support photosynthesis. These expeditions had confirmed the existence of life even below 1,000 m, far deeper in fact than the euphotic zone. Dredging along the bottom had demonstrated the existence of life at all depths which were probed. There was also a new technical and practical reason for establishing conditions along the ocean floor, namely the laying of cable for transoceanic telegraphy. This technological breakthrough in communication had already become part of developments supporting the establishment of a network of systematic ocean observations, as envisioned by Maury.

The planning for the *Challenger* expedition was carried out under the auspices of the Royal Society through a special committee, and the Royal Navy made the ship available. The organization and cooperation that formed the backbone of this expedition came to constitute the founding of oceanography. The scientific programme encompassed all required science disciplines and the *Challenger* was transformed from a naval vessel into a scientific ship with two laboratories, a small library and a chart room, and was provided with equipment for dredging, trawling, water sampling and hydrographic, magnetic and meteorological observations. The *Challenger* was also equipped with propeller and auxiliary steam power, which was used to keep the ship hove-to at oceanographic stations. This important technological development was of great significance for emerging ocean research, making it possible to keep the ship reasonably steady for hours while drifting with the current. Another important invention available

10 Our institute participated in the international cooperative research project on the Danish Navy ship *Fylla*, supported by NATO, MILOC Baltic, for about three weeks in the southern Baltic in 1967. The Danish Navy also gave considerable support to the development of the Danish national programme for the International Decade of Ocean Exploration 1971–80 (see Chapter 15).

to the team on board the *Challenger* was the recently developed technique of photography.

Although the main scientific interest of the *Challenger* expedition was biology, regular observations encompassed physics, chemistry and geology, making for an integrated programme. Rocks and corals were collected when possible, and a sample from Christmas Island retrieved by John Murray, one of the scientists onboard, was found to originate from a rich phosphate deposit. Murray obtained a concession from the British Government to mine the deposits, and the money returned to the government from Murray's company more than covered the costs of the *Challenger* expedition (Cowen, 1960).

Challenger returned home with a vast collection of marine organisms, together with other samples and data from 362 oceanographic stations. The data identified major current systems and water temperature distributions, and highlighted the prevailing low bottom water temperature. Although preliminary analyses and reporting had been made during the voyage, the main work to analyse samples and data and undertake reporting in a systematic scientific fashion still remained to be done. This process necessitated broader international cooperation, which for practical reasons could not be accomplished on the ship. Scientists from most countries with marine interests were invited by Wyville Thomson, as the director and leader of the *Challenger* Commission, to join the team in Edinburgh where the *Challenger* office was established. In all, 50 volumes of reports were published. Wyville Thomson was later succeeded by John Murray and through his leadership the work was successfully completed, providing a solid foundation for ocean science and a wealth of material and inspiration for oceanographers (Cowen, 1960; Linklater, 1972).

The proceedings of the *Challenger* expedition and the underlying international cooperation, in addition to stimulating many national oceanographic developments, also supported the efforts of scientists who pursued a formalized development of international cooperation in ocean research. The result was the creation in 1902 of the International Council for the Exploration of the Sea (ICES).

5 Industrial revolution and institution building 1860–1914: How need and opportunity created the International Council for the Exploration of the Sea (ICES)

The Vienna Peace Conference of 1815 led to a period of relative global peace before several shorter, bilateral wars fought on the European continent in the second half of the nineteenth century changed the political situation. The warming climate during the second half of the century also provided a respite from severe famine, failed harvests, cold outbreaks and associated social unrest, and even revolutions. Additionally, decades of relative peace outside Europe provided an opportunity for several new nation states, and even empires, to consolidate and for colonization to continue.[11]

Against this backdrop, the Industrial Revolution was progressing apace with numerous technical innovations. However, industrial development also led to increased transportation of goods and migration of people, which provoked changes and unrest. Urbanization, often in coastal areas, became a significant social factor driven by the need for workforce and subsistence, with a shift from agriculture towards more concentrated industrial production. This led to a series of social conflicts during the first half of the century. It also highlighted the need to ensure sufficient food production for populations with changing distribution in countries. Technological developments helped to address these needs through the advent of enhanced transportation facilities on land and sea.

During the 1840s, international railroad lines started to transform Europe with increasing exchanges between nations and the gradual creation of a European-wide culture (Figes, 2019). Such technological development also provided evidence for – and the spread of – the scientific revolution of the 1600s, and the ideas of the Renaissance and the Enlightenment. The transportation revolution led to the movement of people and goods towards the coasts from where

11 The whole process and the associated competition, however, led to a gradual increase in nationalism at the turn of the century, similar to that which emerged as a consequence of the globalization process about 100 years later.

goods could be carried further and exported, stimulating more development of shipping as well as urbanization of the coasts. In addition, coastal areas were the site of much raw material and gradually evolved into regions of industrial and infrastructure development. The whole process generated more trade and exchanges of people, encouraged by population migration and the development of steam ship lines. Competition between nations in finding raw materials, food and new territory also drove geopolitical changes.

From around 1850 onwards, the rise of Prussia, as part of the process of German unification, made the state a leading contender for dominance on the continent, following the relative weakening of France as a result of the Revolution and the Napoleonic wars. The war with Denmark in 1864 forced the Danish monarchy out of the German Federation, an outcome repeated following the war with Austria in 1866. Following the German victory in the war with France in 1870-71, the unification of Germany was complete and it became the dominant nation on the continent, with France losing important natural resources in Alsace-Lorraine. This outcome can be seen as leading to the First World War of 1914–18, as noted by Bergström (2019), which ultimately resulted in Germany reverting to a situation similar to that of post-war France in 1871. The First World War, furthermore, led to important social changes in Europe, which gave rise to support for nationalism and sowed the seeds of the Second World War.

It is remarkable, therefore, that ocean science, while still relatively young, could during this period stimulate a level of international cooperation that led to the establishment of an intergovernmental institution. The establishment of the International Council for the Exploration of the Sea (ICES) in 1902 saw all competing nations become members and, furthermore, managed to survive the First World War. The same can be said for meteorology, with the creation of the first international institution in 1873.

In spite of the various political processes at work, international cooperation in science was not only maintained but also advanced in many branches, including oceanography. The process was stimulated by the efforts initiated by Maury and consolidated by the Brussels conference in 1853, demonstrating the social value of cooperative science-based ocean observations. The *Challenger* expedition further encouraged growing interest in ocean research, and was supported by new technological developments in communication, observations, recording and precise navigation. Likewise, the *Vega* expedition drove interest in ocean and

marine research.[12] These developments, however, were also inspired by the quest for goods, raw material (e.g. for infrastructure, building, harbour developments) and food. Marine exploration was supported by leading maritime nations, including the United Kingdom, the British Empire having adopted the paradigm of the freedom of the seas from the beginning of the nineteenth century (see, for example, Kullenberg, 2008).

Cooperation in marine science was developed further at the regional level, including through several exploratory and scientific expeditions in the North Atlantic, which were also facilitated by advances in steam power and the warming climate. The 1870s and 1880s saw several national research expeditions to the North Sea, Skagerrak, the Kattegat and the Baltic Sea, from Germany, the United Kingdom and the Scandinavian countries (Smed, 1990). The results of these ventures stimulated further cooperative efforts. Examples include an initial synoptic survey of the Skagerrak and northern Kattegat in early 1890, with five Swedish ships; regular synoptic surveys of the Kattegat, the Belts and Belt Sea by four Danish ships from 1891 onwards; and the implementation of cooperative international seasonal surveys during 1893–94, covering a wider region and involving five countries (Smed, 1990).

The initial survey efforts of the Scandinavian countries, headed by Prof. Otto Petterson (Svansson, 2006), covering the Baltic, Kattegat and Skagerrak, gradually led to the involvement of all the nations bordering the Baltic, North and Norwegian Seas. An important motivation behind this development was fisheries, based on the thinking that fisheries management should be founded on science. This defined the necessity for regional cooperation to gain coverage of the entire marine area, both in spatial and temporal terms, so as to obtain a reasonably clear picture and understanding of environmental conditions. The governments were also motivated by considerable concern about overfishing. This may seem strange in light of the statement by T. H. Huxley in the 1880s that 'there will always be sufficient fish in the ocean to meet the human needs for sea food' (Simon, 1984), but in the congested areas of shelf seas, overfishing was already an issue, and a key motivating factor in fisheries management. Overfishing became a problem due to subsequent, mainly technological, developments as demonstrated for example with the decline of herring stocks,

12 The Swedish *Vega* expedition under Nordenskiöld first navigated through the north-east passage in 1878–79 (Kish, 1973). However, the ship, provided by the Royal Swedish Navy, became trapped in the ice not far from the Bering Strait in the autumn of 1878, spending the winter there, and was feared lost. These worries were forgotten when the leader of the expedition cabled from Yokohama about ten months later in the early summer of 1879, confirming the success of the passage. The success of the expedition was mostly due to the experience, persistence and leadership of the naval captain Louis Palander, and of Nordenskiöld himself, obtained through several earlier expeditions in the North Atlantic.

which was due at least in part to overfishing (Höglund, 1976; also Andersson, 1958 and Cushing, 1982). The discussions on this problem in the early association with the establishment of ICES are elucidated by Rozwadowski in her book on ICES (2002). Today, overfishing is considered a major global issue.

One leading scientist addressing the problem of overfishing in the early stages was Dr C. G. Johannes Petersen of Denmark. Petersen is renowned for his studies of the eel in Danish waters, which showed that silver and yellow eels are the same species, and for his development of new methods of catching fish and measuring their length (see Thomasson, 1981; Poulsen, 2016). His pupil Johannes Schmidt (see Chapter 2) continued eel studies around the world, including in the Sargasso Sea, and examined their breeding in the open ocean. Petersen introduced the use of tagging or marking fish to trace migration or non-migration. In order for this system to operate successfully, the method required international cooperation to mark fish systematically over a large area. One such area was the North Sea. Tagging experiments on a non-migrating species such as plaice may, over a limited period of time with sample statistics, help identify overfishing as a factor in fisheries decline. Assuming that fisheries statistics show the value of the total yearly catch of a given species decreasing year after year, and that there is no reduction in the efforts and prices of fisheries, or negative changes in the physical conditions of the area, then the decrease must be due to organic factors, such as humans through fishing, food abundance for the fish, or predators.[13] Petersen and his pupils created a leading floating laboratory in Denmark, which attracted visiting scientists from most of Europe and North America.

Many of the above survey efforts had a practical purpose related mostly to national fisheries. Governments were, in particular, motivated by the need to secure food from the seas to meet the demands of expanding coastal urbanization – a result of growing industrialization, including fisheries. Expeditions covering the Norwegian North Atlantic were carried out during the summers of 1876, 1877 and 1878, with information on these waters linked to studies of the North Sea. The reappearance of herring in Swedish western waters in the winter of 1877–78 triggered hydrographic observations of the fishing grounds, which aimed at investigating possible connections between the water conditions and the occurrence of fish. The results demonstrated that small-scale local surveying was not sufficient to reach the intended objective and led to the implementation of the larger synoptic Swedish survey in early 1890.

13 The analysis by C. G. Johannes Petersen was published in the *Journal of the Marine Biological Association of the United Kingdom* (1903) and reproduced in Thomasson (1981).

International cooperation was also driven by competition and concern regarding the potential for conflict in limited regional seas, such as the North Sea, the Mediterranean and the Baltic. This was with respect to shipping, commerce, resources utilization and fisheries. The cooperation continued in parallel with, and despite, growing nationalism in many countries, and gradually resulted in agreements on common norms and control measures. The development was particularly notable in the case of the North Sea. In the scientific domain, cooperation built on regular observations and reporting according to agreed schedules and methods for data exchange. This collaborative approach was further driven by leading scientists with diplomatic skills, abilities and status, with a view to forming friendships, capitalizing on opportunities and obtaining the ear of national leaders, including heads of state.

The Swedish scientist Otto Pettersson, in cooperation with others, worked to extend cooperative investigations to the entire north-eastern Atlantic region on a regular repeated basis, and to map seasonal and interannual variations. At a conference held in Copenhagen in 1892, he launched the idea of international cooperation to achieve the goal of studying the whole region of the eastern Atlantic according to a common plan. The Conference of Scandinavian Naturalists approved a proposal to prepare such a plan for the Scandinavian countries covering their adjacent waters. Through the combined efforts of Pettersson and the Swedish scientist Vagn Walfrid Ekman, this cooperative effort was expanded to include the Baltic Sea, the North Sea and the adjacent waters of the North Atlantic in the form of an International Hydrographic Survey. The plan for the survey was based on the Danish approach with fixed stations observed regularly on a seasonal basis, including observations from stationary light vessels and commercial routes. The plan covered one year, starting on 1 May 1893, and was successfully implemented with the participation of Danish, German, Norwegian, Scottish and Swedish institutions.

The success of the survey encouraged further efforts. Continuation and persistence over some decades led to the formal establishment of ICES in 1902, with the headquarters established in Copenhagen (Rozwadowski, 2002; Went, 1972). The International Geographic Congress in London in 1895 may be seen as a launching platform, with its resolution stating that 'the Congress recognizes the scientific and economic importance of the results of the recent research in the Baltic, the North Sea and the North Atlantic, especially with regard to fishing interests, and records its opinion that the survey of areas should be continued and extended by cooperation of the different nations concerned on the line of the scheme presented by Prof. Pettersson' (Smed, 1990), demonstrating the importance of the congress mechanism in developing international cooperation.

6 Regional cooperation in oceanography: Serving basic socio-economic needs

Regional cooperation in marine sciences and ocean observations continued to develop over the twentieth century and gradually came to include most ocean regions and serve social needs related to food supplies and their safety, and marine environmental conditions.

The International Council for the Exploration of the Sea (ICES) was initially established for a five-year period with a stipulated and collaborative multination programme covering the North Atlantic region from the Baltic to the Norwegian Seas. The scientific programme was based on agreed hydrographic sections for physical and biological oceanography to be run regularly by the participating nations. Following the successful completion of this venture and convincing results, the decision was taken to maintain the International Council. As stated earlier, ICES managed to survive the First World War and continued to develop and expand: cooperation between scientific communities and Member States increased in the period between the world wars, which can be considered remarkable in view of the level of social unrest in Europe and elsewhere during this time.

This period was also marked by technological developments in shipbuilding, navigation, transportation and fisheries, which necessitated an increase in scientific inputs to fisheries management, as well as other socio-economic sectors dependent on the marine environment. In parallel, advances in scientific methods and technology increased the volume and dispersal of scientific information.

A key innovation for mapping the biological production and elements of the health of the ocean was the introduction of the continuous plankton recorder in the North Sea and North Atlantic. The recorder was developed and first used by Sir Alister Hardy in 1931,[14] and was thereafter towed by research vessels and commercial ships along agreed sections, amassing data as part of the Continuous

14 Lowestoft Marine Laboratory (1989).

Plankton Recorder Survey. This survey 'has provided the international scientific community with its only available monitor of the general state of the oceanic plankton over large space and time scales' (Lowestoft Marine Laboratory, 1989); and although interrupted by the Second World War, has continued and been expanded to cover several areas of the North Atlantic and later the South Atlantic, and now also gathers data on key physical and chemical parameters. The self-contained automatic plankton recorders were towed by Ships of Opportunity[15] from ten nations along fixed routes at monthly intervals and at a standard depth of 10 m (see Lowestoft Marine Laboratory, 1989). The importance of these and similar standard observations in space and time over long periods cannot be overstated. Such observations allow for the detection of variations in plankton and fish production caused by overfishing and varying environmental conditions, including climate change (e.g. Cushing, 1982; Plymouth Marine Laboratory, 2013).

In the new millennium, ICES covers most branches of marine science, applying and providing scientific advice on a regular basis to the governments of Member States and the European Union. Such advice concerns not only fisheries but also environmental conditions, marine pollution, and implications for food and human health security. The underlying cooperation provides for the development and testing of methods, the regular monitoring of regional seas under the auspices of the related regional conventions, and the regular preparation of overviews of conditions as demanded by these conventions. Such conditions concern the fish populations and their food supply, climate conditions and variability across the region, occurrence of algal blooms including those harmful to the environment, and marine pollution problems and the related implications for human health and the health of the sea area or region, such as the Baltic and North Seas.

Regional cooperation in the marine sciences in service of fisheries and other uses of the regional seas developed further over the twentieth century. Many regional fisheries organizations emerged to deal with fisheries management, based at least in part on science and scientific advice developed through such regional scientific cooperation. While industry interests and political concerns likely and unavoidably influenced the end result of regional fisheries negotiations – which aimed to establish valid limits – oceanographic scientific cooperation and information constituted the starting point. In addition to technological developments, the issue of overfishing over the past 100 years has also been exacerbated by changing environmental conditions, climate change

15 Ships of Opportunity are vessels that make regular crossings over parts of the ocean basin, the Atlantic or other basins, whose managers accept to provide services for observations, including mounting and towing of equipment and taking proper care of recovered samples.

and pollution, influencing the availability of the resources and their quality. During recent decades, ongoing ocean acidification, warming, de-oxygenation, increasing pollution of the open ocean, in particular by debris and plastic material, changes in ocean circulation and biological diversity, together with continued overfishing, have brought these issues, which include food safety, to the top of the international agenda, in parallel with climate change. Furthermore, the problem of food availability and security has been exacerbated by the sharp rise in the global population and by the fact that food commodities are subject to the dynamics of global markets and finance.

The security of people and infrastructure is further threatened by hazards originating at sea, such as extreme weather events, and seasonal changes like El Niño – a manifestation of ocean variability in the eastern tropical Pacific Ocean – and monsoon variability, which also strongly influence food security. These factors are augmented both by increasing sea level and continuing urbanization, with large concentrations of people in coastal areas, including megacities and other urban centres. Thus, a multitude of factors and effects influencing human society are now driving, as well as politically underwriting, the need for scientific cooperation. These factors and motivations are stimulating and supporting basic research and systematic and sustained observations with data exchange and modelling for forecasting, which serve administration and management, infrastructure and human health protection, and comprehensive security.

However, in this context, the need to support basic, curiosity-driven, mostly academic research remains important, particularly in relation to sustained ocean observations. These are crucial for advancing modelling and enhancing understanding of ocean circulation and possible changes in relation to climate variation. The observations in combination with dynamic modelling and computing can result in forecasts of climate variability, such as the El Niño phenomenon in the equatorial Pacific. This is possible due to the long memory of the ocean, which enables researchers to follow signals of heat and freshwater inputs into the ocean, including the deep layers, over seasonal timescales lasting several months. In combination with modelling, these observations can help clarify changes in ocean circulation and ventilation that relate to climate variability and change.

BOX 2. The Southern Ocean, Drake Passage 1976: A programme of the International Decade of Ocean Exploration (IDOE) 1971–1980 (see Chapter 15)

Having experienced the conditions in the northern seas of the Atlantic, I was pleased when the Institute of Physical Oceanography at the University of Copenhagen, where I was a lecturer at the time, was offered the opportunity to participate in the International Southern Ocean Studies (ISOS), a programme of the IDOE, on one leg of the expedition in 1976 studying the Southern Ocean Front across the Drake Passage from Cape Horn, South America, to the Antarctica. We were invited to study the front by optical means, including light scattering for the distribution of suspended material across the front, and to make ocean colour measurements of the surface layer and observations of light quanta available for primary production in the euphotic zone.

The planned expedition would include international participants from Denmark, Germany, Sweden, the United Kingdom and the United States. A variety of observations and experiments were planned, as well as cooperation with other ships participating in the ISOS Programme. The expedition would take place during March–April 1976, leaving from Punta Arenas in southern Chile on the research vessel *T. G. Thompson*, which belonged to the University of Washington, Seattle.

We had to ship our equipment from Copenhagen to Seattle for installation on the vessel. This included a winch with 1,000 m of 7 conductor wire cable, and beam transparency, light scattering, quanta and colour meters, with associated electronic and recording equipment. Transporting the equipment necessitated significant logistical planning, including a number of papers and declarations for customs authorities, but the process worked. Arrival and installation was confirmed by the receiving marine facility of the University of Washington.

The scientific leader of the cruise was to be Dr Terry Joyce from the Woods Hole Oceanographic Institution (WHOI). We had previously shared a cabin on the *Atlantic II*, when he was a graduate student at Massachussets Institute of Technology (MIT), during an expedition to the Sargasso Sea in September 1968 under the leadership of the renowned Prof. Henry Stommel. This lent the cruise a personal character, and Terry and I corresponded about the planned expedition via traditional mail and telex up to the week prior to departure.

The expedition was a large, cooperative effort involving several different operations. We would run sections across the front using profiling conductivity-temperature-depth (CTD) equipment, make current measurements with drifters by the float technology courtesy of Dr Art Vorrhis, and control anchored current meter buoys. The planned duration of the expedition was three weeks.

I travelled from Copenhagen to Punta Arenas in the company of our research engineer, Mr Henning Hundahl, making an overnight stop in Santiago de Chile on 7–8 March 1976. The following morning we travelled on to Punta Arenas, and on arrival proceeded to the Hotel Cape Horn, where we met others of the scientific crew, including Terry Joyce. The ship docked the next day, 10 March. After boarding the ship and making our introductions, we started checking all the equipment, paying careful attention to the installation and working of the winch for the scattering meter. Part of the wire cable had been damaged, so it had to be cut and the end of the cable refashioned. However, all the instruments functioned and the winch ran fine on 450 volts powered by the ship. We also installed and checked the other profiling instruments and the deck photometer for the surface daylight measurements needed for the quanta and colour observations. Although the process of installing and testing equipment packed and shipped months before is always tense, any fears on our part were unfounded. The result proved the sense of responsibility, competence and cooperation of the ship's crew and the managers of the marine facility of the University of Washington.

Before sailing in the evening of 13 March, there was an exchange with scientists from a Chilean research vessel which had taken several expendable bathythermograph (XBT) sections across the Drake Passage to locate the position of the Southern Ocean Front. These also gave an indication of the structure we could expect and provided information for planning the positioning of sections and possible launching of floats. The time of our departure was set to allow us to pass specific positions in the Strait of Magellan at a predetermined time, and maritime pilots navigated our passage. The weather was fine with occasional fog and rain squalls, making it difficult to see land as we passed through the Strait. It was difficult to observe the coastline, although as we passed a deep archipelago we saw high mountains stretching up to 1,500–1,800 m with falls of melt water, and green hills with trees close to the water line, which reminded me of the mountain birch in Scandinavia.

There were no signs of people or houses. However, birds, seals, and floating weeds and wooden debris were plentiful, but no oil, plastic or paper waste. We passed a number of bays and narrow passages in the archipelago with black mountains, saw patches of snow during the day, and passed several mountain ranges with snow coverage and glaciers, some reaching down to the water front.

During our transit to the working area, the cruise programme was discussed: the timing of the bathythermograph (BT) sections, the float launches, stops at stations for optical deep scattering measurements; and the timing and procedure of the CTD section to record changes in the structure of the water profile. Watches were posted with four hours on and eight hours off, with four scientists on each watch, taking into account the flexibility required for differences in procedures at the stations. In the evening of 14 March, we passed Ushuaia, Argentina, the most southerly city, and entered the open South Atlantic around 02.00 local time on 15 March.

We conducted our first equipment test at a station around midday. The winch motor overloaded and burned out, but the engine crew helped us to change the power supply and the motor, exhibiting a high level of professionalism. The remaining equipment worked fine. We left the test station in the evening, heading south-east from Cape Horn, measuring temperature profiles every hour with XBTs as we sailed to retrieve a current meter mooring, a distance of about 240 nautical miles. The weather was fine with a gentle wind and calm sea with a light swell. We reached the mooring position during the night and the recovery was completed in good order by 11.00 on 17 March, in fine weather with partly clouded skies. This was to be the southernmost station at a latitude of 59°4', longitude west 63°53.9'. However, we did not pass the southern Polar Circle, much to my regret.

During the day of 16 March, the chief engineer and his crew resolved our issue with the winch. In the afternoon of 17 March, we reached our first real observation station where we deployed the winch and scattering meter south of the front, reaching a depth of 450 m. The scattering signal was weak with variations in the profile related to the temperature and stratification in the water column. The surface water was very clear with a low amount of suspended matter. It reminded me of the Sargasso Sea water with its intense blue colour. The following day we obtained one scattering profile reaching 500 m, north of the front. On 19 March, a clear sky and sunlight allowed us to make

optical measurements using colour and quanta meters. The wind was mostly weak, in the range of 5–15 m/s with a moderate sea. When light conditions permitted, we took surface layer optical measurements. The scattering meter worked very well: the instrument was lowered to the decided depth, thus obtaining a scattering profile. On the way up, the winch was stopped at selected depths depending upon the structure in the profile and the scattering curve was taken from scattering angles of 5° to 165°. On 26 March, in fine weather, we saw two albatrosses with wing spans of 2–3 m, gliding less than 1 m over the sea surface. We also spotted two big whales blow and jump above the water.

On 27 March, the wind and sea increased, reaching 25–30 knots, preventing us from taking further optical measurements. On occasion, it proved difficult to locate the position of the front. Eddies were identified by deploying floats which could then be tracked. The minimum temperature was observed in the middle of an eddy of 1.25 °C. The cold water showed higher scattering than the warm water, suggesting more suspended matter in the cold water layers. The temperature transition layer, the thermocline, had the strongest scattering signal, indicating suspended matter trapped in the transition layer. On 30 and 31 March, the wind and sea increased, preventing us from taking scattering profiles, as the ship was moving too much to guarantee safe operation of the instrument. During the day, we spotted several Cape pigeons with white underbellies and black and white wings in a flock close to the ship, but no more albatrosses.

Our northerly course continued in good weather until 4 April, when deteriorating weather briefly interrupted our measurements. However, we were able to carry out most of the planned operations, managing to obtain in all 47 light scattering profiles, including several scattering functions. The profiles were normally taken as close to the CTD profiles as permitted and possible. Due to the varying cloud conditions, the number of optical measurements was limited to 15 good ones. On 5 April, we hit strong seas and winds of about 30 knots as we approached Cape Horn. On 6 April, we sailed past the Cape from east to west and back, with gentle winds, cloud cover and light swell. Cape Horn was a grey-black cliff jutting high out of the ocean. It reminded me of landscapes visited in Iceland and the Faroe Islands, while the coast recalled Greenland, as well as islands in the Baltic Sea, such as Gotland.

We saw some green cover and patches of snow but no trees, although flocks of birds and penguins were observed in and above the water. Isla

Hornos was visible with a number of small islands towards the north, and the Cape was home to a lighthouse. From the Cape we set a north-easterly course towards the Magellan Sound. In the afternoon of 6 April we reached Picton Island, where we waited for the Argentine maritime pilots who would guide us back through the Strait. We anchored at the port of Tierra del Fuego under calm but cloudy skies, with birds and penguins in the distance. The pilots arrived early the next morning and we sailed around 07.30 on 7 April from Picton Island – a very flat landscape with small, green trees, cypresses and steep cliffs descending into the sea.

Around midday we reached Ushuaia, a freeport with hotels and limited tourism facilities, which were being developed, although we had little time to explore. On the morning of 8 April, we continued through the Beagle Channel, entering the Magellan Sound after 24 hours. The ship arrived in Punta Arenas around 14.00 on 9 April. During the passage we had maintained, cleaned and packed away our equipment, which would remain on the ship to be transferred to our next expedition on the *Melville* in spring 1977 (see Box 5). We disembarked on 10 April, leaving the ship at 11.00. We said goodbye to the officers and crew, thanking them for their help, friendship and understanding. During the expedition, I had been able to visit the bridge, make friends with the officers on watch and see satellite navigation for the first time. The technology was still in its infancy, and comparisons with astronomic positioning indicated uncertainties, making it necessary to supplement this new form of navigation with traditional techniques. Later at the airport, all the scientists made their farewells in good spirits. This was a cruise to remember.[16]

16 Some results of our efforts are presented in Kullenberg (1978, 1984a and 1984b).

7 The Mediterranean: The role of culture, seafaring, trade and security

In parallel with developments over the last 150 years in the regional seas of the Northern Atlantic, similar processes took place in the Mediterranean, involving southern Europe and Northern Africa and adjacent areas. In the contexts of exploration, science and cooperation, it is important to note that the Classical Mediterranean cultures all developed navigation and trading by sea routes, with the first mutual insurance policy devised in around 800 BC as part of the Rhodes Law of the Sea. Aristotle may be considered the first important contributor to ocean knowledge, based on his account of the origin and nature of the sea (Deacon, 1997, cited in Zore-Armanda, 2004). Later, during the Renaissance, efforts were made to develop an organized system of knowledge on currents and tides. According to Pinardi et al. (2018), the first *in situ* measurements of sea water density with noted geographical positions and time were obtained by Marsili, from the Adriatic Sea, Aegean Sea, Marmara Sea, and the Bosporus, through the oceanographic cruise 1679–80. The Mediterranean can thus be considered a cradle of international physical oceanography.[17]

At the beginning of the seventeenth century, the Mediterranean also provided an early contribution to the understanding of water exchange and the renewal of deep water in regions of the ocean separated from the open ocean by sills. The application of fluid mechanics offered an explanation of water exchange between the Atlantic and the Mediterranean, as well as between the Black Sea and the Mediterranean, consisting of an inflowing surface layer current and a compensating outflow of more dense water through an undercurrent. Subsurface temperatures were observed which showed the temperatures of deeper water at about 200 m to be almost constant. Further observations seemed to support the idea that deep waters were static, a conjecture that persisted for over 100 years, supported by salinity observations. The understanding of the behaviour of deeper waters remained poor until after the Second World War, due mainly to a lack of proper observing technology and instruments, such as the reversing thermometer and depth sounding. The importance of the sill depth of the Strait

17 See Zore-Armanda (2004) for a thorough account.

of Gibraltar in preventing the inflow of deep intermediate Atlantic water is evidenced by the almost constant deep water temperature in the Mediterranean.

From 1870 onwards, the colonial powers increasingly sought to demonstrate their presence at sea, stimulating growth in oceanographic research in the Mediterranean. The opening of the Suez Canal in 1869, which considerably enhanced international traffic through the Mediterranean, also promoted interest in this new field. As a result, the maritime powers carried out many cooperative scientific expeditions during the period 1870–1910. For example, Danish expeditions resulted in breakthrough studies of the hydrographic conditions of parts of the Sea (see, for example, Nielsen, 1912). In addition, several marine stations were established during this time, including the renowned Oceanographic Museum of Monaco, which opened in 1910, as well as important stations at Naples, Trieste and Villefranche. These boosted the development of international cooperation and understanding. Then, in 1910, a proposal was made to create a Mediterranean counterpart to the International Council for the Exploration of the Sea (ICES) – the International Commission for the Scientific Exploration of the Mediterranean (ICSEM), today better known under its French name, the *Commission internationale pour l'exploration scientifique de la Méditerranée* (CIESM), which was formally established in 1919. The creation of this commission also triggered the establishment of oceanographic commissions at the national level to support oceanographic activities (Zore-Armanda, 2004).

Following the end of the First World War in 1918, maritime research by the colonial powers was unable to return to its former levels. The outcome of the war also changed international geopolitics, with the creation of several new countries and a new political situation. The developments following the end of the Second World War were similar, exacerbated by the collapse of several former colonial powers. However, the Cold War led to a resurgence in maritime research among the two main powers, the United States and the Soviet Union, which also led to a shift in international cooperation. Several American expeditions were carried out in the following decades with the participation of Mediterranean and other countries. The International Geophysical Year (IGY), which lasted from July 1957 to December 1958, also played a major role in stimulating oceanographic research in the Mediterranean, including by China and Japan (Zore-Armanda, 2004).[18]

18 During earlier periods, smaller countries outside of the region had participated in the research, as Denmark in fisheries research. The preparations for the Swedish *Albatross* expedition 1947–48 included a test cruise across the Mediterranean with the research vessel *Skagerrak* in 1946.

During the second half of the twentieth century, concerns for environmental conditions played a large role in generating cooperative research in the Mediterranean, as was also the case in other regions. The creation of the United Nations Environment Programme (UNEP) at the United Nations Conference on the Human Environment (Stockholm Conference) in 1972, led three years later to the establishment of the cooperative regional Mediterranean Action Plan – the first of the organization's Regional Seas Programmes. This stimulated the development of the Blue Plan of the Mediterranean in the 1980s (UNEP, 1988). A number of cooperative international research programmes were also implemented, and large-scale programmes were supported by several international bodies, including the Intergovernmental Oceanographic Commission (IOC), UNESCO, UNEP, the Food and Agriculture Organization of the United Nations (FAO) and the Mediterranean Science Commission, which is the current name of CIESM. From around 1985 onwards, several separate, sustained, large-scale programmes studied water circulation and overall physical conditions in the Western and Eastern Mediterranean. On the basis of the results from these programmes, the Scandinavian countries continued their research in the Mediterranean.

It is worth noting here some of the Scandinavian research expeditions between the end of the Second World War and the end of the century. The first of these, in 1946, was a Swedish expedition on the research vessel *Skagerrak*. This was also the first deep-water research cruise using the piston core devised by my father, Börje Kullenberg (Kullenberg, 1947), which successfully retrieved a number of 10 m undisturbed sediment cores. These cores have been used to help determine climate variations over vast geological timescales (Arrhenius, 1991; Emiliani, 1955; Eriksson, 1965; Kullenberg, 1955a). The expedition was a prelude to the global *Albatross* expedition of 1947–48, which also used the piston core to obtain long sediment cores in all the major ocean basins (see Chapter 8). Although national in origin, these cruises covered the main science disciplines and led to international cooperation based on the use of pioneering equipment and technology. Another example of such international cooperation was the Norwegian-Danish-Swedish expedition by the Norwegian vessel *Helland Hansen* in 1971, which covered the western end of the Mediterranean and involved participants from the United States.

The European Union has provided strong support for oceanographic research in the Mediterranean through a targeted programme, Interdisciplinary Research in the Mediterranean Sea, the initial pilot phase of which covered the period 1993–96. The project's aim was to examine the functioning of the Mediterranean Sea in all its aspects, including a dedicated multidisciplinary approach involving

the simultaneous study of physical, geochemical and biological processes. Ten different projects involved 200 scientists from 70 institutions and 14 European countries (Lipiatou, 1997), and the publication volume presenting the results exemplified this broad cooperation and multidisciplinarity. Following the pilot phase, the programme continued for a second phase.

Through the history of the Mediterranean EU programme, it is possible to see the development of oceanography in the countries of the region, involving cooperation across a range of scientific disciplines. This development underlines the importance and results of the dedicated training and technical assistance activities supported since 1975 by the UNEP Regional Seas Programme. However, all of this would have been impossible without strengthened international cooperation, including institution building, and the development of oceanography following the Second World War, which was stimulated in part by the technological advances resulting from the war and the subsequent rebuilding process.

BOX 3. Investigating the optical properties of ocean water: Sargasso Sea, 1966 and Baja California, 1968

Research in optical oceanography was an important focus of the Institute of Physical Oceanography at the University of Copenhagen,[19] which was created in the early 1960s with Prof. Nils Jerlov as founding director. Optical observations of the water characteristics were used to identify and trace the paths and mixing of water masses in different regions. In most cases, we worked in oceanic frontal zones such as straits or upwelling areas, coastal currents, estuaries and outflows from regional seas, where the water contained a variety of different suspended or dissolved substances, both organic and inorganic. However, this research was not focused directly on studying the optical properties of sea water.

In order to study the optical properties of ocean water, we had to explore areas of the ocean where the water was uncontaminated, as far as possible, by other substances or properties, such as the content of suspended matter or dissolved organic substances. Examples include central anticyclonic gyres in ocean basins, associated with open ocean convergence zones. The surface water layer is very old, with very low levels of nutrients or contaminants and relatively high salinity due to evaporation. Nutrients driving primary production have been consumed and most of the particulate matter is lost by sedimentation and the sinking of the surface water. The most outstanding of these zones is the Sargasso Sea in the central part of the North Atlantic temperate anticyclone. The water there is very blue – the true colour of pure ocean water.

Many stories have been spun about the Sargasso Sea from the era of sailing ships, becalmed amid large patches of floating yellow-brown seaweed (Sargassum) originating from the African coast. The region is also a breeding ground for the European eel. Well-known Danish scientists have undertaken eel research since the end of the 1800s up to the present day.[20] The Director of the Danish Fisheries Research Institute, Dr Erik Bertelsen, pursued research in this field with several of his colleagues in the 1960s. Prof. Nils Jerlov and Dr Erik Bertelsen found a common interest in the Sargasso Sea. Through joint collaboration,

19 For more details, see Jerlov (1968, 1976).

20 See Poulsen (2016) for more information.

they managed to raise funds for an expedition there for eel and ocean optics research.

The ship chosen for the expedition was the Danish fisheries research vessel named *Dana*, after a famous Atlantic expedition in 1921–22. That expedition was the first to use long steel wire with pelagic nets to catch larvae and fish. The original *Dana* travelled across the Caribbean and through the Panama Canal discovering large anoxic areas in the eastern Pacific Ocean.[21]

The objectives of our expedition focused on eel wandering, hatching/breeding and survival, and the optical properties of water in the Sargasso Sea. The expedition received national and international funds, and would take place over several months in 1965–66. Because of the dual objectives, the expedition was separated into parts, with two different teams studying eels and optics. A significant period of preparatory work was necessary for the optical team, who had to build and test their instruments. Much of this work was undertaken at the Oceanographic Institute in Gothenburg, Sweden – another example of strong Nordic cooperation. It was also agreed that the leading mechanical expert at the Gothenburg institute, Mr Axel Jonasson, would join the expedition as a member of the optical team. Mr Jonasson was renowned for his role in the Swedish *Albatross* expedition of 1947–48 – where he worked alongside Prof. N. G. Jerlov as well as my father, Prof. Börje Kullenberg.

Once the equipment had been tested and packed, it was shipped from Gothenburg to Copenhagen to be installed on the *Dana*. The ship finally sailed in the spring of 1966, with most of the biological eel team and one of our engineers, Bo Lundgren, on board. Our team, which included participants from Denmark, Norway and Sweden, joined the ship in Bermuda, having travelled there separately. We had the workings of the ship and its crew explained to us by our colleague Bo Lundgren. The sight of the intensely blue Sargasso Sea was impressive, with patches of Sargassum drifting around, but no evidence of any mass that could have represented an obstacle to becalmed sailing ships.

The purpose of our team's work was to investigate the optical properties of ocean water through *in situ* and laboratory measurement. This involved several processes and observing techniques, including:

21 See Poulsen (2016).

measuring light penetration and distribution; beam transmission at different wavelengths; light scattering in red and blue wavelengths; near-forward scattering using a red laser beam with a specially constructed instrument, designed to measure light scattering at very close angles to the beam; instruments measuring the light available in the upper layer for primary photosynthetic production zone and, separately, the colour of the surface layer water by measuring reflected blue and green light just below the surface, the ratio of blue to green giving a colour index of the surface water. Investigation of the optical properties of ocean water included measurements of transparency through the transmission of a light beam over 1 m. The light was emitted from an ordinary light bulb and the use of different filters allowed for the detection of various wavelengths. Light scattering was measured in the surface layer at angles of 10° to 160°, for several different wavelengths. Small angle scattering was measured separately using a laser beam. This made it possible to reach small scattering angles close to the beam at about 0.3°. The laser was fixed in a cylinder about 1 m from the detector housed in another cylinder, the two held together by three tubes and lowered with a cable horizontally into the sea. The laser beam was red. We also tried using a blue-green laser beam, which was emitted by a laser that required water cooling, but the operation proved overly complicated. The overall construction was lowered by means of the hydrographic winch wire with a separate cable to a maximum depth of about 100 m. The laser beam instrument was also lowered several consecutive times to measure scattering at a set of larger angles. Combining the series of measurements allowed us to determine the light scattering curve.[22]

The *Dana* expedition to the Sargasso Sea provided us with a large amount of data, which took a long time to analyse. The optical team concluded its work successfully in Bermuda, from where the ship sailed back to Copenhagen. I remained on the ship for the return leg with Mr Frede Herman as the new expedition leader. We made a hydrographic section from Bermuda to the Azores and on to Europe. It was another great experience to work with Frede Herman. We made a stop in the Azores where I recalled some memories from my visit there with the navy training cruise in 1958–59.

Our initial application of the laser technique to study light scattering in the Sargasso Sea had caught the attention of Prof. Walter Munk, the

22 For more information, see Kullenberg (1968).

Director of the Institute of Geophysics and Planetary Physics (IGPP) in La Jolla, California. He invited me to undertake a feasibility study on the use of the Doppler technique to observe motion in the ocean bottom boundary layer. This represented a great opportunity and could be coupled with my involvement in the multinational expedition during April and May 1968 in Baja California on the *Ellen B. Scripps*.

The aim of that expedition was to test several different optical instruments developed for the study of light conditions in the productive euphotic zone. In particular, the light quanta integrated over the spectral range (from blue to red) available for primary organic photosynthetic production was to be measured by a new instrument constructed by Prof. Jerlov and Mr K. Nygaard at our institute. The expedition was organized by the Scientific Committee on Oceanic Research (SCOR), which provided institutional support through an associated working group, which included two leading Danish scientists, Prof. Nils Jerlov and Prof. Steeman Nielsen.

The ship sailed south from La Jolla to Baja California, where the tests were carried out. The team of two from our institute, Mr K. Nygaard and myself, brought the light quanta meter, the scattering meters – the ones used on our expedition in the Sargasso Sea – and the colour index meter. I had made the same voyage twice before in my life on a Swedish Navy training ship. After the expedition, I remained in La Jolla, where I worked as a research assistant at IGPP. I managed to perform a feasibility study and provide a report for Prof. Munk, but ultimately the institute decided that the laser technology demanded too much power to be maintained in a capsule on the ocean floor for any length of time. However, our institute in Copenhagen pursued the idea to develop an instrument applying the Doppler technique for studying small-scale turbulence in cooperation with a private Danish industry syndicate. The resulting instrument was tested, together with several other current meters, at a cooperative experiment held in August 1974 at the Belgian Stareso Research station outside Calvi in Corsica. The instruments were mounted on a tower anchored to the bottom of the bay outside the station, and the experiment confirmed the potential of the technique. However, acoustic Doppler technology proved to be much more feasible for use in the ocean.

8 Organizing global cooperation in ocean research: The creation of the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC)

After the Second World War, international cooperation in oceanography gradually matured, becoming more institutionally organized over a period of two to three decades. The development of such wide-reaching collaboration in ocean research and technology fitted well with the cooperative spirit following the end of the Second World War and the start of the rebuilding process.

Two global expeditions undertaken by the *Albatross* (1947–48) and the *Galathea* (1950–52) – of Swedish and Danish origin, respectively – brought the use of new technologies into focus, and led to major new scientific results, and in some cases to breakthroughs in geophysics, ocean physics, chemistry and biology (Pettersson, 1953; Bruun et al., 1953). As noted previously, major contributions included the retrieval of many undisturbed sediment cores up to over 20 m in length by my father's piston core technique (Kullenberg, 1947, 1955a, 1955b), which made possible studies of sedimentation rates and climate variability over geological timescales; the determination of primary production through the Carbon-14 method by Steeman-Nielsen; and deep sea trawling by the *Galathea* expedition, which also made use of the winch developed for piston coring on the *Albatross*. These considerable efforts by small countries involved international cooperation on an individual scientific basis. They demonstrated opportunities for new science developments with the potential for discoveries concerning the Earth's history through ocean research, stimulated interest and generated new thinking. They also highlighted the very limited number of institutions capable of conducting advanced deep water oceanography, and the small number of oceanographers. This highlighted the need for education, training and mutual assistance in further developing ocean research, as well as the requirement for international cooperation in this context.

There was also a need to share the growing body of knowledge of the ocean with the wider public and universities at large. This was achieved to a large extent by Dr Rachel Carson through the publication in 1951 of her book *The Sea Around Us*. Based on thorough scientific studies, Dr Carson gave an overview of contemporary knowledge of the ocean, including information about the sea bed, submarine mountain ranges, ocean circulation, tides, waves and wind conditions. Much of the material was based on data collected during the Second World War, including in particular from submarine warfare. Her follow-up book, *The Edge of the Sea*, published in 1955, closed the gap with the coastal zone and seas, and affirmed the need for international cooperation (see also Chapter 24).

Accordingly, several consultations were held in the 1950s involving leading scientists and organizations (e.g. ICSU, IAPO, IUBS and IUGG)[23] on how best to organize constructive and persistent international cooperation in ocean science. The coupling of physical, chemical, geological and biological processes and conditions in the ocean together with ocean dynamics required interaction between scientific disciplines, as well as international cooperation driven by the nature of the ocean. It could not be studied fruitfully without taking into account ocean-atmosphere-land-cryosphere interactions, or the coupling between the ocean and other compartments of the environment, as had already been noted by Maury. At the same time, the very limited capacities to conduct advanced ocean research represented serious obstacles with only a few leading institutions possessing the capacity to drive extended deep-ocean research. The limitations in question related both to human resources and infrastructure. How could well-qualified scientists be encouraged to join this new field and what was the best means to attract sufficient funding? Previous efforts had to a large extent been based on private initiatives and donations, including the provision of ship time from private shipping companies and national navies. Social developments and needs, as well as the dynamics and size of the ocean, made a clear case for internationally organized cooperation and the involvement of governments; however, this was not easy to achieve, especially as scientific fisheries services were organized at the regional level. Undertaking ocean research meant adopting a global approach. ICSU and UNESCO took up this challenge.

Following consultations between leading scientists, ICSU established a Special Committee on Deep-Sea Research (SCOR), which first met in 1955. The committee argued that the main problem was to 'apply recent great

23 The International Council for Science, the International Association for Physical Oceanography, the International Union of Biological Sciences and the International Union of Geodesy and Geophysics.

developments in all basic sciences to the study of the ocean to bring about a level of understanding of the earth and of living organisms' (Wolff, 1990, 2010). It concluded that more knowledge of the ocean biology could encourage scientists to revisit studies of terrestrial organisms and help shed further light on the evolution and distribution of plants and animals. The committee stressed that processes related to the origin of continents and ocean basins need be clarified, together with forces in the interior driving the formation of mountains, volcanism and earthquakes. Furthermore, questions regarding the processes responsible for driving changes in the atmosphere and hydrosphere could not be resolved without extensive exploration of the ocean. Moving forward, cooperation between scientists from many different disciplines was considered to be essential. This was a visionary approach. The committee recommended the establishment by ICSU of a Special Committee for Oceanic Research (the name of which was later changed to Scientific Committee for Oceanic Research) (Wolff, 1990, 2010), the activities of which should include taking note of the actions of intergovernmental bodies, including UNESCO, the International Council for the Exploration of the Sea (ICES) and others. The non-governmental character of the proposed committee would constructively supplement the work of these other bodies. In 1957, SCOR was created on the basis of the committee's recommendation.

SCOR was given the initial task of continuing and guiding the implementation of the oceanographic programmes initiated during the International Geophysical Year 1957–58 for a five-year period (Wolff, 2010). In response, the new committee adopted a method of organizing the specific scientific work through dedicated working groups. This approach brought scientists together – which had been an essential aim – to formulate and specify programmes to address the problem areas and agree on implementation. Many new technologies had been developed that could be applied in ocean research and which could help attract well-qualified scientists to undertake ocean research. The committee aimed to make this a reality on the basis that such incentives represented opportunities for scientists to work in a new field, using new ideas and technologies, in a cooperative, interdisciplinary context. The dedicated working groups generated contacts between scientists, stimulating cooperation and the preparation of joint proposals, and the pooling of limited resources, both equipment and people, between different disciplines.

In parallel with this development, UNESCO explored the possibility of creating an intergovernmental mechanism dedicated to ocean science and related education and training. It soon became clear that there was a strong need to involve governments in global efforts concerning the strengthening of ocean

science, observations and capacity development, with related cooperation and exchange of technologies. This realization, while not new, was rooted in a growing understanding of the significance of global and planetary perspectives.

However, it was not until the intergovernmental UNESCO Conference in July 1960, held in Copenhagen, that agreement was reached on the establishment of the Intergovernmental Oceanographic Commission (IOC) (Holland and Pugh, 2010; Kullenberg, 2016; Roll, 1979). The convening of the Conference was decided by the UNESCO General Conference, November 1958 (Roll 1979). UNESCO accordingly prepared a draft agreement which was accepted by the Conference with minor amendments. The support of the major powers at the time – the Soviet Union, the United Kingdom and the United States, as well as other nations including Japan, France, Germany and Scandinavian countries – was secured with participation of leading scientists Dr George Deacon, Dr Roger Revelle and Dr Lev Zenkevitch. The leader of the *Galathea* expedition, Dr Anton Bruun, referred to government acceptance of the agreement as 'the largest milestone in the history of ocean research' (e.g. Kullenberg, 2016). The Conference recommended that an Intergovernmental Oceanographic Commission be established within the framework of UNESCO, and the recommendation was adopted by the UNESCO General Conference in November/December 1960 (Roll, 1979).

Ocean research to date had been supported mainly by private and civil society, as well as national navies and some shipping companies. For example, the *Albatross* expedition was supported by private efforts, with the main Swedish shipping company supplying the training ship *Albatross*, while the Royal Danish Navy provided the frigate *Galathea* for the expedition of that name. Conversely, the research community had experienced problems in getting support from and the attention of governments. This was a principal motivation behind the creation of an organization acceptable to governments and in which they would participate. UNESCO was ready to provide the required financial resources and to host the new body. From the perspective of UNESCO, the main motivation was the need to educate and train humans to become scientists to perform ocean research and, thereafter, to use the results for the benefit of the people. One important reason identified for the limited development of ocean research was the lack of human resources. This was partly because the main needs of society, people and users, related to management and utilization. However, this included the protection of ocean resources and, in particular, marine living resources. Furthermore, large amounts of non-living resources had been found on and in the sea floor, and documented in evaluations and publications throughout the 1960s.

The IOC was called upon to cooperate with other relevant bodies, in particular SCOR, but also regional organizations such as the ICES. It would coordinate projects already planned by UNESCO in cooperation with SCOR, which from the outset had been identified as an advisory body to the IOC. In particular, a planned Indian Ocean investigation was to become a flagship undertaking as part of the International Indian Ocean Expedition project initiated by SCOR. The possibilities provided by a regional approach in stimulating both cooperation and involvement of governments were already demonstrated.

9 Cooperation in the North Atlantic region

International, including intergovernmental, cooperation in the North Atlantic advanced substantially after the end of the Second World War. The cooperation generated experiences capable of providing guidance to and stimulating development in other regions on the basis of experiences, including intraregional differences relating to political conditions and levels of capacity for ocean studies.

The consistent and well-organized support of the International Council for the Exploration of the Sea (ICES) provided for the strong development of cooperative studies in the North Atlantic and its regional seas. In the 1970s, several programmes consisting of research and coordinated regular observations were the recipient of government support. These were developed and managed through groups specifically appointed for the project. In most cases, they reported to a regional parent group and possibly to a standing committee of ICES on hydrography, biology or chemistry, or an interdisciplinary committee, such as the advisory committees for fisheries or marine pollution. In most cases, the research incorporated socio-economic perspectives. The development of coordinated investigations into marine pollution in the Baltic and North Seas are illustrative of this process. The highly encouraging results, not only of science but also cooperation and understanding between scientific communities and countries from the first International Baltic Year (1969–70), provided a basis for a conference in Helsinki in 1971 which recommended the creation of an ICES-SCOR Working Group on the Study of Pollution of the Baltic Sea (see Chapter 16).[24]

For the North Sea, a similar pattern was pursued through the Working Group for the International Study of the Pollution of the North Sea and its Effects on Living Resources and their Exploitation. This group was established simultaneously

24 The results of this working group were reported to both ICES and SCOR, and were also evaluated during the Second International Year of the Baltic (1985–86), decided by ICES at its 72nd Statutory Meeting 1984.

with the Baltic Group by the 59th Statutory Meeting of ICES in Helsinki in October 1971.[25]

The tasks of the new working group focused on the North Sea were as follows: (i) to undertake as a priority a baseline survey of pollutant levels in food fish (carried out in 1972); (ii) to make measurements of the same pollutants in selected indicator organisms (e.g. locally confined fish stocks and seals, sea water and sediments); (iii) to investigate the physical, chemical and biological fate, rates and modes of transport of pollutants in the North Sea; and (iv) to obtain information on the rates of input of pollutants and contaminants through a questionnaire. For the latter, selected contaminants included petroleum, chlorinated aromatic hydrocarbons such as DDT and its metabolites, dieldrin and polychlorinated biphenyls (PCBs), as well as halogenated hydrocarbons, in particular the chlorinated aliphatic waste products of PVC manufacture, and metals, particularly mercury, lead, copper, zinc and cadmium. For these studies, the North Sea included the Skagerrak and the Kattegat. The coastal waters were to be studied in more detail than offshore areas, but not to their exclusion.

By 1974, work had advanced and a substantial report was produced addressing the levels and distribution of contaminants. The rates of inputs of contaminants had been analysed in 32 geographical regions of the North Sea coastline. The report included information on sewage loads and their biochemical oxygen demand (BOD) but lacked details on organochlorine pesticides, PCBs and metal content. The working groups accordingly recommended that more analyses of sewage be carried out by the Member States. The report also recommended that studies be implemented of fluxes of contaminants from estuaries and fjords to the open ocean. The information regarding the levels of contaminants in fish and shellfish was analysed by the experts who carried out the sampling, and it was concluded that the levels of organochlorine pesticides and PCB content in fish and shellfish were very low in samples collected in coastal areas, apart from some zones of the Netherlands, Belgium and England (ICES, 1974).

These results from the 1972 baseline survey laid the foundation for regular monitoring at a national level, which was coordinated by the ICES. The reported results were analysed by the working group, with emphasis on species, substances and sampling areas that would require special attention in the coming years. The intercalibration of analytical procedures was deemed necessary to ensure high

25 The North Sea Group was chaired by Mr Arthur Lee, director of the Lowestoft Marine Laboratory, who reported regularly on the group's work to the Standing Committees on Fisheries, Hydrography and Plankton. Meetings of ad hoc groups in 1971 contributed to the group's creation, together with the results of the earlier ICES Working Group on Pollution of the North Sea, which helped to specify tasks for the new working group.

quality. Accordingly, agreed samples with unknown levels of substances were circulated to all participating laboratories, with return of analysis requested for a specific date and all results kept strictly secret. The Baltic Working Group was invited to participate in these quality assurance exercises. This kind of regional cooperation involving dedicated laboratories and following an internationally agreed procedure at an intergovernmental level, with well-established organization and leadership by an acknowledged international secretariat, provided a model and a factual basis for the development of several regional agreements negotiated during the 1970s and 1980s, which focused on the protection of the marine environment, its resources and uses.

During this period, research regarding fisheries continued. Concerns were growing for overfishing, impacts of pollution and climate variations, including seasonal changes such as El Niño in the Pacific, the monsoon in the Indian Ocean and anomalies in the North Atlantic, coupled with variations in the trade winds, the Gulf Stream and the North Atlantic Index. The pollution concerns mentioned above were to some extent addressed by environmental programmes, but the other issues were not. However, many dedicated programmes at both global and regional levels attempted to tackle these problems. The Food and Agricultural Organization of the United Nations (FAO) took a leading role at the intergovernmental global level, working in cooperation with regional fisheries organizations. The organization acknowledged the importance of the sea for food, particularly with regard to the provision of animal protein and essential amino acids.[26]

26 The whole development of fisheries, with global and regional overviews, with focus on effects of climate variability, including the El Niño and climate change, with related social consequences, are examined by Cushing (1982).

10 The need for a comprehensive legal regime for the ocean

The Law of the Sea Conferences

The Geneva Conventions on the Law of the Sea, resulting from the first and second Conferences in 1958 and 1960, dealt separately with the continental shelf, the high seas, the territorial seas, fishing and conservation of living resources. This was not an integrated approach, and only marginally considered ocean sciences and ocean observations (Kullenberg, 2018; see also Jarmache, 2010).

Almost another decade was to pass before the matter was brought up before the UN General Assembly in 1967 by the UN delegate of Malta, Arvid Pardo, in an electrifying speech that convinced the Member States to take action (Pardo, 1975). This development also demonstrated the interests and needs of the new set of nations that emerged during the era of decolonization prior to the Second World War, but which grew in strength in its aftermath. The development and negotiations at the Third Law of the Sea Conference from 1973 – in which the IOC participated – were driven by these new developing states. The negotiations were successfully completed with the United Nations Convention on the Law of the Sea (UNCLOS) signed in Jamaica in 1982, very much as a result of the cooperative efforts of these emergent nations (United Nations, 1983). The Convention entered into force in November 1994.

The Law of the Sea provides the legal framework within which the IOC acts. While the newly emerging nations were not involved significantly in the creation of the Commission, they gradually became persuaded of its importance during the 1970s and 1980s. The negotiations to establish UNCLOS played a substantial role in this gradual process, as did UNESCO. In establishing the IOC, the scientific community and UNESCO recognized the need and opportunity for combined scientific enquiry, curiosity-driven ocean research and socio-economic development, acknowledging the need and role of international scientific cooperation in this regard.

The Baltic and the North Sea

An examination of marine scientific research with observations and related cooperative arrangements in the Baltic Sea and the North Sea over this period – and the associated intergovernmental agreements and binding conventions – highlight the need for a comprehensive global legal regime for the ocean.

The process began with the first International Baltic Year (1969–70) and a conference in Helsinki (1971) as part of preparations for the United Nations Conference on the Human Environment, also known as 'the Stockholm Conference', held in 1972. The backdrop to this process was cooperative research and reporting on the environmental deterioration of the sea during the 1960s (e.g. Fonselius, 1962; Voipio, 1981). This research focused on environmental deterioration with inputs from the land and atmosphere influencing ecosystem conditions and related processes – early global examples of which were the effects of chemicals such as DDT (e.g. Carson, 1962; Simon, 1984). The research confirmed the need for action at an intergovernmental level and identified priorities to be addressed.

The Conference on the Protection of the North Sea, held in Bremen (1984), with the participation of government ministers from all riparian states and observers from related European organizations, including the European Economic Community (EEC), reached agreement on several measures to be implemented,[27] including:

- Reduce pollution from land-based sources, with regard to contamination from rivers and coastal waters, through further binding regulations for selected substances to be adopted within the framework of the EEC, the Paris Commission and its River Commission, if possible, by 1985.
- Develop a joint initiative within the Paris Commission concerning an additional protocol to the Paris Convention relating to the prevention, reduction or elimination of marine pollution through the atmosphere.
- Intensify activities aimed at phasing out the use and discharge of PCBs.
- Protect the Wadden Sea due to its importance for the whole North Sea area.
- Intensify work to prevent marine pollution caused by the operation of ships and ensure a comprehensive system of reception facilities, with stringent controls on ships entering North Sea ports in accordance with the Memorandum of Understanding of Port State Control.

27 Bremen Declaration 1984. See: https://www.ospar.org/site/assets/files/1239/1nsc-1984-bremen_declaration.pdf

- Prevent oil pollution from platforms through the application of best available technology subject to agreed-upon consideration regarding discharge values.

The ministers also underlined the need to intensify the development of a coherent Joint Monitoring Programme of the Oslo and Paris Commissions,[28] and to examine in this context the establishment of a Joint International Environmental Database on the North Sea and the North East Atlantic. This comprehensive result came out of significant preparatory work carried out since the Stockholm Conference in 1972, involving the Oslo Commission, the International Maritime Organization (IMO), the EEC and other regulatory bodies. All these achievements would not have been possible without the work and participation of the scientific community, operating within the cooperative framework of the International Council for the Exploration of the Sea (ICES) and interacting with related organizations within the UN system and NGOs such as the Scientific Committee on Oceanic Research (SCOR), IAMAP and IAPSO.

Technological advances and sustainable development

Scientific advances over this period owe much to cooperation of scientists with technological companies and related industries. This includes significant progress in sampling and sample preservation, and analytical technology and intercomparison and intercalibration programmes. Major advances in observation technology also played a key role, moving beyond the stationary anchored current meters of the 1960s and 1970s to include remote sensing from satellites, as well as drifters and remotely controlled submersibles and enclosed experimental platforms or enclosures for various biological studies. In addition, data handling and exchange processes underwent continuous development, including data control and storage (as in the case of the ICES hydrographic service and global intergovernmental programmes developed by the IOC) – improvements which facilitated the timely delivery and exchange of data.

This period also witnessed an increase in interdisciplinary exchanges and programmes, with studies aimed *inter alia* at understanding the function of the whole ecosystem. Examples include several cooperative programmes undertaken during the International Decade of Ocean Exploration 1971–1980 (see Chapter 15) such as regional experiments in the Baltic and North Seas,

28 The two Commissions eventually unified 1992, supported by the Oslo Convention (1972) and the Paris Convention (1974). See: https://www.ospar.org

coastal upwelling ecosystem studies and harmful algal bloom studies. Such scientific cooperation came to include most of the natural science disciplines, although not as yet the economic, social or ethical sciences. This changed with the publication of the Brundtland report in 1987, which introduced the sustainable development principle, and the 1992 Rio Conference (World Commission on Environment and Development, 1987; United Nations, 1992). Global change and increasing concern for the limited availability of basic resources made it necessary to incorporate these dimensions into studies and programmes, not only to obtain a more complete picture but also to gain public acceptance of proposed solutions. It should be recalled that sustainable development principles are codified in the Law of the Sea, including through the principle of the Common Heritage of Humanity. The Law of the Sea also covers numerous issues surfaced by research and observations in the North Atlantic region. About 100 years before UNCLOS, international cooperation in the North Atlantic worked to address issues of a socio-economic nature relating to marine food availability and the associated management of fisheries on scientific basis (see Chapters 6, 7 and 8). This cooperation led to the establishment of ICES and gradually to other conventions presented herein.

In parallel, several regional agreements based on cooperation among adjacent states were gradually established through the UNEP Regional Seas Programme. One example of this approach is the International Workshop on Marine Pollution in the Caribbean and Adjacent Regions, held in the Port of Spain, Trinidad and Tobago (13–17 December 1976). The proceedings highlighted the need for training and assistance between participating nations in order to ensure a reasonable equality in terms of the ability to use and interpret data and results, and participate in and contribute to the common good (see Chapter 17).

11 Enhancing global capacity and cooperation for marine research

Global differences in capacity for marine research and observations

Ocean research is dependent upon international cooperation as well as interaction between different science disciplines, including those dealing with other compartments of the environment.

During the first decades of the Intergovernmental Oceanographic Commission (IOC), most ocean research was conducted by a small number of countries – Canada, France, Germany, Japan, the Soviet Union, the United Kingdom and the United States. However, the capacity of many other nations gradually increased, notably Chile, China, Norway, Peru and Thailand, in relation to specific interests such as fisheries, and several countries of the Baltic and North Sea in relation to marine pollution problems. The IOC initially developed several large-scale, regional, cooperative research programmes, such as the first International Indian Ocean Expedition (1959–65) in cooperation with the Scientific Committee on Oceanic Research (SCOR), and programmes in the Caribbean, the Western Pacific, along West Africa and in the Mediterranean. However, these programmes highlighted a lack of capacity and, in response, the IOC Assembly, at its third session in 1964, took note of the need for national programmes and training through mutual assistance.

The capacity for marine research and sustained ocean observations was not as developed globally and had not advanced sufficiently to meet the needs of nations, in particular with respect to their coastal and shelf seas. It was in their own interest to develop their resources for marine research due to the large amounts of living and non-living resources in the ocean and the exclusive economic zones (EEZs) resulting from the United Nations Convention on the Law of the Sea (UNCLOS) of 1982, as well as emerging international initiatives and agreements regarding the use and management of these resources. In the context of the Geneva negotiations and resulting conventions at the end of the 1950s and the waste management agreements of the early 1970s, it became clear that most nations needed to be able to participate in and contribute to related

negotiations in their own interest, as well as for the global good with respect to management of the ocean and its resources.

Early experiences showed that participating in cooperative international research is an ideal approach to developing and maintaining a national cohort of scientists. Through such participation, scientists can contribute to the national interest in relation to the interpretation and use of research results and data, and can serve as experts in international exchanges, consultations and negotiations. They can further help in the development of useful, meaningful national policies regarding the ocean, its management and uses. It was in the interest of all nations for such capacities to be developed, since only through the participation of most nations could global coverage of the oceans be achieved, and the conventions become of service as intended.

Exchange of data with related information constitutes the most basic form of scientific cooperation. The International Oceanographic Data and Information Exchange (IODE) programme of the IOC was an early initiative of the IOC – one of the first of its kind – and continues to be maintained and developed, with training offered. Such exchanges were also an important motivation behind the creation of the International Council for the Exploration of the Sea (ICES) and several other bodies of a similar nature. The need to develop capacities to collect, control, exchange and use data for national and other interests in a transparent and trusted manner was self-evident.

Although an important reason behind the creation of the IOC was the need to increase science capacity and the number of marine scientists in the developing world – through education and transfer of marine technology – it was the negotiations for the Law of the Sea during the 1970s that made the case among new states for obtaining national capacity in marine science and technology (Lie, 1990). This persuaded them to become Member States of the IOC[29] and to support the national development of marine scientists in their countries. Training in marine scientific research through training courses, shipboard training and scientific workshops was facilitated through fellowships provided by several maritime nations with well-developed education and university institutions. However, the costly development of infrastructure required for ocean research was much more difficult to achieve. For this, assistance from various donor organizations and countries was required. Over the same period,

29 As a result, membership of the IOC with respect to developing countries increased from 19 in 1961 to 42 in 1970, 76 in 1980, 93 in 1990 and 95 in 1995, while the number of developed, industrialized countries rose from 21 in 1961 to 30 in 1995 (e.g. Haq, 1995), although funding did not increase correspondingly. As of 2021, the number of IOC Member States is 150.

a significant increase in marine science technology took place, mostly benefiting developed countries where the number of marine scientists and institutions increased at a faster pace than in developing countries. The gap between developed and developing nations continued and even increased as funding from donor countries began to stagnate (Lie, 1990).

At the same time, the need for global cooperation and active participation in ocean studies increased. This was due to several factors: global demand for ocean resources; management of over-fishing and in particular migrating stocks; increasing regional and global problems, notably dumping at sea; the spread of radioactive contamination and other polluting substances; acid rain mainly at the local level which influenced important fish stocks; and ocean acidification through carbon dioxide uptakes. These issues have since increased in importance and now include open ocean pollution by plastics, increase in oxygen depleted coastal zones and ocean de-oxygenation, and continued deterioration of coastal areas and coral reefs on a global scale.

In order to be successful, global studies require adequate capacity for marine research and the broad use of marine technology by all countries. This reality has driven the IOC, UNESCO and other organizations, such as the United Nations Environment Programme (UNEP) and the United Nations Development Programme (UNDP), to support major assistance programmes and to facilitate cooperation, organization and support from national and international donors. However, funding is still insufficient, even following the establishment of the Global Environment Facility.[30]

Creation of the Training, Education and Mutual Assistance (TEMA) programme

The need for a concerted effort on capacity development in ocean science at the intergovernmental level was clear. Following the Stockholm Conference in 1972, the IOC developed a dedicated Training, Education and Mutual Assistance (TEMA) programme in 1973, and in 1982 formally adopted a Comprehensive Plan for a Major Assistance Programme to Enhance the Marine Science Capability of Developing Countries. The TEMA Working Committee

30 The Global Environment Facility provides the financial mechanism for the 'Rio Conventions' (the Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC) and the UN Convention to Combat Desertification (UNCCD)), as well as the Stockholm Convention on Persistent Organic Pollutants (POPs) and the Minamata Convention on Mercury, with a specific focus on assisting developing countries in meeting the provisions of the environment-related conventions they have ratified.

was established in 1973 to guide the development of the programme and its implementation. In order to identify the needs of Member States, a series of meetings were organized covering different regions and were held in Cairo, Casablanca, Manila, Mexico City and Montevideo (Haq, 1995).[31] In 1977, the second session of the TEMA Working Committee adopted 21 recommendations for a range of activities, although lack of funding proved to be a major obstacle to implementation.

Training was initially coupled to ongoing regional programmes of the IOC but gradually became part of subject area programmes. Actions were adjusted to meet needs identified at the regional level and the overall approach was based on cooperation at both the regional and institutional level, and the pooling of resources and capacities. The more advanced countries could provide required support, assistance and training to the less advanced participants, while support from national and other donor agencies was necessary for infrastructure and equipment. The UNEP Regional Seas Programme contributed strongly in this regard, as well as providing associated training. Reflecting on TEMA, Berque and Desa (2010) underscore the importance of national ownership and addressing national priorities as key factors in its success, alongside a long-lasting process focused on education and research, rather than short training courses with external support. The authors also note that dependence on external funding is not productive as it can undermine longer-lasting national support. They conclude by stating that 'the road to global science starts with local priorities', a conclusion very much in line with experiences from my own education and training.[32]

31 Dr S. Mazhar Haq has provided an overview of the TEMA developments during the subsequent decades. He notes that interest in the initial consultations was quite low, likely due to several factors, including a lack of understanding of the role of marine science for the national economy and development, and a lack of human resources, infrastructure and motivated receiving groups (Haq, 1995).

32 The evolution of the TEMA programme and the adoption of a new strategy is discussed in Chapter 28. Elements of training, education, assistance and technology transfer in the decades since the programme's inception in the 1970s are also detailed, in particular in the context of the development of ocean governance and management related to UNCLOS. See the discussion of developments in the Pacific Region in Chapters 20, 21 and 22, and the sections on ocean economy and changes in the ocean in Chapters 26 and 27.

12 Marine scientific research and the Law of the Sea

The importance of marine science and observations is acknowledged in various sections of the United Nations Convention on the Law of the Sea (UNCLOS). The need for cooperation and exchange of information on the ocean and its resources among nations, governments and international organizations has continued to increase over the years. High scientific standards in coastal nations, in particular, are required to support adequate management of related resources and ensure the safety and security of people and infrastructure. This is highlighted through the gradual implementation and application of UNCLOS, a process which constitutes a good example of global cooperation. However, the consent regime of UNCLOS, whereby coastal nations must give their consent for research by other nations, has not necessarily facilitated international marine science cooperation (Lie, 1990).

The size of the ocean makes plain the need for global cooperation. However, the size of the relevant technical assistance programmes is not adequate. This is evident in the case of climate change and multiple associated issues. There is a strong need for the marine science community to work to ensure the rational use of provisions stipulated in the section of UNCLOS on the conduct and promotion of marine scientific research, and in particular on the consent regime, in order to benefit from the continued development of marine science cooperation. This also applies to any new agreement regarding the regime beyond the limits of national jurisdiction and the Common Heritage of Humankind. The Law of the Sea has certainly influenced ocean research organizations through the establishment of well-defined ocean regimes and of norms and rules for research. The influence has been manifested both on the political and the scientific side; and its implications can be seen in the mobilization of national interest in the ocean, the extension of national jurisdiction over living and non-living marine resources, and the extension of national jurisdictions over research (Wooster, 1990).

The discoveries and mapping of non-living resources on and below the ocean floor has raised the interests of states in the ocean, which was manifested during the negotiations for the Convention of the Law of the Sea. This is also

very noticeable in terms of the change in membership of the Intergovernmental Oceanographic Commission (IOC), which more than doubled from 40 countries in the 1960s to 87 Member States in 1975. While most of the initial Member States came from Europe and North America, the number of countries from outside these regions increased nearly threefold (Roll, 1979; Wooster, 1990). The implications for the IOC of this regional diversity included greater attention to policy, marine resources, applied research and training, and education with mutual assistance, so as to meet the interests of new Member States.

This dynamic also influenced the cooperation and partnership between the IOC and the Scientific Committee on Oceanic Research (SCOR), the main scientific advisory body of the IOC (Wooster, 1990). The partnership and cooperation between the two bodies initially worked very well. However, growth of the IOC and the increasing interests of nations in ocean resources and conditions, with the associated legal and socio-economic implications, gradually led to a certain competition and an associated lack of trust between the organizations. This might also have been exacerbated by the growing realization of the importance of the ocean in the context of major social concerns such as climate change, human security and health, food availability and marine pollution, for which basic research is required to find solutions. While the initial partnership between SCOR and the IOC was close during its first decade, this has not been the case since. The extension of national jurisdiction of coastal states over national waters and the exclusive economic zone (EEZ) constitutes the principal influence of UNCLOS over freedom of scientific research. This affected fisheries management in particular, and the application of related scientific advice. However, it was concluded that 'experience to date has shown that scientific objectivity is not incompatible with sensitivity to the political consequences of management recommendations' (Wooster, 1990).

The increased interest of Member States in marine resources led the IOC to establish programmes addressing living and non-living marine resources. These involved cooperation with related international organizations, in particular the Food and Agriculture Organization of the United Nations (FAO), the International Council for the Exploration of the Sea (ICES), UN-DOALOS, the International Seabed Authority (ISA) and the International Hydrographic Organization. There was and is a documented need for cooperation in scientific research in the context of living resources, fisheries and aquaculture, and non-living marine resources. UNCLOS thus offers many opportunities for the IOC to organize, stimulate and guide cooperative research with related Training, Education and Mutual Assistance (TEMA) activities and the transfer of marine technology. This has required a gradual transformation and adjustment of

priorities and programmes to meet the requirements and aspirations of Member States in association and harmony with UNCLOS. The implications of UNCLOS for the IOC were analyzed by Jarmache (2010), in the context of the 50th anniversary of the IOC. He concludes by noting that 'ocean governance is going to change because of economic and societal challenges that can only be faced through the cooperation of those in marine sciences with various stakeholders who will raise their standards on responsibility, ethics and the protection of the environment'. Cooperation is the key, and the IOC needs to maintain its ability 'to take significant initiatives and to assume responsibility for ambitious programmes in the competent international organizations'. The initiative leading to the ocean science decade indicates that the IOC maintains this ability.

13 The International Ocean Institute (IOI) and broader intersectoral cooperation

Another important non-governmental mechanism for cooperation and dialogue, research, education and training was created in this period. The International Ocean Institute (IOI) was formally established in 1972 at the University of Malta (Mann Borgese et al., 2001) in the context of the negotiations for the Law of the Sea.[33] It met the need for an organization that would allow the experts concerned with the negotiations – including leading personalities in oceanography, as well as the social sciences, peace and disarmament, economy, law, communication and journalism – to continue to provide inputs in a manner complementary to the Intergovernmental Oceanographic Commission (IOC) and other intergovernmental organizations. The organization came into being through support from private donors and a grant from the United Nations Development Programme (UNDP). The process behind its creation demonstrated the ability of the ocean sciences community to cooperate across disciplines and provide constructive contributions to legal and economic areas.

The IOI established several operational centres affiliated with ocean research institutions and universities, on the basis of a memorandum of understanding (MoU). These centres numbered about 20 at the start of the new millennium, and were set up with financial support from private donors, the UNDP and national donor organizations, in particular the Canadian International Development Agency (CIDA), as well as the hosting institutions. Main activities included education, training and communication with the public and various communities highly dependent upon the marine environment. One example of such an activity is the Indian Coastal Villages Programme created by the IOI-India Operational

33 The birth of this NGO occurred as a result of the convening of a series of workshops and a major international conference in Malta in 1970. This process involved a wide range of personalities from different sectors of society, including beyond the sciences. Collectively, they stressed the need for cooperation across sector interests, which ranged from ocean science and observations to disarmament.

Centre, based in Madras.[34] An important contribution of the IOI is the Pacem in Maribus (peace in the ocean) conferences, which cover a broad range of issues relating to ocean science, management and governance (see Chapter 20 for an example).

The IOI also organized numerous training courses, in particular on ocean governance and the Law of the Sea, at the Operational Centre Canada in Halifax, several regional leadership seminars (e.g. on Mediterranean basin-wide co-development and security) at the headquarters in Malta, and a series of training courses at the International Seabed Authority in Jamaica. Courses and research also covered technology co-development and partnership, the sustainable development of basin-wide actions, tourism and fisheries, the integration of sustainable development and regional security. All research and training emphasized a holistic approach, treating the ocean as a whole consistent with the arguments of Arvid Pardo, the 'Father of the Law of the Sea', and the ethos of the UN Convention.

The reach of the IOI was considerable. For instance, at the third World Water Forum, held in Kyoto in 2003, the Institute co-organized a dialogue between the ocean and freshwater communities encompassing forests, rivers, oceans and skies. The aim was to stimulate and enhance dialogue between the relevant communities with respect to the role of the ocean in the hydrological cycle, and the supply and availability of freshwater and related management. In May 2004, the IOI operational centres of Australia and Germany convened a workshop in Delmenhorst, Germany on global learning in ocean science. The workshop formed the basis for further partnerships and collaboration in training among IOI operational centres and European institutions, involving the IOC through Training, Education and Mutual Assistance (TEMA), the United Nations Environment Programme (UNEP) through the Global International Water Assessment, and the United Nations University (UNU), among many others (Bailet et al., 2004).

Cooperation, not only among countries but also between individuals, has played a key role in these structural and institutional developments over two decades. Individuals and scientific leaders have communicated across disciplines and interests, evaluating problems together in order to reach agreement and take action, while remaining reasonably pragmatic in view of the significance of the main goals – an approach very similar to that underlying the founding of the International Council for the Exploration of the Sea (ICES) almost a century

34 The same centre also prepared the report *Voices for the Ocean* for the independent World Commission on the Oceans (IOI, 1996).

earlier. Similarly, cooperation between oceanographers from different political sides continued during the Cold War, again motivated by the desire to maintain exchanges of data, as well as other scientific exchanges and dialogue (see further Hamblin, 2005). Examples of such cooperation can be seen in the work of the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), which included scientific cooperation and the exchange of results (Chapter 14), and in the cooperation across the Baltic through the ICES/SCOR Working Group (Chapter 16).

14 Concern for marine pollution and environmental changes

Several cooperative regional studies during the 1960s and associated evaluations at regional and global level confirmed that marine pollution was a global problem. In the North Atlantic, there was growing concern from the end of the 1960s onwards regarding pollution of the marine environment in the whole International Council for the Exploration of the Sea (ICES) area, far beyond the Baltic Sea. Coastal waters and enclosed or semi-enclosed seas constituted major worries due to potential contamination from land-based sources of marine food produce and bathing water, leading to a requirement for surveillance to protect human health.

Up to around the 1970s, release into coastal waters had been the practice for partly treated or even untreated sewage water from urban centres. In many cases, such releases occurred below the surface layer, and, if possible, below a density transition, thermo- or halocline, so as to trap the material and prevent it from reaching the surface water. A major aim of release technology was to obtain maximum initial dispersion and subsequent dilution through mixing of the released material, so as to achieve concentrations of pollutants below the stipulated critical levels. Various release techniques were used to help decrease the initial concentration of potential pollutants already at the source. However, it was the subsequent mixing and resulting dilution and gradual transport from the area of release that were the deciding factors.[35]

35 The need to understand the physical processes influencing the mixing, transport and the rate of dilution triggered many studies of the processes and the mixing rates under different environmental conditions. ICES organized and supported several such cooperative and interdisciplinary efforts, including the large-scale diffusion experiment RHENO in the North Sea in 1965 (Weidemann, 1973). This was based on the use of dye tracing with the dye rhodamine B, intensely red and emitting fluorescence when illuminated with UV light. Various techniques for tracing the dye were under development in the 1960s. My own experiments included the development of an *in situ* instrument which could be towed from the ship tracing the dye released below the surface layer, mostly in or just below a density transition layer. The dye solution was injected in a layer where contaminants might be trapped, with the aim of studying the mixing in such conditions and possibly relate the rate of diffusion to environmental conditions, such as density stratification of the water, currents, waves and wind (Kullenberg, 1974).

ICES decided in 1970 at its 58th Statutory Meeting that the time had come to obtain an overview of the state of scientific understanding of dispersion processes and rates of mixing in the upper layers of the sea through

In 1972, the United Nations Conference on the Human Environment in Stockholm confirmed the conclusions of the earlier regional studies regarding the global nature of the marine pollution issue. The problem had also received attention from the Food and Agriculture Organization of the United Nations (FAO) through a number of expert meetings and conferences. In 1967, the Intergovernmental Oceanographic Commission (IOC) delivered a report from its working group on marine pollution (IOC-UNESCO, 1967) having endeavoured to focus the attention of its Member States on this issue. The IOC also undertook various cooperative efforts involving a number of organizations and ICES related to the development of global plans. In 1977, the IOC formally established a Global Investigation of the Pollution of the Marine Environment (GIPME) programme on the basis of consultations and the output of the working group (see also Chapter 17).

As already mentioned, one of the founders of the environmental movement who brought the issue of pollution to the forefront of national and international attention was Dr Rachel Carson, whose book *Silent Spring* (1962) provided scientific findings and proof of the deterioration of the environment from human abuse, notably the use of various chemicals. The publication of Carson's book generated a wealth of research and action; however, it took a decade before the Stockholm Conference in 1972 brought environmental deterioration and disturbances to the forefront of the global intergovernmental agenda.

In the intervening time, the aforementioned leading cooperative mechanism was created in 1969 – the United Nations Joint Group of Experts on Scientific Aspects of Marine Pollution (GESAMP). GESAMP was co-sponsored initially by the International Maritime Organization (IMO), the FAO, the World Meteorological Organization (WMO) and UNESCO (with the IOC), with these organizations gradually joined by all relevant UN bodies and programmes, including the United Nations Environment Programme (UNEP). Each co-sponsor of GESAMP nominated and supported the participation of one or more experts within their mandate. This procedure ensured that all, or in any case most, required scientific disciplines were represented. Problems to be evaluated were brought to the group by the sponsoring organizations. Early on, many such questions related to the release of potentially harmful substances to the ocean from land, through the atmosphere or directly at sea from ships. These issues

convening a Symposium on 'The Physical Processes Responsible for the Dispersal of Pollutants in the Sea, with Special Reference to the Near-shore Zone'. The Symposium was held in Aarhus, Denmark, on 4–7 July 1972. I was given the honour of serving as convener working with the Scientific Planning Committee appointed by the Council, consisting of R. V. Ozmidov (USSR), J. W. Talbot (United Kingdom), R. W. Trites (Canada) and G. C. van Dam (Netherlands). The Symposium addressed circulation processes, turbulence-dominated processes, models and measuring techniques, in a total of 60 scientific papers. The proceedings are presented in a special volume by Kullenberg and Talbot (1974).

were addressed by dedicated working groups, which then reported to the annual meeting of GESAMP.

In 1973–74, I was charged with leading one of these working groups dedicated to analysing environmental problems related to dumping at sea.[36] The process and its accomplishments affirmed the need for interdisciplinary work and cooperation between the various disciplines. Interaction between different scientific disciplines, as well as the social sciences and economics, was essential to elucidate these environmental marine problems – and the related science-based solutions – and to clearly communicate them to society as a whole, and obtain their acceptance.

The legal aspects were also of great significance, including concerning which substances were pollutants, and how to define marine pollution. A key issue concerned the identification and definition of what should be considered a potentially harmful substance. This issue was analysed by a dedicated GESAMP working group led by the IMO. The organization was particularly concerned by this question in the context of the transportation of substances and goods by ships which might be harmful to the marine environment. This could include the transport of harmful wastes to countries which offered services for the destruction of such materials. This trade was finally controlled through the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, which entered into force in 1992.

GESAMP also agreed on a definition of marine pollution, which has subsequently been used in the context of conventions and conference outcomes with some adjustments to meet new findings. The original definition reads as follows (GESAMP, 1991): 'introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairement of quality for use of sea water, and reduction of amenities'.

The development of various evaluations of pollution problems was dependent on the collective gathering of quality-controlled data, analyses of related scientific publications and contacts with many laboratories. The scientists involved in the work provided their time and knowledge for free. Unfortunately, some leading scientific institutions proved reluctant to facilitate participation in this kind of work, which implied occasional difficulties for scientists from these institutions wishing to offer their assistance. The GESAMP model of evaluation was only

36 The procedure resulted in substantial, well-documented analyses (e.g. Kullenberg, 1975).

possible on the basis of free contributions from scientists and the use of new technologies for collecting samples at sea for chemical and biological analyses and the analysis of large amounts of data.

It should also be noted that the developments in the 1960s and the 1970s occurred during a period of strong economic growth in many nations, which promoted scientific development as well as the involvement of universities and education establishments. However, there was a need to involve many more nations in order to increase available knowledge and understanding of the ocean and its limits. There was a real need for an international platform and framework to stimulate nations to cooperate in such endeavours and thereby strengthen their ability to benefit from the ocean in sustainable ways. This is where the ocean science community could play a role for the common good – including the IOC.

BOX 4. Actions related to marine pollution problems: Investigating mixing in the upper layer of Lake Ontario, 1972

In 1972, I took part in the Aarhus Symposium, an international conference addressing scientific and social concerns, where I presented a research paper entitled 'Investigations on dispersion in stratified vertical shear flow'. Discussions with Dr C. R. Murthy from the Canada Centre for Inland Waters (CCIW), prior to and during the symposium, led to a cooperative project in Lake Ontario. We prepared a joint funding proposal for a series of mixing studies in Lake Ontario, as an activity of the International Field Year of the Great Lakes, using a dye-tracing technique based on my own experiments. We were successful and were granted support from the Danish Research Council and CCIW. This covered transport of my equipment to the CCIW in Burlington, Ontario; the use of the CCIW vessel, the research vessel *Limnos*; funds to purchase rhodamine dye and other required material for the experiment and travel expenses for myself and my colleague Håkan Westerberg from the Oceanographic Institute in Gothenburg. Håkan had participated in my experiments and was familiar with the process – and also brought his own thermistor chain to obtain detailed vertical temperature structures.

The aim was to carry out a series of experiments in Lake Ontario to obtain evidence of mixing characteristics in the thermocline and hypolimnion parts of the lake. The experiments used a dye-tracing technique where rhodamine B in a water solution was injected at a selected depth. The dye was then traced by means of an instrument measuring the fluorescence from the rhodamine when illuminated by ultraviolet light emitted from the instrument. The rhodamine dye spread out, gradually forming a growing patch which we had to locate and follow during the experiment for as long as possible. The instrument measured the dye concentration and the mixing was calculated by means of the gradual dilution of the dye concentration.[37] We carried out ten experiments successfully, using the dye technique in coastal, intermediate and offshore regions of the lake,[38] which were conducted in the vicinity of deep-water current meter moorings. We obtained additional environmental data on current structures and wind

37 See Kullenberg (1974).

38 See Kullenberg et al. (1973).

conditions on board the ship[39] and used the thermistor chain to acquire details of temperature structures.

Our work on the *Limnos* proceeded well and involved dye solution preparations, injections using high pressure tubes, the towing of a fluorometer from the ship's vane, and navigation relative to the surface float attached by a thin wire to a parachute released at the same depth as the dye. The officers and crew were very understanding, cooperative and supportive. The stationary, moored instruments provided good data over the experiment period, which lasted from mid-August to the end of October, with each expedition normally lasting one week.

Our experiments enabled us to determine vertical and horizontal mixing parameters and relate them to the environmental conditions of vertical current, temperature and density structures, wind, waves and current drift. The vertical current shear was calculated from current measurements.[40] The vertical structure of dye distribution was found to be different from that observed in ocean areas, with greater vertical extension, sharp boundaries at the deep end and more structured step-wise formations in the upper part. Layers could be up to 10 m thick – I had never observed such layer thicknesses in ocean experiments.[41]

The lake experiments often lasted several days, up to a maximum of 80 hours, whereas experiments in the ocean tended to be of a shorter duration – from 1 to a maximum of 2 days. The depth of injection in the lake was mostly below the thermocline, at depths ranging from 15–50 m. The rates of mixing were found to be somewhat smaller than those in the ocean under reasonably similar environmental conditions.[42]

It was quite thrilling to perform these experiments under new conditions. During the first experiment, it took longer to locate the dye patch than expected, despite calm conditions with no waves. Tension in the ship increased and my co-leader, Dr C. R. Murthy, remarked that if we were unable to perform the experiment under such excellent conditions we would never succeed. But we continued the search with help from the bridge watch and finally located the dye tracer, which had by then spread to a small patch at the expected depth. As the experiment

39 See Murthy et al. (1974) for information on the experiment sites and primary data.

40 See Kullenberg et al. (1974).

41 See Kullenberg (1974).

42 The results of the rate of vertical mixing are presented in Kullenberg et al. (1974).

was my responsibility I felt extremely relieved. The dye-tracing procedure then lasted 79 hours. We had succeeded on our first attempt and all the subsequent experiments enjoyed the same success. This was undoubtedly due to solid team work, with great support from Håkan and the entire crew of the *Limnos*. We even managed to keep the ship entirely clean of red rhodamine dye.

15 The International Decade of Ocean Exploration 1971–1980: Furthering global cooperation in ocean research, exploration, education and mutual assistance

It should be recalled that systematic oceanographic research was initiated only in the second half of the nineteenth century, with the global research undertaken by the H.M.S. *Challenger* constituting a milestone in the development and support of ocean research. This expedition stimulated ocean observations and mapping in many countries through single ship expeditions, mostly on a basin-wide scale, although many cooperative regional studies were undertaken prior to the First World War. The inter-war years saw a return to single-ship studies, such as the basic systematic mapping of the South Atlantic, including bathymetry, carried out by the *Meteor* expeditions 1925–27 (see, for example, Lenz and Deacon, 1990). Shortly after the Second World War, two Scandinavian circumnavigation expeditions generated further international cooperation; however, the real quantum jump for international cooperation in ocean exploration and research, together with applications and use of the results, came in the form of the International Decade of Ocean Exploration (IDOE) 1971–1980.

The IDOE was born out of the development of oceanography in the two decades since the end of the Second World War, and the resulting increase in knowledge of the ocean, marine resources and their potential. Technologies for echo-sounding and seismic studies, including magnetometers and gravimeters used by ocean research, had confirmed the global extension of the mid-ocean ridges, plate tectonics and continental drift (e.g. Bullard, 1969; Revelle, 1969). Studies had also mapped the existence of what were potentially large resources on the ocean floor. In parallel, activities in the ocean had increased with the extension of national claims, leading to growing concerns for the environment, and the use and abuse of resources. There was also growing awareness of the need for

ocean governance, in particular regarding questions of ownership and equal use of discoveries and resources by all nations.[43]

In addition to the technological advances mentioned above, further developments included the advent of super ships and super tankers, which weighed up to several hundred thousand deadweight tonnes, and deep-diving submarines such as the *Trieste*, capable of dropping 11,000 m into the Mariana Trench (Bascom, 1969). Advances in deep-sea drilling for scientific purposes required ships to hold positions without anchors for over a month, and drill up to 760 m into the sea bottom at water depths of 5,200 m (e.g. by the deep-sea drilling ship *Glomar Challenger*). Navigation had also improved, reaching high levels of precision through the use of orbiting satellites in combination with inertial guidance systems and electronic devices employing phases of radio waves. Studies of the sea floor had advanced significantly through the use of television and side-scan sonar – and deep-sea diving vessels. These new technologies were all being used by advanced countries, especially by industries such as fishing, deep-sea mining, rescue services and shipping. Such marine technology developments were made possible by the availability of new vehicles, instruments and systems, and especially new materials with low weight, flexibility and strength. These included fibreglass, plastic, titanium and much improved steel, which was in particular demand for deep-diving submarines.

As noted above, satellite technology was being used for many applications such as positioning, monitoring and synoptic mapping. Improved positioning was essential for mooring technology with current meters and other sensors, and for deep-sea drilling. Satellites could also be used for data transmission to land-based receiving stations. Research often used a system-oriented approach combining several techniques for observations and experiments. My own dye-tracer experiments serve as a small example, albeit far from applications in deep-sea drilling. New electronic equipment, such as light detectors and lasers, could also be employed in ocean studies, and was of great importance for advancements in optical oceanography (e.g. Jerlov, 1968).

All of these technological developments were achieved through cooperation involving the sciences, industry and governments. Scientific research aside, such developments were motivated by a need to meet increasing demand for food from fishing and aquaculture, and freshwater through desalination for which the technology was advancing rapidly. National security was also a driving factor, as was international competition. The implementation of

43 See *Scientific American* (1969) for a comprehensive and informed overview of all these developments and concerns.

Intergovernmental Oceanographic Commission (IOC) programmes was made possible by these technological developments, examples of which include the data exchange programme, programmes related to protection and hazard warnings (e.g. tsunamis) and programmes responding to growing concerns around marine pollution. The time had come to launch a substantial initiative with global outreach and appeal.

The idea of an international decade was conceived in 1966 by the US National Council of Marine Resources and Engineering, chaired by the US Vice President. The Council argued the case for such a collaborative global effort on the basis of 'food for the world population, maritime threats to world order, waterfront deterioration in coastal cities, increased pollution of the shoreline, expanding requirements for sea-bed oil, gas and minerals, and expanding ocean shipping'. The concept was officially announced in March 1968 by the US President, Lyndon B. Johnson, in a message proposing 'an historic and unprecedented adventure – an International Decade of Ocean Exploration for the 1970s'.[44] Following consultations, in June 1968 the IOC recommended support for the IDOE. In December of the same year, the UN General Assembly endorsed 'the concept of an IDOE to be undertaken within the framework of a long-term programme of research and exploration designed to assist in a better understanding of the marine environment through science'. The IDOE was to mark a major turning point in ocean exploration and changed the science of oceanography (WHOI, 2002).

An important outcome of the IDOE was the discovery of ocean hydrothermal vents and hot springs on the sea floor (Reed, 2009). Remotely controlled submarine vehicles, developed following the Second World War, provided a means to map and observe the ocean floor, and were instrumental in this finding. Discovered initially in the eastern Pacific in 1972, where they are associated with volcanic hotspots and mountain ranges, vents were later found in other areas of the Pacific and other ocean basins, often associated with the ocean ridges. Such vents were observed to host a new type of ecosystem based on the bacterial production of organic matter through oxidation of hydrogen sulphide in the erupting water. During mixing with the ambient water, cold seawater minerals in the hot water are dissolved, and hydrogen sulphide oxidizing bacteria use the oxygen and carbon dioxide in the seawater to produce organic carbon. This process is used by organisms to build a deep-sea chemosynthetic ecosystem without sunlight, surviving at high pressure and low temperature.

44 Developments are presented in the report by the National Council on Marine Resources and Engineering Development (1968).

These spectacular discoveries were made possible due to cooperation among institutions, scientists and engineers with government support – all inspired through the International Decade of Ocean Exploration. They also stimulated much cooperative research, including pharmaceutical studies to seek new medical cures from the bacteriological actions and new materials associated with the vents (see, for example, Mann Borgese, 1998).

The Decade also saw the adoption by the oceanographic community of the Practical Salinity Scale in 1978, which redefined salinity to reflect the conductivity of seawater (Reed, 2009). Again, this decision was the fruit of cooperation between countries, institutions, scientists and engineers. It began with the German geochemist Forchhammer, whose analysis of a large number of seawater samples in the 1850s–1860s resulted in the identification of 27 different elements in the seawater (Reed, 2009). This was followed by analyses by the German scientist Dittmar of the samples brought home by the *Challenger* expedition, which led to the international adoption of Copenhagen Standard Sea Water as the calibration reference for salinity determinations in 1903. The 1930s saw the introduction of seawater conductivity measurements, performed together with titration of salinity to establish a ratio. Then, in 1955, a technological breakthrough resulted in the conductivity-temperature-depth (CTD) profiler, which made possible combined measurements (Reed, 2009). Meanwhile, parallel developments in analytical techniques enabled the analysis of seawater to detect contamination by various non-natural possible pollutants. The overall result was the substantial progress in marine pollution research during the IDOE.[45] Indeed, the large volume of data collected during the IDOE and subsequently through new technologies, such as CTD, greatly increased our knowledge of ocean conditions. This was to a large extent facilitated through the adoption of the Practical Salinity Scale.

A few years prior to the start of the Decade, in 1965, the IOC prepared a General Framework for the Study of the World Ocean (GSF). Broader perspectives of ocean studies for understanding and making use of the ocean were specified within a 'comprehensive outline of the scope of the Long-term and Expanded Programme of Ocean Exploration and Research (LEPOR)'. The purpose of LEPOR, agreed in 1969 at the Sixth Session of IOC Assembly, was 'to increase knowledge of the ocean, its contents and the contents of its subsoil, and its interfaces with the land, the atmosphere and the ocean floor, and to improve understanding of processes operating in or affecting the marine environment,

45 This wealth of research was very much stimulated by Prof. E. D. Goldberg, who prepared the first review of the health of the ocean, presented to the IOC in 1976 (Goldberg, 1976).

with the goal of enhanced utilization of the ocean and its resources for the benefit of Mankind'. The Group of Experts on Long-term Scientific Policy and Planning (GELTSPAP) was charged with keeping the programme under continued review. The IOC implemented LEPOR through an initial ten-year programme to accelerate the acquisition of scientific knowledge of the ocean and to improve the capacity of all Member States to participate in oceanographic research through the IDOE.

Member States were encouraged to participate in the IDOE and to promote a move from individual, uncoordinated efforts to probe the ocean to new levels of scientific enterprise based on systematic planning and multidisciplinary approaches. Several criteria were specified for potential projects of the IDOE, including: 'Does the research require increased emphasis because of the economic potential of the resources or ocean use, or the urgency of human need to which it relates?'. Individual programmes or projects were proposed by Member States or groups thereof, taking into account the criteria. In order to stimulate and facilitate active participation, the IOC organized a series of regional workshops. On the basis of proposals, the IDOE programme eventually focused on four main areas: environmental forecasting and major physical processes; environmental quality including baseline studies of several contaminants as DDT, PCB and heavy metals; sea-bed assessment addressing plate tectonics, continental margins and non-living resources; and living resources, assessments and ecology, for instance coastal upwelling ecosystems. A coherent approach was emphasized for the projects. The programme structure could be discipline-oriented (geology-geophysics, physics, biology and geochemistry), and should include representative projects of scientific and engineering interest, with consideration of the major uses of the ocean and the benefits from the proposed investigations.

The regional cooperative studies previously initiated by Member States and the IOC continued but were not seen as part of the IDOE programme. However, there is no doubt that they stimulated participation in the IDOE, and helped to highlight linkages between regional and global processes and conditions. Several regional subsidiary bodies of the IOC were launched during the 1971–80 Decade. At the national level, the IDOE also served to develop and raise support for subregional cooperative studies involving several Member States. Some of these studies could extend over several years and encourage further cooperation and data exchange between scientists and institutions. Gradually, sustained ocean observations were initiated with the Integrated Global Ocean Services System (IGOSS) in cooperation with the IOC and several agencies, including

members of the Inter-secretariat Committee on Scientific Programmes Relating to Oceanography (ICSPRO).[46]

In some countries that were Member States of the IOC, the IDOE initiative stimulated the development of national cooperative programmes addressing various needs and concerns of society. One such example is provided by Denmark, where a national IDOE committee was established involving all relevant national institutions. The committee was interdisciplinary and formulated a number of programmes. The ocean areas with Danish interests reached from the Baltic into the Arctic, including Greenland. One substantial effort was dedicated to the Baltic environmental problems. The programme, named the Belt Sea Project, focused on the transition area from the North Sea. This was linked to other projects, including in the Baltic and in the Kattegat-Skagerrak area, and involved a great deal of Nordic cooperation. The project was managed by the new Marine Pollution Laboratory established by the Danish Environment Protection Department.

The efforts, spirit and opportunities of the International Decade raised considerable support from governments for ocean research and observations, and stimulated much interest in the ocean and the marine environment, including marine resources and their use and management. Research during the IDOE also triggered and stimulated support for several large-scale global ocean research programmes, which became part of the World Climate Research Programme and International Geosphere-Biosphere Programme, as well as studies of marine pollution including the biological effects of contamination and interactions between physical, chemical and biological processes. Sustained observations, monitoring and warning systems attracted increasing attention, including for seawater and seafood contamination, and algal blooms. International reviews of the health of the ocean by GESAMP were initiated, with the first completed in 1982. At the end of the Decade in June 1981, the IOC requested its advisory bodies to make a study of 'expected major trends in ocean research up to the year 2000', which resulted in the report *Future Ocean Research* (SCOR, 1982). Investigations and assessments of regional seas were pursued.

46 ICSPRO was created in 1969 with the aim of providing support to the IOC Secretariat in the context of the LEPOR and IDOE initiatives by promoting the development of effective forms of cooperation between organizations of the UN system concerned with oceanic programmes.

BOX 5. Participation in other programmes related to the International Decade of Ocean Exploration

My participation in several programmes of the International Decade of Ocean Exploration (IDOE) enabled me to follow the initial development and growth of interdisciplinary cooperative ocean research, while my work with GESAMP, the International Council for the Exploration of the Sea (ICES) and the Scientific Committee on Oceanic Research (SCOR) and other bodies of the International Council for Science (ICSU) allowed me to participate in the development of efforts linked to environmental issues.

Mixing studies in the upper layer of the ocean

The North Sea: Interactions of physical and biological processes

Early 1976 saw the implementation of ecosystem studies in the North Sea as part of a large interdisciplinary cooperative programme called the Fladen Ground Experiment. One aim of these studies was to enhance understanding of the primary production cycle in the sea. The Fladen Ground Experiment involved most of the countries around the North Sea and the Institute of Physical Oceanography at the University of Copenhagen, where I was based, participated in two studies. The first consisted of observations of the optical conditions of water masses on board the research vessel *Meteor* from Hamburg, carried out under the leadership of my colleague Dr Niels Højerslev. The second of the studies concerned mixing in the euphotic zone by means of dye tracing using the same technique that I had developed and deployed in Lake Ontario (Box 4).[47]

The experiments for the mixing studies were carried out from the research vessel *Friedrich Heincke* of the Biological Institute Helgoland (BAH), which was put at my disposal for this joint experiment. As part of the study, we cooperated and interacted with the research vessels *Gauss* of Hamburg and the *Explorer* of Aberdeen, Scotland. These observations focused on plankton distribution in the productive surface layer by means of UV fluorescence. The weather conditions were not ideal, as might be expected in April-May in the North Sea. However, three dye experiments allowed us to determine the vertical exchange in the stratified water column and the rate of horizontal mixing.

47 See Kullenberg (1974).

The plankton distribution mapping was undertaken in cooperation with the *Explorer*, under the leadership of Dr John Steele, and was organized in parallel sections of about 15 km in length, with a gradually increasing distance between the two ships of 2 km up to 15 km. The mapping provided a good overview of the small-scale distribution of the plankton population. The observations showed that a separation between the mapping lines of the order of 1–2 km was required to map a plankton patch and produce the information needed for patchiness studies.

These observations were similar to those carried out in 1977 as part of the Baltic Open Sea Experiment, which also aimed to enhance understanding of the ecosystem in the open sea (see Chapter 16). This experiment was also part of a large, regional effort under the umbrella of cooperation between ICES and SCOR through the Baltic Working Group on the study of pollution of the Baltic. The Fladen Ground Experiment was likewise part of a large regional cooperation effort organized and implemented within the ICES framework. This programme aimed to gather information about the water exchange between the Atlantic and the North Sea, the residence times of water layers in the North Sea, the physical mixing of water masses, the chemical and biological conditions, and the overall pollution situation.

The Fladen Ground Experiment was a decade-long programme, organized and managed by several groups of scientists and involving the management of participating laboratories to ensure communication with funding bodies and policy-makers. Thus, our participation in the Fladen Ground Experiment was supported by the Danish National Research Council, university funding and, not least, the provision of ship time from Germany. Without that support, our participation would likely have been impossible. Moreover, these kinds of research and observation programmes involving considerable infrastructure support could not be conceived, organized and implemented without government involvement and assistance. They included the communication and exchange of results and joint analyses for use in policy advisory mechanisms, for which intergovernmental organizations played an important role.

Furthermore, the cooperation between individual scientists and groups spanned up to a decade or more, and was shaped through correspondence and the exchange of ideas and experiences at meetings, workshops and symposia at national and international levels. Through these opportunities to cooperate, trust, understanding and mutual

respect was achieved, as well as confidence, readiness to contribute and a willingness to show extra effort when required. This became particularly important when working at sea under difficult conditions, where trust was a basic requirement and hard weather, unexpected accidents or equipment failure might precipitate decisions to proceed with or abort operations.

Air-sea interaction experiments

In 1978, the long-standing cooperation between our institute at the University of Copenhagen and the Institute of Marine Sciences in Kiel gave us the opportunity to participate in the Joint Air Sea Interaction (JASIN) programme. The overall aim of the programme was to study the interactions and fluxes between the ocean and the atmosphere. The subprogramme in which we were a partner specifically aimed to elucidate the physical processes that can generate mixing in the oceanic and atmospheric boundary layers between the ocean and atmosphere, quantify the rate of mixing and relate it to the environmental conditions, such as wind, current and stratification in the water column. The project also sought to investigate aspects of heat and momentum budgets in the boundary layers and the flows between them. In many ways, this represented a logical expansion of our work during the Fladen Ground Experiment.

We aimed to investigate the mixing rates in the stratified upper layer of the water column by means of dye tracing, similar to the experiments we carried out in the North Sea in 1976, as well as in Lake Ontario. However, this time the fluorometer would detect dye mounted inside a 'fish', which could then be towed in an oscillating mode with a wire cable transmitting the fluorometer signal to recording units on the ship, thus avoiding the use of a separate cable for the fluorometer. The signals would be recorded on a strip chart recorder and by a computer. The fluorometer unit was fitted inside a small apparatus shaped like a fish to ensure minimal water resistance, with small openings in the front and end to allow water-through flow. The fluorometer mounted inside the towed 'fish' recorded dye concentration as well as temperature, salinity and depth.

In order to test and refine the experiment, we carried out two test cruises in the western Baltic on the research vessel *Poseidon* from Kiel. The equipment functioned well and the team proved their ability to carry out the experiment. The process required close collaboration

between the operators of the fish and the signal recorder, the navigator, the helmsman and the experiment leader. The dye signal was plotted in real time as the ship crossed the area. The complete experiment procedure involved obtaining several density profiles of the water column, preparing the dye solution to the density of the planned depth of injection, releasing a parachute drogue at that depth tied to a surface buoy with a radar reflector to serve as a position reference, injecting the dye while noting the position of the ship relative to that buoy and directly tracing the dye with the fluorometer inside the towed 'fish'. The ship was then manoeuvred to pass through the injection area relative to the drogue buoy. It was crucial to locate the small dye patch early on, in depth and relative to the drogue buoy. The position was also noted in terms of appropriate radio navigation, as Decca coordinates.

The real experiments were carried out in the JASIN area in the Irish Sea in the second half of August 1978. We carried out three experiments, twice with injection of the dye at 40 m, below the thermocline, and once at 20 m in the thermocline. These experiments proceeded satisfactorily for several hours, then in each case the cable failed. Transmission of the signal did not function properly and the experiments had to be terminated. We managed to fix the problem twice, but after the third failure we were unable to remedy the fault. The cable was broken. This was a great disappointment, and although we managed to prove the feasibility of the experiment, we did not obtain the results for which we had worked so hard. The cooperation between the international team of scientists and the crew of the ship was in all aspects excellent, and I personally appreciated the ship, the crew and the positive, understanding and willing attitude of the captain, which seemed to permeate the whole ship. The leader of the whole activity was Prof. John D. Woods, whom I had known for many years. He was very supportive and a good friend.

Coastal upwelling ecosystem studies

Many studies of fronts in mainly coastal areas concern structures associated with straits and fjords that separate water masses from land runoff, or geological and topographical features such as sills or land extensions, such as capes. There are other categories of frontal zones which host important ecosystems of great food value with their related economic implications. These are the large and seasonally persistent coastal upwelling ecosystems. They depend on the boundary between

the ocean and the land, together with the influence of the wind and the rotation of the Earth driving coastal zone circulation.

The programmes of the IDOE were international, cooperative and interdisciplinary in character. They dealt with regional or global ocean problems requiring joint and coordinated research efforts and the pooling of resources, with many being of socio-economic interest. Some global IDOE programmes of a regional nature focused on coastal upwelling ecosystem studies. My institute was given the opportunity to participate in some of these.

Upwelling is pronounced and occurs seasonally with persistent winds along the coast. The friction of the wind on the water drives circulation in the upper layer which, together with the effect of the rotation of the Earth, generates a vertically integrated transport offshore in the surface layer. One such area is the coast off Chile and Peru in the Pacific Ocean. This area has been investigated extensively due to the presence of large fishery resources there, which are supported by the coastal upwelling. The Coastal Upwelling Ecosystem Analysis (CUEA) programme of the IDOE focused on this system. The aim was to elucidate the processes driving such a system from primary production to the very rich fisheries. The primary driver of this is the upwelling along the coast of intermediate water rich in nutrients for primary photosynthetic production in the surface layer. The physical forcing is a result of the combination of a persistent meteorological system with wind along the coast and the rotation of the Earth driving the surface layer circulation.

Prof. V. W. Ekman of Sweden explained that the friction of the wind drives the motion in the top of the water column. The vertical integration results in a net transport to the right of the wind direction on the northern hemisphere and to the left of the wind direction on the southern hemisphere. This process is now referred to as the *Ekman effect*. Accordingly, the seasonal winds towards the Equator along the west coast and from the equator along the east coast of the continents generate a net offshore transport in the surface layer. This must be substituted by water coming up to the surface layer from the intermediate water, bringing nutrients to the euphotic productive zone, which forms part of the surface layer. The constant supply of nutrients supports high primary production, feeding the next step in the food chain, zooplankton. These feed the fish larvae, and so on.

These rich fishery zones exist along the coasts of continents in a more or less pronounced manner, depending on the variability and stability of the weather system, which normally follows a seasonal pattern. The richest fisheries are associated with these zones and are found most noticeably off Chile and Peru along the west South American coastline, along the coasts of Senegal and Mauritania on the West African coast, by Angola and South Africa on the West and East African coast, and outside Somalia in the Indian Ocean. The particularly rich fisheries off Chile and Peru led these states to adopt the Santiago Declaration in 1958, establishing a 200 nautical mile national fisheries zone. This action promoted the creation of the exclusive economic zone (EEZ) written into and agreed upon in the Law of the Sea – a result of the drive, cooperation and persistence of developing countries.

Through IDOE programmes, it became possible for us to participate in upwelling studies outside West Africa and Chile and Peru. Our contribution to the research was based on our ocean optical studies in relation to the content of suspended matter in the water column, the irradiance penetration integrated over the range of wavelengths useful for photosynthesis (the quanta meter), our *in situ* fluorescence measurements for chlorophyll a, and our colour index measurements. These measurements could help obtain a complete picture of the ecosystem conditions, together with other physical, chemical and biological measurements. The upwelling programmes ran for several years. We were invited to participate with our equipment on one expedition in April 1977 outside Peru on the research vessel *Melville*. This action was coordinated from our side with our participation in the Drake Passage studies 1976, see Box 2. We used the same equipment which was shipped directly from the *T. G. Thompson* to Seattle, the port of departure for the *Melville*. We, however, boarded the ship in Callao, the port city of Lima, Peru.

In Lima, we made contact with Dr Louis Codispoti, our cruise leader, met several other scientists and visited the Institute of the Sea of Peru (IMARPE). We boarded the ship at 11.00 on 26 April and started installing and checking our equipment. The winch was attached to the deck and adjusted for the power supply of the ship, with the help of the ship's electrician. The equipment also included a scattering meter and quanta, colour and incoming solar radiation meters. The initial plan was to sail on 28 April; however, an oil leak prevented our immediate departure while the ship was examined. We used the intervening time

to complete the installation of the winch, and to present and discuss our cruise plan, which was based on the observations of the previous legs of other ships and inputs from the scientists at IMARPE. It included four long Callao-lines (C-lines), sections perpendicular to the coast, with sampling of hydrography, CTD, nutrients, chlorophyll, oxygen and optics.

The ship remained docked for several more days. We waited on board working on the equipment, completing the installation of the winch and calibrating the instruments as required. Finally, the *Melville* departed at 19.30 on 3 May, heading towards the first station on the C-lines, with expected arrival at 21.00 on 4 May. We encountered a light southerly wind, around 10 m/s and a light sea with green surface water, similar to the Baltic Sea surface layer.

The expedition involved several institutions and a large scientific crew. The cruise worked in sections, the C-lines, across the upwelling area. Our specific aim was to measure the optical conditions in the surface layer by means of the quanta and colour meters, and the distribution of suspended matter in the water column with the scattering meter from the shallow inshore water across the shelf zone to the open sea in the whole water column, as far as possible. In many ways, our work and situation were similar to the conditions on the *T. G. Thompson*, see Box 2. The main difference in the distribution of water properties was the strong variation across the upwelling zone between the relatively cold upwelled water and the warmer surface layer water further out from the coast, outside the upwelling zone. The high primary production in the upwelling zone was noted through the high level of scattering. At intermediate levels, the water drawn in towards the coast to compensate for the net outflow in the surface layer was marked by considerably less scattering, implying much less suspended matter, and active inflow of offshore water. Close to the bottom on the shelf and slope there was a bottom boundary layer of high scattering, including one notable layer with maximum scattering in the profile. This distribution was to be expected and conformed to the circulation and production conditions. The prevailing wind system generates the net outflow compensated by the upwelling from intermediate levels. This brings nutrients to the surface layer feeding persistent high primary production.[48]

48 The results of our observations are presented in Kullenberg (1978, 1981, 1984a, 1984b).

A proper analysis of the upwelling ecosystem properties requires the involvement of several disciplines cooperating in an interdisciplinary manner; hence, many other science disciplines were represented in the scientific crew. The cooperation between the teams worked well, with a growing understanding of our respective parts in the expedition. On the passage north from Callao, heading towards Panama City, we passed the Equator and participated in the customary celebrations of that occasion. The members of the party who had not previously crossed the Equator on a ship were welcomed to his realm by King Neptune, represented by the captain, and duly baptized into this honour.

This was the third upwelling cruise in which we – our engineer or a graduate student and myself – had participated. The first, which was also a coastal upwelling ecosystem analyses expedition, took place between 23 February and 13 March 1972 on board the research vessel *Meteor* from Hamburg. The scientific party was interdisciplinary, including colleagues in the fields of biology, fisheries biology, microbiology, chemistry and physics, from Denmark, Germany, Sweden, the United Kingdom and the United States, under the leadership of Prof. G. Hempel from Kiel. Dr Voorhis from Woods Hole Oceanographic Institution (WHOI) brought his new floats, which could be tracked acoustically by transponders mounted on them.

We participated with optical equipment for measuring light scattering at a 90° angle *in situ*, beam transparency, the light quanta available in the euphotic zone integrated over 400–700 nm wavelength, the colour index for the surface, the ratio of upwelling light in the blue and green wavelengths, and, in the laboratory, scattering at 45° and 90° on water samples in glass bottles drawn from hydrographic casts. The *in situ* instruments were lowered from the hydrographic winch with attached cables. On this occasion we did not have the deep scattering meter with its wire cable winch, thus our observations were limited to the top 100-m layer.

We joined the ship in Dakar, Senegal, having previously transferred and installed our equipment in Hamburg. We sailed from Dakar on midday 23 February 1972 in fine weather, 20 °C with a light northerly wind. Our first stop was at a station to test the equipment and organize the multisampling scheme, the sequence and the time required by the different teams to carry out the sampling or observations. We were heading towards an area of upwelling located earlier and tracked by the research vessel *Planet*, from Kiel. The area was located to the north

around latitude 19°40'–19°55' N and 17°19'–17°23'–17°50' W. The mapping of the area by the *Planet* showed a frontal zone along the coast with patches of cold upwelled water with a temperature of around 15 °C. The *Planet* had installed current meter moorings, deep sea tide gauges and conducted CTD sections perpendicular to the coast.

Our navigation was complicated by a lack of satellite signals due to dust clouds from the desert near the coast. Our plan was then to operate across the upwelling zone including the front between the upwelled water and the open ocean water, amid a rather dense network of stations. Dr Voorhis' three floats were to be used to follow the upwelled water patch and provide regular information about its position. Accordingly, we expected to be able to follow the development of conditions in the patch, including nutrient chemistry, microbiology, light conditions, salinity, temperature and particulate matter developments.

The first experiment started early on 27 February with a float deployed for the *Meteor* to follow. The northerly wind conditions were favourable for us and the upwelling, with a strength of 4–6–8 Bf and a light to moderate sea with some swell. The currents were quite strong, reaching around half a knot. A second float was deployed in the late afternoon in the frontal zone. The plan and operations worked quite well with good coordination between the teams, and adjustments made as required by the weather or other conditions. The wind and state of the sea increased at times to 8 Bf with rough sea preventing some measurements from being made. The experiment continued over several days, including recovery of the floats. Afterwards, we proceeded inshore to make a detailed repeated section across the frontal zone, an operation requiring about 18 hours. The section was obtained from inshore, starting at a depth of about 50 m in a south-westerly direction out to a depth of about 1,100 m, after which the two floats were recovered on 7 March. One float had grounded while the other had drifted in a southerly course during the operation.

A particular feature of the local topography was the presence of a canyon stretching in a north-south direction along the coast with depths ranging from 50 m to about 440 m, followed by a rise to a sill with a depth of about 200 m. This may be conjectured as an effect of the outflow from the Banc D'Arguin south-east of Cap Blanc. This outflow was observed in the particle-scattering distribution along our subsequent section from outside. It started at the 850 m depth contour

in late 7 March, running towards the coast along a north-easterly course ending at the 50 m depth contour in the morning of 8 March. The expedition continued this approach, with sections across the frontal zone, terminating at a last station in the morning of 9 March. Thereafter, two floats were recovered after drifting for 50 hours in a south-easterly direction from the morning of 7 March.[49] We docked in Dakar on the morning of 11 March and were scheduled to disembark early on 13 March.

It remained for us to depart from the *Meteor*, a very fine ship with highly qualified officers and crew, and magnificent style. When taking my farewell of the Captain, he gave me a very nice compliment, saying 'I have never seen such a small man eat so much and enjoy it so much'. Then and there I decided to continue along that line. We travelled together with some of the scientific crew and then thanked them and said goodbye. In particular, I expressed my great appreciation and admiration for Prof. Hempel, whom I considered as a friend.

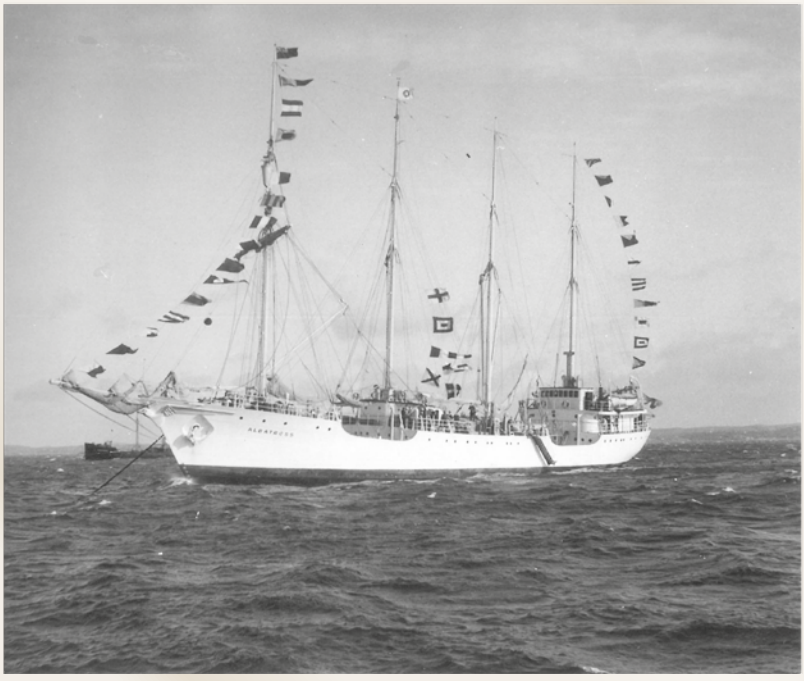
We were able to repeat the observations of the West African upwelling zone through participating in Upwelling 1974 on the RRS *Discovery*, leg 2, 18 February–8 March 1975, departing from and returning to Santa Cruz de Tenerife. The physical oceanography of both cruises included current measurements with moored instruments, hydrography in repeated sections perpendicular to the coast at slightly different alongshore positions, and our optical observations of scattering and total attenuation in profiles, colour index of the surface layer and quanta irradiance measurements across the euphotic zone. We boarded the *Discovery* at midday on 18 February and installed our equipment, including the winch for the deep scattering meter. The equipment was the same as on the *Meteor* expedition with the addition of the deep scattering meter. Our observations were thus extended to reach the bottom boundary layer over the shelf and slope. The results, by and large, are very consistent with those from the *Meteor* cruise.

On ships, it was important for foreign visitors to at least establish contact and a good working relationship with the crew and obtain the trust of the ship's officers and the scientific leaders. In my work, this proved essential to the success of the dye experiments, as the procedure required navigating or directing the ship in relation to a drifting buoy with a radar reflector, while towing the detecting instrument with a

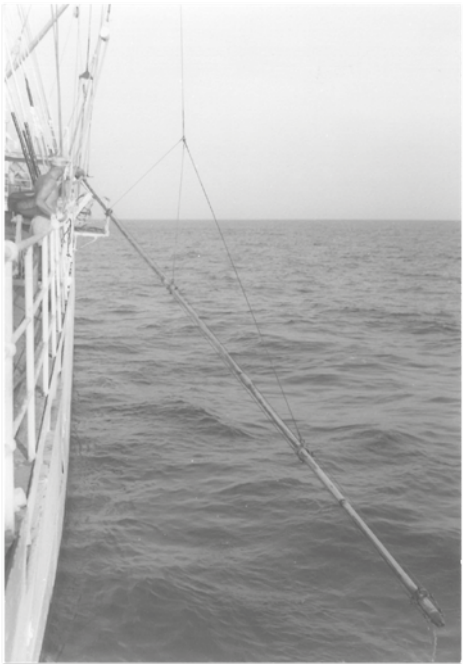
49 Some results of our work are presented in Kullenberg (1977a, 1977b, 1978, 1981).

cable in an oscillating mode between certain depth levels in order to first find, then trace the dye patch. The position relative to the drifting buoy was determined by optical distance and bearing measurements and the use of radar on the bridge. The position of the ship relative to the buoy was plotted throughout, even when outside of the dye patch. Without mutual understanding and strong cooperation between the scientist in charge, the member of the crew on watch and the bridge, as well as the crew operating the winch with the towed instrument, such experiments would be impossible.

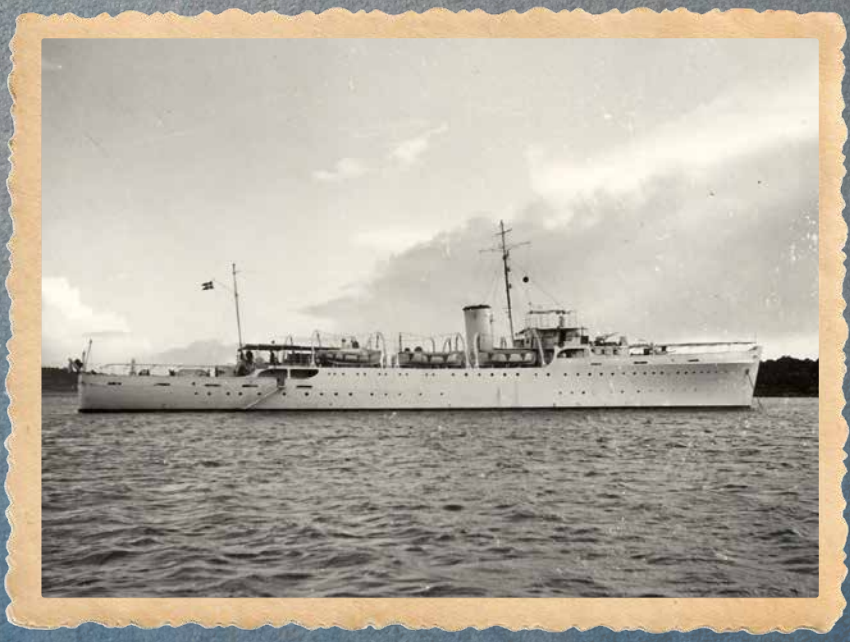
Piston core vertically mounted ready for lowering (approximate date: during the 1950s). The man on the right of the photo is Prof. Börje Kullenberg.



R/V *Albatross*.



Piston core operation, likely on the R/V *Albatross*, showing the long tube lowered.



Frigate *Galathea*.

Participants in the SCOR Bureau meeting in Gothenburg, January 1957. No. 17 is Prof. Börje Kullenberg (see Chapters 7 and 8); No. 27 is Prof. Håkon Mosby (see Chapter 2); and No. 29 is Prof. Nils Jerlov (see Chapters 7 and 18).

Engineer Henning Hundahl operating the deep light scattering meter on the R/V *T. G. Thompson*, Drake Passage, 1976.

With Mario Ruivo in Paris at the UNESCO headquarters, around 1989–90.

With Dr A. Metalnikov in Moscow, 1990.

With Director-General Dr Federico Mayor and Dr Manuel Murillo, Chair of the IOC, and David Pugh (UK) on the occasion of the Roger Revelle lecture 1992, and the presentation to the Director-General of UNESCO of *The Fram Atlas of the Southern Ocean* from the Institute of Oceanographic Sciences Deacon Laboratory (UK). The Roger Revelle lecture was given by John Knauss.

Meeting in UNESCO with the Secretary General of the WMO, Dr G.O.P Obasi and Dr John Knauss, 1st Vice-chair of the IOC 1991–93.

UNCED 1992, Rio de Janeiro, with the Deputy Executive Secretary of the IOC, Dr Klaus Voigt, and Dr Manuel Murillo, President / Chair of the IOC.

With the Director-General Dr Federico Mayor and Dr Vagn H. Hansen at The North Sea Oceanarium (at that time the North Sea Museum) in an exhibition simulating the bridge of a vessel.

With Iouri Oliunine in St Petersburg around 1994–96.

Relaxing with my wife Kristina at Lamu Island, Kenya, on the occasion of the UNEP General Conference 1995.

Man and the Ocean Conference – Commemorating the International Year of the Ocean (Tokyo, 1998). The author is on the front row, fifth from the right.

With Vladimir Ryabinin in the IOI office, Malta, when we were both serving the IOI (Malta, 2001).

16 The Baltic Sea: A regional case study

Following the lead of fisheries management, countries gradually began to address issues of marine pollution through regional cooperative mechanisms. A good example of such cooperation was seen in the Baltic Sea, where environmental problems associated with contamination and inputs from land were identified early on. Cooperative studies of the Baltic were underway at the end of the nineteenth century and became a regular feature of the region following the creation of the International Council for the Exploration of the Sea (ICES) in 1902 (Smed, 1990). Serious pollution problems influencing the oxygen balance in the sea were later confirmed in the early 1960s (e.g. Fonselius, 1962; Voipio, 1981).

The particular conditions of the Baltic (see, for example, Svansson, 1980; Voipio, 1981) make the entire sea vulnerable to the input of nutrients, organic material and potentially harmful substances from the atmosphere and primarily land through numerous rivers and other sources.[50] Studies of the Baltic Sea conditions over decades highlighted many scientific problems that required interdisciplinary research and regional cooperation. This led to the creation of dedicated regional groups, including the Baltic Oceanographers, the Baltic Marine Biologists and a special group of hydrologists and meteorologists studying the Baltic water balance. These groups received the support and attention of the governments

50 This vulnerability can be linked to the combination of several natural conditions, in particular significant river inputs of freshwater and restrictions on water exchange between the Baltic and the more open ocean. Regarding the latter, the entrances to the Baltic are narrow and shallow, restricting water exchange and water renewal in the Baltic basins. The water from the North Sea must pass through the Skagerrak and Kattegat before streaming over the shallow sills into the Baltic. In addition, the Baltic basin is divided into a series of sub-basins separated by sills, which restrict water renewal in the basin beyond the sill. The deep and bottom waters in the separate sub-basins therefore tend to have long residence times. This situation is exacerbated by the exchange with outside seas, which are essentially forced by weather conditions. Westerly storms act as the main force for water exchange, bringing relatively high-saline waters into the Baltic. The new water sinks due to its high density and renews the deep and bottom waters in the Baltic basins. However, substantial periods of time may elapse between storms of sufficient magnitude and persistence to trigger this renewal process. This means that organic material settling down from the upper layers will lead to oxygen in the water being gradually consumed by bacterial oxidation. As a result, oxygen in the water may reach concentration levels too low for life, resulting in so-called dead bottoms. The significant inflow of freshwater furthermore implies that vertical mixing is weak, with little oxygen being mixed down into the deep waters below the freshwater layer. This layer can extend to a depth of 60 m.

of the Baltic nations. However, political and governance differences between the Soviet Union and Western-oriented countries resulted in some concerns related mainly to strict government controls of participating scientists, information and data exchanges, quality control, the interpretation of results and representation in the groups. These matters were normally well handled through direct contacts between the scientists. However, participation of scientists from other regions beyond the Baltic region could also help address the related concerns.

In 1971, following a regional science conference on the marine pollution problem, held in Helsinki, ICES and the Scientific Committee on Oceanic Research (SCOR) agreed to create a joint working group involving all Baltic Sea states to address the Baltic marine pollution problem. The non- and intergovernmental nature of the working group helped to ensure the participation of scientists from all the countries around the Baltic, while reporting to governments through the ICES, and to the wider international scientific community through SCOR. Additionally, through SCOR, experts from countries beyond the Baltic region could be invited and given support to participate in the meetings and work of the joint working group. The involvement of ICES also provided for organizational and administrative support related, *inter alia*, to reporting and outreach.

The initial tasks of the joint working group included: a study of the exchange between the Baltic and the North Sea and physical processes in the Baltic; the development of monitoring of primary production in the open Baltic; and encouraging the exchange of information and data in the field of pollution studies among all Baltic countries. The initial terms of reference provided greater detail regarding the working group's activities:

- identify from the point of view of pollution the need for further basic hydrographic studies, including the development of theoretical models as well as surveys;
- coordinate these surveys using existing groups of experts;
- coordinate and develop further programmes for biological monitoring stations with indicators of changes in the environment such as micro-organisms, benthic macro-flora and fauna, and plankton;
- develop plans for the coordination of studies on the level of toxic substances in food fish and the marine environment;
- pay special attention to the planning of shipboard and laboratory intercalibration tests of sampling, storage and analysis of toxic substances;
- develop a scheme for the collection of all available information on inputs of pollutants into the Baltic Sea.

One specific motivation for the work was concern for possible eutrophication[51] of the open Baltic and its potential effects. This called for monitoring of primary production in the open sea to record the situation and follow fluctuations over a long period.

The support of the scientific community for the joint working group and its ambitious aims exemplified the significant progress made in ocean research in the decades since the Second World War. The tasks also called for cooperation with other groups, including the Conference of Baltic Oceanographers, the Baltic Marine Biologists, and the International Hydrological Decade Working Group on the Water Balance of the Baltic, jointly sponsored by UNESCO and SCOR. The founding meeting called for more in-depth studies of processes in the transition area influencing the exchange of water and material between the Baltic and the North Sea.

The whole process constituted an early effort to address regional marine pollution problems in an organized, coordinated and cooperative, interdisciplinary fashion through the active participation and involvement of all the riparian states. A clear need was identified for intercomparisons, for information on the methods being used for sampling, storage and analysis, and on the standards used by laboratories participating in these studies. In order to prepare a baseline study of the pollution, a questionnaire was circulated to all parties involved, and the responses were collected, examined and collated by an expert group. The analytical problems were also evaluated at a meeting which agreed on the methods to be used for the baseline study. All the Baltic countries participated in these exercises and actions, which extended over a period of several years. A dedicated planning group specified the plan for the baseline study, to include analysis of a limited number of identified obligatory substances, as well as organisms, by all participants. Finally, a timing of the year for sampling was agreed alongside the division of responsibility between the participating countries.

The joint working group also undertook other specified tasks related to the exchange of water and matter with the North Sea, an extended open sea experiment to sample the water column, a Baltic Sea circulation study involving the development of an exploratory model and field experiments, and a study to determine the level of toxic substances throughout the food chain (as a follow-

51 This term refers to changes in the sea caused by the gradual increase of nutrients such as nitrogen, nitrate, phosphorus, phosphate and silicate, leading to an overload of nutrients; the Baltic Sea has changed from an oligotrophic (poor in nutrients) to a eutrophic sea, mainly by inputs of nutrients from land and releases from the oxygen-free bottom areas.

up to the baseline study). Plans were agreed over the period 1972–1974/75 and implemented over a decade.

The working group was further charged with organizing a multidisciplinary experiment in the open Baltic proper. Plans were elaborated throughout 1976 on the basis of results from the group's work, including on physical processes, the effects of eutrophication, pollutant inputs and their distribution and levels in fish (ICES, 1977). A coordination group proposed a framework for the experiment, which was discussed at the ICES 1976 statutory meeting and circulated to scientists in Baltic countries and outside. By the end of 1976, all Baltic countries had submitted proposals for their contribution to the experiment. A workshop in early 1977 integrated the contributions and a complete programme was specified and agreed. The design of the plan was supported by a conceptual model which helped to demonstrate the interactions between physics, chemistry and biology. The overall objective was to obtain simultaneous observations of physical, chemical and biological parameters covering the basic parts of the ecosystem. The experiment was named BOSEX-77, and was planned for three to four weeks in September in the southern Gotland Basin.

The programme was designed according to the available resources, with tasks divided so as to obtain optimal coverage of basic requirements in all disciplines. It included stationary ships at a central station for profiling; mapping of conditions in a regular routing around the centre by four moving ships over a square area with 30-km sides; special experiments, including regular meteorological observations; current measurements using 50 moored current meters at 10 stations covering the square area; and pollutant measurements for trace metals, petroleum and chlorinated hydrocarbons in water, plankton, fish and sediments. In all, 12 ships representing all Baltic countries participated in the BOSEX-77 experiment. Unfortunately, the planned activities were disturbed by extreme weather conditions, with a storm preventing several of the ships from operating during the period 10–16 September. During the peak of the storm, even the larger ships had to break off, bringing to a halt the quasi-continuous series of observations (ICES, 1977).

Oceanography at the time was very sensitive to weather conditions. Accordingly, the bad weather conditions limited sampling to 50–60% of planned physical and chemical observations, but only 20% of pollution observations and 10% of sediment and biological ones. Communication between the ships during the field phase worked according to the pre-agreed schedules and content of reporting and information exchange. The exchange of data through the Service Hydrographique of ICES also proved to be well organized, and resulted in the circulation of a BOSEX atlas to participants, continued long after the fieldwork.

Results of this fairly substantial experiment were also used in several studies and assessments.

A meeting in April 1978 reviewed the accomplishments of the joint working group so far. SCOR had provided reports about BOSEX-77 in their proceedings, ensuring a broad reach, and the study of pollutant inputs to the Baltic and the results of the baseline study had been published by ICES.[52] Intercalibration exercises on analyses of metal concentrations in fish flour and organochlorines in an oil matrix were underway, with samples to be distributed in mid-1978. The working group also provided inputs and advice to the preparation of manuals for regular monitoring exercises on the basis of its experiences from conducting baseline studies. An overview of the field work accomplished during the Baltic Open Sea Experiment confirmed the extensive physical and chemical observations. However, the data from the more limited biological coverage would not permit a study of the transfer of pollutants. Following the reviews of ICES and SCOR at their annual meetings in 1978, it was concluded that the joint working group had completed most of the original tasks. Work would continue in several subject areas, including modelling, coastal dynamics, scientific principles for the assessment and surveillance of the marine environment, and the emergence of new problems in the Baltic, with a focus on potentially harmful organic substances.

Lastly, the active support and participation of the ICES Secretariat in the work, meetings and reporting was of singular importance for the work, accomplishments and long duration of the joint working group – a point brought home to me during my time as its chair. Without that professional support, it would not have been possible to implement the agreed tasks. The ICES Secretariat representative, normally the Environment Officer, participated in regular meetings and organized scheduled communication between members and the ICES secretariat, sharing work concerning research, analyses, data gathering, interpretations and reporting. The communication, exchanges and meetings helped to generate constructive dialogue, reviews and reasonably solid reporting. Contacts established through the group members and co-sponsors helped to stimulate the work, generate action and ensure control, while cooperation with other existing regional groups helped to avoid duplication and promote coordination. Scientists from all Baltic countries regularly participated in the work and attended annual meetings, while the support and outreach provided by SCOR encouraged the active participation and involvement of leading scientists from outside as well as inside the Baltic region.

52 ICES (1978).

17 Global perspectives: New technologies, increasing environmental concerns, social needs and new institutional structures for scientific cooperation

The underlying motivations for cooperation during the post-war period were simultaneously scientific, administrative and political. Scientific development was stimulated by a range of new technologies that emerged from the Second World War, with applications for a wide range of human activities. In ocean research, this included the introduction of recording instruments for currents, temperature, salinity, suspended material and light conditions in the euphotic zone and at depths, including fluorescence from dissolved material and creatures. In terms of chemistry, new equipment made possible the detection and identification of natural as well as human-derived substances at very low concentrations, making possible long-range tracing. It was now possible to trace radioactive material over basin-wide scales, as well as other materials entering the sea from the land or air, including metals such as lead, cadmium and copper. Biology also benefited from these advances with new technologies to catch animals, tag fish, cultivate species in laboratories and create species banks (e.g. of plankton). The development of the piston core benefited geology and geophysics, enabling long undisturbed sediment cores to be obtained and the increasing application of drilling technology became capable of reaching greater depths, far beyond the coring technology.

In parallel, computing progress produced advances in modelling and increasing physical-mathematical insights leading to clarification of ocean circulation mechanisms – for example, concerning the existence and forcing of the Gulf Stream, initiated by Stommel in 1947 (Stommel, 1948). The role of circulation and physical processes for biological conditions was also increasingly clarified: primary production in the temperate zone was related to and explained by the combined forcing of circulation, the upper layer mixing by wind, and the availability of nutrients and light, together with the importance of warming and increasing light in spring, and cycles of cooling and warming. Meanwhile, advances in diving technology enabled the study of physics and biology in the

upper layers, leading to a wealth of new insights. These included the discovery of microstructures and thin layers, which shed light on mixing processes in the ocean. The whole development also attracted new talents to oceanography – scientists who applied insights from other disciplines to the study of the ocean. These included addressing climate change, biochemistry and biological effects of wastes in the sea, details of interactions between processes of physics, biology, chemistry and geology, with increasing interaction between the disciplines, technological developments related to energy extraction e.g. through ocean thermal energy conversion (OTEC) and waves, ocean mining, the health of the ocean and interactions with social sciences. Another legacy of the Second World War was the use of advanced and tested navigational tools. Radio beacons and radio signal networks covering large regional areas allowed for increasingly precise positioning of research vessels and moored equipment. Then in the 1960s and 1970s, research vessels started to use satellite navigation.

The communications revolution enabled data exchanges in real time. Data and observations from wide areas of the ocean can now be transmitted via satellites to several receiving stations from platforms at sea, including from drifting floats. These data include environmental information from the ocean surface layer, as well as information on shipping, fisheries, drilling and other activities at sea. These advances in observation and communications technologies have opened up enormous possibilities for forecasting and warning of environmental conditions, as well as for identifying changes in ocean conditions and ocean circulation. Individual observations of conditions can likewise be exchanged between groups and authorities.

Technological developments have also contributed significantly to maritime transport and shipping, including cruise liners. Much infrastructure is required, safety in ports and at sea needs to be addressed and insurance costs are high, which has all led to several conventions and norms regarding shipping. The Port State control mechanism regarding safety of ships, conditions for crews and health conditions is of great importance, including for the tourism industry (see, for example, Kullenberg, 2008). Historically, the role of ships in transferring health risks and epidemics may be recalled, not in the least in context of the large diversity and number of people on a cruise liner. High demands, costs and technological drive have led to a marginalization of shipping and the maritime sector in many developing countries. The same is the case for the artisanal fisheries which many such areas depend upon.

All of these technological developments led to an increase in fishing and transportation and greater exploitation of non-living marine resources. National interests also increased accordingly, resulting in extensions of national

jurisdictions. One consequence was an increase in waste material reaching the ocean both from land and discarded at sea. As a result of ocean circulation, much long-lived waste accumulated in ocean gyres. This process was first recorded in the 1970s and led to the establishment of marine debris research and monitoring cooperative programmes, including the Intergovernmental Oceanographic Commission's (IOC's) Programme of Global Investigation of Pollution in the Marine Environment (GIPME) (Andersen et al., 1977). The GIPME Programme developed very close cooperation with other bodies, notably the United Nations Environment Programme (UNEP), as well as the World Meteorological Organization (WMO), the Food and Agriculture Organization of the United Nations (FAO), the International Maritime Organization (IMO), the International Council for the Exploration of the Sea (ICES) and the Scientific Committee on Oceanic Research (SCOR). In addition to training and mutual assistance, GIPME undertook several baseline studies, intercalibration exercises, and the development, testing and introduction of sampling and measurement methods and studies on the biological and chemical effects of pollution. These different activities were pursued by separate groups of experts who reported to the working committee for GIPME, which in turn reported to the IOC Assembly. Open ocean baseline studies of trace contaminants were carried out in the Atlantic (Cutter et al., 1996). The GIPME programme also benefited from other marine pollution programmes of the IOC which focused on oil pollution. In 1971, the WMO and IOC agreed that their joint Integrated Global Ocean Station System (IGOSS) would provide a suitable platform and framework for the coordination of marine pollution monitoring with respect to physical and some chemical parameters. A pilot project on petroleum monitoring was specified, and the experiences provided the basis for the development of an integrated programme (Levy et al., 1981).

The growing need for more interdisciplinary work led gradually to increased cooperation among disciplines. However, while some problems have been solved, new ones have emerged. For example, concern about climate change is not recent but only became part of the global agenda in the 1970s, with the creation of the World Climate Programme and the associated World Climate Research Programme (WCRP). Initially, the ocean was treated as the bottom boundary layer for atmospheric conditions; however, ocean research has demonstrated the fundamental role played by the ocean in the climate system. This represented a major breakthrough in our understanding of the Earth's environmental systems. Associated problems such as sea level rise, ocean warming, loss of oxygen and acidification, coastal erosion and multistressor impacts are all now major issues.

The WCRP was created formally through the first World Climate Conference in 1979 by the WMO and the International Council for Science (ICSU), following a proposal for such an initiative by a conference in Stockholm in 1974. One component was the World Climate Research Programme, which included the Tropical Ocean-Global Atmosphere project and the World Ocean Circulation Experiment programme, both involving the IOC. However, the IOC became co-sponsor of the WCRP only in 1993, following the signature of an MoU by the WMO, ICSU and IOC of UNESCO, and evaluations by the IOC governing bodies in 1991 and 1992. The joint SCOR-IOC Committee on Climate Change and the Ocean was then transformed at the IOC Assembly in 1993, in agreement with SCOR, into a technical and scientific advisory body for the Global Ocean Observing System (GOOS).

The United Nations Conference on the Human Environment 1972, more commonly known as the 'Stockholm Conference', had a significant global impact on the development of cooperation in oceanography. At the conference, the seven Baltic Sea States decided to create an Interim Baltic Marine Protection Commission (Melvasalo, 2008a). The aim was to create a convention over the interim period of 1974–80 on the protection of the marine environment of the Baltic Sea area. This became the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area. The drafting required two years and the Convention was signed in 1974 and entered into force in 1980. The Convention covered the whole Baltic Sea, the entrances and the Kattegat. The objective was to protect the Baltic marine environment against all forms of pollution from land, sea and atmospheric sources. During subsequent decades, developments led to a revision of the Convention, and a new version was signed in 1992 and entered into force in 1999. The new Convention included more details on reporting, dealing with specific industries and protection against pollution caused by the transport of oil and chemicals. From 2004, the Convention included nine Baltic Sea countries and two partners who participated in the negotiations, the European Union and Russia.

The Helsinki Convention also enabled scientific advice to be obtained from various groups and organizations – with ICES playing a leading role and the work and results of the ICES/SCOR Working Group contributing to the whole process. Government interest in scientific advice and science-based solutions to problems related to the environment, food availability and security, and protection of human health has long been evident. Such interest has also played a vital role in stimulating oceanography, which as an expensive undertaking is dependent on government support, with trade and shipping as early beneficiaries. The need for internationally agreed norms and rules regarding

navigation, transport and safety at sea were soon recognized. This was in part due to dramatic events, such as the sinking of the *Titanic*, but also as a result of research related to hydrography, topographical mapping, marine pollution incidents and the transportation of hazardous goods.

The combined response of industry and governments was the Inter-Governmental Maritime Consultative Organization (IMCO), created as a UN specialized agency in 1948, which became the IMO in 1982. This led to a gradual understanding of the need for cooperation in training and education at a global level with a common, agreed curriculum. The result was the creation in the 1980s of the World Maritime University (WMU) in Malmö, under the auspices of the IMO and with the support of several national donor organizations, in particular the Swedish International Development Cooperation Agency (SIDA), the Danish International Development Agency (DANIDA), the Canadian International Development Agency (CIDA) and the Nippon Foundation of Japan. This university was the result of cooperation between several sectors, reflected in the interdisciplinary education and training it provided, which encompassed shipping and other marine industries. The WMU curriculum also includes relevant aspects on how the ocean functions and the importance of the ocean for society beyond shipping. Accordingly, UNESCO established a cooperative relationship with the WMU: the UNESCO Director-General was a member of the Board of Governors and during my period of service, the IOC provided the substance of a course on the elements of ocean physics, chemistry and biology.

The combining and pooling of human and infrastructure resources proved to be an important factor in stimulating and supporting the gradual development of regular cooperative observations, which also involved Ships of Opportunity – building on the Maury model – under the auspices of the IMO and the IOC. The whole process was also driven by the need to study and follow the development of conditions in the marine environment. The deterioration of coastal areas and shelf seas continued and even increased due to mounting pressures from large-scale coastal infrastructures, growing urbanization and use of the coastal zone for economic developments, including for the growing tourism industry.

The creation of UNEP in 1972 by the Stockholm Conference 1972 represented a major global cooperative effort to address these and other environmental problems. As part of this effort, in 1974–75 UNEP initiated the Regional Seas Programme (e.g. Melvasalo, 2008b). The programme initially addressed regional marine pollution problems on the basis of scientific evaluations and science-based cooperation. Plans of action were agreed by the scientific community and governments, and covered fairly well-defined regional seas

(i.e. the Mediterranean, parts of the West and East African coastal areas, the Caribbean, the Asian seas in the Indian and Pacific Oceans, and coastal seas of South America). In some respects, the process followed a path similar to that of the ICES/SCOR Working Group regarding the study of pollution in the Baltic, with the addition of regional conventions and intergovernmental commitments.

Those involved in organizing the programme at UNEP soon realized that government support was crucial to regional cooperation. Programme activities reliant on such cooperation included: observations at sea; regular monitoring; data and information exchange on production, sources and inputs of waste material, as well as contaminants and harmful substances – including nutrients from fertilizing; and an open exchange of data. In order to ensure reliable, quality-controlled information and documentation, those activities included agreement on methods for collection and observations, substances to be included and quality control of data. This required intercomparisons of methods and intercalibration of measurements. These exercises helped to identify needs for training and the sharing of experiences, as well as the provision and instalment of standardized and new equipment. Such training and mutual assistance activities soon became essential parts of the whole cooperative programme. The IOC-UNESCO programme on Training, Education and Mutual Assistance (TEMA) also formed part of this cooperative effort. The process governed by the UNEP Regional Seas Programme over time stimulated education and scientific development. The importance of the programme is reflected in its global coverage, which encompasses at least 12 regions, and is widely acknowledged as a leading example of scientific and intergovernmental cooperation (see, for instance, Melvasalo, 2008b).

It is useful to mention briefly the role of language in building regional and international cooperation. Linguistic differences can in many cases seriously impede collaboration. Misunderstandings can lead to incorrect actions, faulty data and poor treatment of equipment. While intergovernmental negotiations and meetings benefited from interpretation, this service was not normally available for purely scientific meetings. In the case of the Baltic, English was used and supplemented by German and French, as well as Russian, on a case-by-case basis. The Nordic countries also benefited from the similarity in their languages and culture, as discussed in Chapter 18.

Building regional cooperation in the Caribbean

The IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions, held in the Port of Spain, Trinidad and Tobago

(13–17 December 1976) (IOC-UNESCO, 1976), provides a good example of regional cooperation building in an area, including both developed and developing countries. The workshop formed part of a regional effort to combat pollution of the marine environment through regional cooperation and also formed part of the Regional Seas Programme of UNEP, which addressed regional environmental problems as a dimension of socio-economic development. The main objectives of the workshop were to identify major marine pollution problems in the region and to recommend a set of priority actions that would enhance understanding of the main issues.

Environmental problems in the region were approached in an integrated manner through regional action plans. These could cover a series of subjects, including protection of marine environmental health; human settlements; industrial, technological and natural resources developments; and natural disasters. Once priorities were identified, they were addressed through an action plan, in this case to be developed in cooperation with the Economic Commission for Latin America, with the expectation that relevant parts of the UN system would provide full assistance for development and implementation. The action plan would also be developed in close consultation with the governments of the region and then presented for discussion, modification and approval to a Caribbean intergovernmental conference to be convened at the highest possible political and technical levels at the end of 1978.

The actions to be carried out on the basis of the recommendations of this workshop would be undertaken by experts and institutions from the region. This required a substantial training programme to strengthen the capabilities of national institutions. This first step could be implemented with the support and assistance of relevant specialized bodies of the UN system. Accordingly, governments of the region would then consider their needs in light of the outputs of the workshop.

In order to obtain an overview of the oceanographic and marine environmental conditions in the region, a series of special lectures and papers related to marine pollution in the Caribbean were presented at the workshop. My contribution gave an overview of pollutant transfer and transport in the sea. Examples of major physical factors influencing the transfer and concentration of substances included the stratification of waters and coastal upwelling. The exchange between the Caribbean and the open central Atlantic was also a major factor in the whole process. The presentations led to the identification of a number of marine pollution-related problems, including oil pollution, human health aspects of marine pollution, coastal processes related to the transfer and mixing of contaminants, and the effects of marine pollution on living resources. The

presentations also offered proposals for research and monitoring with an emphasis on TEMA and data handling.

The entire process provided a good example of cooperation across research, observations and integrated evaluations, with potential for further studies and possible actions in relation to marine environmental conditions – in a region characterized by very different levels of development of marine awareness and capabilities in marine research, ocean observations, data handling and analyses. The process may be compared with the initiation of regional cooperation in ocean research in the European Mediterranean and the regional seas of the North Atlantic almost 100 years earlier. In the latter case, the socio-economic aspects of fisheries and related management were the initial subject of focus, and the need for regional cooperation and integrated evaluations was gradually realized and undertaken after decades of dialogue. In the Caribbean, other social problems were the subject of focus, including coastal zone poverty and health problems from seafood, algal blooms (e.g. ciguatera).

The IOC created its Sub-Commission for the Caribbean and Adjacent Regions on the basis of interest expressed by Member States and the results from the regional programme Cooperative Investigations in the Caribbean (CICAR), which operated over the period 1968–75 and resulted in the creation of the IOC Association for the Caribbean and Adjacent Regions in 1975, also known as the IOCARIBE Association 1975–92, followed by the subcommission in 1982 (Garcia Montero, 2010). At its meeting in 1976, the association established the regional marine pollution and monitoring programme which became part of the follow-up to the workshop of UNEP, the IOC and the FAO. The results of the programme were presented at the CARIPOL Symposium in Puerto Rico (2–6 December 1985) (Caribbean Journal of Science, 1987).

BOX 6. Marine pollution and international cooperation

The ocean receives much waste material produced by society through rivers, other land-based runoff, and atmosphere by direct exchange, precipitation and particulate matter fallout, in addition to direct disposal operations. The ocean is the ultimate recipient of such wastes, partly due to the various cycles of elements and exchanges between the different compartments of the environment.

Marine pollution due to increasing use of dumping at sea had become an environmental problem. The released material often contained hazardous substances with potentially harmful effects on marine life and other influences in coastal and near-shore areas. The need for more regulatory actions at the international, intergovernmental level became clear. This resulted in the Dumping Convention of 1971, later renamed the London Convention, under the administrative direction and guidance of the IMO.

My work and my paper at the 1972 Aarhus Symposium (see Chapter 14) attracted the interest of scientists involved in the UN Joint Group of Experts on Scientific Aspects of Marine Pollution (GESAMP), later renamed the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. They were interested in the possibilities my experiments proposed, especially in relation to the release of wastes at sea. I became a member of GESAMP in 1973, sponsored by UNESCO, and agreed to lead a working group charged with analysing the state of knowledge with respect to the selection of dumping sites at sea.

GESAMP needed to produce an overview of physical processes responsible for the spreading of contaminants, including estimates of rates of dispersion depending upon environmental conditions, which could be obtained through the dye tracer studies presented in Box 4. The need for data related to the selection of dumping sites, following the London Convention. This new responsibility as head of the working group represented a challenge, as well as an opportunity to become involved in a new area of international cooperation related to disciplines other than physics.

The FAO was appointed the lead agency of the working group with financial support provided mostly by UNEP. Among the experts was Dr Bostwick Ketchum from the Woods Hole Oceanographic Institution

(WHOI), where I had undertaken a course in advanced geophysical fluid dynamics the summer following my expedition in the Gulf of California. Dr Ketchum was a renowned scientist, willing to share his knowledge and experience, who contributed greatly to the work. Following meetings and correspondence, the working group prepared a progress report which generated feedback from GESAMP, and a final draft report.[53] My work on the issue and the cooperation of the other working group members, and GESAMP as a whole, including the representatives of the sponsoring UN agencies, taught me a great deal. The entire process demonstrated the potential of international scientific cooperation to address problems of socio-economic significance.[54]

Furthermore, the results of the GESAMP Working Group shed light on the importance of physical conditions for the dilution of released material, and the potential chemical and biological effects of various released substances. The use of dumping as a waste disposal option was gradually stopped.

I continued to cooperate with the ocean research community on problems of ocean pollution, waste disposal, and processes influencing the distribution and effects of contaminants, editing an overview of physical, chemical and biological transfer processes influencing the distribution of pollutants in the ocean.[55] These volumes included contributions from several scientists with whom I had worked in the context of interdisciplinary studies. The results of related research of socio-economic importance were published in a series on wastes in the ocean.[56] This process demonstrates how the ocean research community understood the need to address practical questions of great socio-economic importance and provide a scientific basis for management and regulatory intervention by governments. Much of the research was in fact supported by governments with the specific aim of obtaining scientific advice.

My own involvement as an academic university scientist in cooperative, interdisciplinary research and assessment efforts with respect to

53 See GESAMP (1975).

54 See Kullenberg (1975) for an overview of ocean dumping sites.

55 Kullenberg (1982).

56 The first three volumes in the series were *Industrial and Sewage Wastes in the Ocean* (Duedall *et al.*, 1983); *Dredged-Material Disposal in the Ocean* (Kester et al., 1983); and *Radioactive Wastes in the Ocean* (Park *et al.,* 1983). They were followed by three more volumes: *Energy Wastes* (Duedall et al., 1985); *Deep-Sea Waste Disposal* (Kester et al., 1985); and *Near-Shore Waste Disposal* (Ketchum et al., 1985).

related natural and human-driven processes, and their consequences, concluded with the organization of a meeting on a scientific basis for the role of the ocean as a waste disposal option in April 1985. The meeting was sponsored by the NATO Science Committee, Marine Science Panel.

The aim of the meeting was to define a scientific basis for the selection of options using a series of case studies covering different regions and waste categories. Evidence of widespread damage to the sea was referred to in the form of changes in phytoplankton populations, reduction of primary production and increase in the prevalence of fish diseases. The meeting examined concerns regarding the disposal of drilling mud, petroleum hydrocarbons, heavy metals, radioactive waste and potential future problems such as the disposal of toxaphene and chlorinated hydrocarbons. It also addressed engineering aspects, and analysed case studies from the Mediterranean, the US coast, the North and Baltic seas, giving examples where waste disposal led to the receiving capacity of the locality being exceeded in relation to oxygen content and changes in species composition. Finally, the meeting evaluated containment options in relation to differences between land and sea disposal (Kullenberg, 1986).

18 Nordic cooperation in oceanography: The significance of common culture and language

Scientific cooperation within regions can benefit from similarities in culture and language. One such example is the long-lasting cooperation between the Nordic countries – Denmark, Finland, the Faroe Islands, Iceland, Norway and Sweden, as well as Greenland and Åland. The intergovernmental mechanism which underpinned this regional cooperation was the Nordic Council of Ministers, established in 1971 under the Helsinki Treaty, which agreed to support marine science groups in the fields of marine biology and physical oceanography, who had initiated cooperation in the early 1960s.

Apart from my early expeditions on the *Helland Hansen*, my experience with Nordic cooperation began in 1965 with the Nordic Council for Physical Oceanography (NCPO). The aims were to pool resources and elicit support in the form of seed money for cooperative physical oceanography projects and training, involving related university institutions in the Nordic countries. The NCPO developed cooperative research projects, Nordic training courses, and organized symposia and exchanges of scientists and graduate students among university institutions. In some cases, the activities also involved participants from countries outside the Nordic region.

The NCPO proved to be a highly effective cooperative mechanism with only limited administrative constraints. The exchange of experiences, knowledge and ideas proved to be an important motivation for the mixed community of scientists, which ranged from senior professors to graduate students and even younger. The NCPO also made possible the pooling of human, infrastructure and financial resources, including research vessels, which allowed for the creation of joint research projects and the possibility to secure additional financial resources underwritten by several institutions. Further stimulation was provided by joint publications, seminars, exchanges of training, research experiences and ideas, and the possibility to attract leading foreign scientists.

Among the numerous projects made possible through the NCPO were studies in the Baltic and Transition Area, including the Danish Sounds, Kattegat and Skagerrak, the North Sea, coastal currents along the western coast of Denmark, the Jutland Current, the Norwegian Current, Norwegian fjords, and the water exchange in the North Atlantic between Iceland and the Faroe Islands. The expeditions concerned mainly physical oceanography but also explored the interactions between physical, chemical and biological processes. Examples of biological experiments coupled with physical studies included fish migration through tagging experiments, plankton distribution and patchiness with studies of microstructures, and mixing experiments using injected dye tracers.

An important aspect of these projects was the testing of new equipment and the development of new measurement technologies. One particular experiment was designed to study the mixing, current structure and ocean-atmosphere interaction by means of sustained measurements through instruments installed on a bottom-anchored tower in the middle of the Kattegat. This study involved oceanographers and meteorologists from Denmark, Norway and Sweden, and took place over several years. The field operations were mainly carried out from the Norwegian research vessel *Helland Hansen* of the University of Bergen. The vessel also constituted a platform for a joint international expedition to the Mediterranean in 1971. The aims of this included studies in the Strait of Gibraltar on the physical conditions, optical conditions and properties of the water in the Western Mediterranean, and turbulent mixing in the upper layer to about 50 m. This expedition also included research institutions and financial support from outside the Nordic countries.[57]

Symposia were regularly organized, frequently with participants from outside the region, and often on the basis of joint research projects or specializations of participating university institutions. The NCPO also provided a limited number of stipends for graduate students to study at other participating institutions for extended periods ranging from about six months to three years. This mechanism proved to be fruitful and rewarding for both the institutions and the recipients of the stipend.

The Nordic Council of Ministers also supported the convening of several interdisciplinary ocean seminars at the Nordic House in the Faroe Islands. These were attended by scientists, authors and artists from the Nordic countries, as well as other nations including the United Kingdom and the United States. They were open to the public and involved numerous disciplines other than ocean

57 Several outcomes of Nordic cooperation – many of which resulted from expeditions on the research vessel *Helland Hansen* – are presented in the volume *Nordic Perspectives on Oceanography* (Lundberg, 1990), prepared in honour of Börje Kullenberg, and presented on 11 May 1986 on the occasion of his 80th birthday.

science, including music, literature and art. Accordingly, the seminars provoked interdisciplinary exchanges between sectors that rarely reached out to one other. One aim was to stimulate public understanding of the role of science, culture and the humanities, and to support the dissemination of scientific findings to the public, for instance with respect to fisheries, food security and pollution, and changes in the environment related to ocean circulation and the climate.

One lesson from Nordic cooperation confirmed the important role of visionary scientific leaders able to work together and across the science-policy interface for a common cause. Such cooperation led by ocean research leaders at universities in Bergen, Oslo, Copenhagen, Gothenburg and Helsinki in the 1960s, among other things, resulted in the creation of the NCPO. Cooperation between the Scandinavian countries is of long standing and predates the existence of the NCPO, as noted earlier in the context of the creation of the International Council for the Exploration of the Sea (ICES).

Nordic cooperation and good economic conditions resulted in support for marine research for about two decades after the 1960s (Report of Executive Committee of Nordic Council, 1984 (unpublished)). This increased support benefited mostly sector organizations, rather than basic research. However, support for basic research and associated graduate studies remained essential to provide for and achieve high levels of quality.

Similar languages, cultures and social structures create good conditions for Nordic cooperation in marine science. In addition, such cooperation is motivated by the pooling of resources and efforts through several stakeholder groups working together. Additionally, such cooperation can help achieve much broader coverage of scientific disciplines and stimulate interdisciplinary research. Moreover, the exchange of specialists and the ensuing cooperative endeavours broadened the recruitment of scientists and graduate students, and promoted in-depth science education. Cooperation on a regional Nordic basis also facilitated participation in larger international programmes and exchanges with scientists from leading oceanographic institutions. The entire process proved to be of great importance for academic, curiosity-driven basic ocean research in the Nordic countries, and it is worth emphasizing that the NCPO was driven by the scientists themselves.

Nordic cooperation was particularly well demonstrated during the International Decade of Ocean Exploration (IDOE). Joint international projects received support for planning through workshops, symposia and training exercises. Limited financial support from the NCPO could be provided to facilitate participation in an international expedition or data analyses. Nordic-wide

projects were supported by the NCPO up to 10–50% of the total costs. The NCPO regarded such support to research projects (which also involved training) as of high importance. It was understood that ocean research needed to become more multi- and interdisciplinary and that cooperation was essential to these efforts and to support this need. It was also noted by the NCPO, however, that major infrastructure resources, such as research vessels, were mostly managed by sector organizations, such as those responsible for the management of fisheries, the marine environment, energy production and non-living marine resources, and not generally by universities – one notable exception being the *Helland Hansen*. During the 1970s, the number of institutions in the environmental sector increased strongly, notably through the UNEP Regional Seas Programme, initiated in the mid-70s, in addition to the creation of national environmental ministries or departments with associated laboratory capacities. Joint interdisciplinary projects addressing environmental problems were established and received considerable support. Examples include the work and projects of the ICES/SCOR Working Group on pollution in the Baltic and cases linked to the North Sea and the Mediterranean.

Nordic cooperation in the context of the IDOE also opened up the possibility of participation in and influence over large-scale open ocean research. Together, the Nordic oceanography institutions covered a wide range of research areas; however, the small size of the individual units tended to encourage specialization. Socio-economic motivations for regional Nordic cooperation included the following:

- Small national groups could achieve much broader coverage in terms of substance, space and timescales by working together on larger interdisciplinary projects, as well as on joint education and training activities.
- Cooperation allowed for more complete educational coverage and pooling of infrastructure and resources, making possible training on a wide range of equipment.
- Special training courses became more cost-effective.
- More effective use could be made of costly infrastructure, including instruments and research vessels.
- The common language makes communication between the groups and individuals quite easy.
- A formalized cooperative organization with governmental endorsement can function over an extended period of time – up to several decades – which facilitates long-term planning.[58]

58 Report on future Nordic marine research cooperation to the Nordic Council, April 1984 (unpublished).

Nordic cooperation also stimulated moderately ambitious activities outside Scandinavian waters. In 1966, Danish institutions launched a six-month expedition to the Sargasso Sea with the primary aim of continuing the search for eel and studying the optical conditions of the water, and repeating a hydrographic section north from the Azores to the North Sea and Skagerrak (see also Box 3). Another international project with strong Nordic participation was the SCOR Working Group on Primary Production, for which our institute under the leadership of Prof. N. Jerlov developed a quanta meter, which was used in conjunction with other optical equipment during an expedition in early 1968 on the research vessel *E. B. Scripps*, sailing from San Diego to Baja California (see Box 3). The Nordic cooperation benefited from many similarities, both in the research community and between the countries, whereas other regional cooperative efforts were motivated by regional socio-economic and environmental issues, and faced many differences between the participating countries.

BOX 7. Expeditions in the Arctic Basin 1981 and 1984

Almost two decades after my experiences in the Denmark Strait on the *Helland Hansen*, I got the opportunity in the summer of 1981 to venture further north again into the Arctic Basin on an expedition with the research vessel *Lance* of the Norwegian Polar Institute. The expedition was the initiative of several research institutions in Scandinavia and their partners in the United States through the Fram Strait Programme of the IDOE.

Our research engineer, Henning Hundahl, and I travelled from Copenhagen to Longyearbyen on Svalbard via Bodø in Norway, arriving the night of 28 July, and embarked on the ship directly. Our equipment had been shipped in advance to Norway, and during the following day we checked it all – our faithful winch with the wire cable, optical instruments for light scattering profiling and scattering curves, ocean surface colour and light quanta in the euphotic zone, and the *in situ* chlorophyll fluorescence meter for use mainly in the surface layer. We also spoke with the ship's electrician as the power connection for the winch needed be adapted. We sailed from Longyearbyen in the evening of the same day at 21.00 GMT, heading out to the open sea through Isfjorden, the second longest fjord in Svalbard archipelago. Our first operation was a planned CTD section run across the Fram Strait from Svalbard to Greenland along a latitude of 78°08' N. We were now well north of the northern Polar Circle.

The aim of our optical programme was to study the distribution of suspended matter by means of the light scattering technique, including scattering functions, from shallow to deep water across the shelf. We would also make observations of daylight penetration in different water masses combined with surface colour measurements, in order to provide a water quality index. Lastly, we planned to study the surface layer distribution of chlorophyll a fluorescence, combined with CTD profiles, as far as time permitted.

The light scattering was measured in the red wavelength of 660 nm, which produced a good measure of scattering from particulate matter suspended in the water column, at a fixed forward angle of 20° going down. The scattering function was then measured at angles from 10° to 160° on the way up, with the instrument stopped at the selected depth. Daylight penetration was measured with the quanta meter integrating irradiance over the spectral range of 400–700 nm. The colour index was

obtained by measuring upwelling irradiance in two wavelengths around 450 nm (blue) and 520 nm (green), with the index defined as the ratio of blue over green. This can be related to the chlorophyll a content in the surface layer and to satellite measurements in a similar spectral range, as with the coastal zone colour scanner. The light scattering meter was connected to the winch by a 7 conductor 1,000 m-long wire cable. The observations were made in conjunction with CTD casts, making it possible to relate the scattering profile to the vertical structure and stratification of the water column. The colour and quanta measurements were carried out only in good weather conditions with clear sun, during the CTD casts in order to save time. In all, 63 scattering profiles were obtained, together with 40 fluorescence, 36 colour and 10 quanta meter stations. These indicated a euphotic zone depth of 40–60 m. The fluorescence profiles showed marked peaks of some metres in thickness at the surface layer at about 20–40 m depth, with single or double peaks. This generally compared well with the scattering profiles which showed maximum scattering at the same depths as the maximum fluorescence. The water at intermediate depths well below the surface layer exhibited very weak scattering, showing low content of suspended matter. The variations in scattering could be related to different water masses and frontal zones, as were identified from the hydrographic CTD measurements.

At most of the stations, a bottom boundary layer with relatively high scattering was found showing more suspended matter, possibly generated by boundary layer currents, in view of the very clear water above. At the stations east of the Nansen Ridge, the bottom layer was very marked. In the fjords around Svalbard, the scattering and particle content was generally larger in the surface and bottom boundary layers than in the open sea. However, intermediate layers of very low scattering were also observed in the inshore waters, indicating circulation with water exchange in several layers and penetration of open sea water towards the coast. Such structures were found in most of the sections, implying active circulation and water exchange. At the northernmost stations we were close to or even inside drifting ice around latitude 80°30' N, where we observed very thin bottom boundary layers through the echo sounder of the ship. However, we did not lower the scattering meter too close to the bottom due to the risk of damage.[59]

59 Some results of our studies are presented in Kullenberg (1984a and 1984b).

The expedition terminated in Longyearbyen on 13–14 August 1981, and our equipment was packed ready to be shipped to the new research vessel *Håkon Mosby* in Bergen. We thanked the ship and crew and the other scientific party and returned as we had come via Bodø to Copenhagen.

Dye tracing in the ice

The experiences and results from the Svalbard-Fram Strait-Arctic Basin expedition in 1981 were good and invited further study, especially of the ice edge. At the time, this field was pursued through the international cooperative project Multidisciplinary Expeditions to Enhance the Understanding of northern ecosystems (MISEX), which included physical, chemical, biological, cryosphere (ice) and geological disciplines. In 1984, I received an invitation to participate in a multidisciplinary expedition during the summer season again on the *Lance*. The objective was similar to the first expedition with one important and challenging addition: to try to examine small-scale mixing at the ice edge by means of dye-tracing. The plan was to use my rhodamine B dye-tracing technique. This would involve dye injections at a suitable depth using a drifting buoy attached to a parachute opened at the depth of the dye injection, as a reference point for navigation. The tracing would be performed by a fluorometer towed by the ship and operated in an oscillating mode across the expected depth of the dye. The positions were plotted relative to the drifting buoy which also was equipped with a radar reflector. This technique was the same as the one we used on the *Limnos* in Lake Ontario in 1972 and the *Friedrich Heincke* for the North Sea-Fladen Ground Experiment in 1976 (see Boxes 4 and 5).

The expedition included participants from Denmark, Norway, Sweden and the United Kingdom. This international effort also included cooperation with the international research station on Svalbard, where scientists from Poland and the Soviet Union were based. The scientific crew joined the ship in the afternoon of 18 July 1984 in Longyearbyen, Svalbard or Spitsbergen. The equipment was installed and checked in rather full laboratories. I would lead the dye experiments from the navigation bridge, which would necessitate close communication with the bridge crew and winch operator.

The dye tracer equipment included an *in situ* fluorometer, the dye itself and barrels in which the dye solution was prepared. These came with a

high pressure air tube for the injection process. The density of the dye solution had to be adjusted to match the observed density of the layer where the injection would be made. The densities were measured with aerometers using water samples from the required depths. The density of the dye was then adjusted by adding salt water. The injection was performed through a hose connected to the barrels with a 2 m-long sealed tube with holes at the lower end. The dye solution was thus injected in a layer about 2 m thick. This resulted in horizontal spreading due to the current shear normally present in the stratified water column, which facilitated the process of finding the dye cloud.

The *in situ* fluorometer was lowered directly after the dye injection. The fluorometer attached to the winch wire was operated by running the winch in oscillating mode across the expected depth of the dye cloud. The position relative to the drifter, which was attached to the parachute drogue and released before the injection of the dye, was determined every other minute by optical means (e.g. binoculars), bearing and radar, when conditions permitted. The operation required good communication between the watch officer on the bridge and the scientist directing the experiment who plotted the position relative to the buoy and followed the signal from the fluorometer. When a dye signal was indicated, the position relative to the buoy was taken by optical means or radar, and plotted. The watch keepers also had to survey the instrument cable and adjust course and speed to avoid entanglement with the ship or any other object such as drifting ice. This was a very tricky process, especially close to the ice edge and drifting ice flakes. In all, we managed to conduct three dye experiments with a duration of the tracing of 26–28 hours in the pycnocline layer, the transition from the surface to the intermediate water, at around 25–35 m below the surface. The dye cloud drifted at 300–500 m per hour or 10–15 cm/s. We also made an injection at 11–13 m depth which was traced for 12 hours, showing a considerably larger rate of mixing than in the deeper layer. The final experiment consisted of an injection at the surface. This could only be followed and observed for a few hours due to strong mixing at the ice edge in the drifting ice. The other dye experiments were carried out 3–5 nautical miles from the ice edge.

The purely optical measurements were made when the weather conditions were good, with clear sky and known sun height for the colour and quanta measurements. The scattering meter observations showed a similar pattern as those observed during our previous

expedition on the *Lance* in 1981. In many cases, there were several layers, with surface and bottom boundary layers with high scattering separated by an intermediate water mass with much less scattering. Tongues of high scattering water in the surface layer originating from outflows from fjords and glaciers were visible. Unfortunately the winch for the scattering meter malfunctioned at mid-cruise and could not be repaired on board.

After the surface layer dye experiment we visited Kvitøya – the White Island – arriving on the northern side in the evening of 6 August. The island was low-lying with a glacier reaching down to the sea. The beach was covered with stones and rough gravel. There, we found the last camp of the Andre expedition of 1897, with a memory plate engraved with the names Andre, Strindberg and Fraenkels, a simple monument to this ill-fated balloon flight. A pole had been added with the names *Vega* and *Ymer*-80, in memory of the Swedish Arctic expedition of 1980 on the ice breaker *Ymer*, which took place about 100 years after the *Vega* expedition through the north-east passage (e.g. Kish, 1973).

After stretching our legs on the beach, we returned to the ship which left late in the evening of 6 August. The day had been a memorable one, but soon took an unexpected turn. After a short distance, we struck ground, and became stuck for two to three days until the water level rose, allowing us to depart. Fortunately the weather was good and the ship was not seriously damaged. The expedition continued, stopping at a number of stations on the return route to Svalbard and Longyearbyen, where we arrived on the morning of 14 August. We packed our equipment and I said my goodbyes, thanking my scientific colleagues and the crew. This had been a remarkable expedition, and turned out to be one of my last before I joined UNESCO in May 1985. The *Lance* had taken us north where we had worked from 76° N, 24° E, to 81° N, 28° E and we had been in the ice. I expressed my great appreciation to the Captain and thanked him, the officers and crew for a highly professional, friendly and willing assistance.

19 Other mechanisms for regional cooperation: Partnerships and large marine ecosystems (LMEs)

This chapter highlights two different approaches to establishing and supporting sustained cooperation in marine environment protection and management, with related research and observations. PEMSEA, the Regional Programme on Building Partnerships in Environmental Management of the Seas of East Asia, is a Global Environment Facility (GEF)-funded project that began in 1993, implemented by the United Nations Development Programme (UNDP) and executed by the International Maritime Organization (IMO) (Chua et al., 2008). The partnership model builds on cooperation between two or more partners to collectively undertake one or several activities while not being bound by legal agreements to achieve the common goal. Major goals achieved by the project in the first period until 2007 included the formulation and adoption of integrated approaches, the development of human resources, demonstrations of the applicability and effectiveness of the integrated coastal management approach, and development and adoption of a sustainable regional mechanism to protect and manage the coastal and marine environment. The partnership model is different from the approach adopted by the UNEP Regional Seas Programme, which builds on intergovernmental conventions and related legal agreements.

The Large Marine Environment (LME) programme, on the other hand, was developed in the early 1970s through the support of the US National Oceanic and Atmospheric Administration (NOAA) (e.g. Sherman et al., 2009; Sherman and Alexander, 1986). The objectives include identifying areas of the world ocean for conservation purposes and application of the concept of ecosystem-based management through a cooperative approach, within transnational areas defined on the basis of their ecosystem properties, and working in conformity with customary international law as reflected in the United Nations Convention on the Law of the Sea (UNCLOS). The 66 LMEs so far cover 80% of global marine fisheries biomass and contribute US$12.6 trillion annually to the global economy in terms of goods and services (Costanza et al., 1997). The programme has grown to become a global, international effort involving many international regional

and global organizations, including the Intergovernmental Oceanographic Commission (IOC), and is supported financially by the GEF.

PEMSEA is a regional programme, to promote improved coastal management and regional collaboration among participating countries, as part of a shared vision for the seas of East Asia. This objective was achieved within its first decade and formalized in the Putrajaya Declaration, signed by 12 member nations in 2003 at the East Asian Seas Congress. During the subsequent decade, this effort gradually led to the establishment of a regional organization – a partnership in the form of an agreed regionally driven programme based on the collective efforts and contributions of all interests, but without a legal, binding convention. Research was identified as an integral part of the programme but does not drive the agenda.

PEMSEA constituted a transboundary, multipurpose initiative – culturally, geographically and in terms of focus. It paid close attention to the economy and economic development. The PEMSEA vision reflected the ethos of UNCLOS, that 'the problems of ocean space are closely interrelated and should be considered as a whole', and that the ocean should be used strictly for peaceful purposes, for the benefit of humanity as a whole. At the same time, PEMSEA recognized linkages with the land and land uses in the context of environmental and integrated management and sustainable development. The PEMSEA vision interprets the definition of ocean governance in practical terms. Its success was manifested in the development and acceptance by Member States of the Strategy for Sustainable Development of the Seas of East Asia (SDS-SEA) (PEMSEA, 2003).

Participating countries also agreed to support the programme's continuation through a separate, evolving mechanism. This approach underlined the need for cooperation, not only across scientific disciplines and national borders but also with other sectors of society, in order to gather more proxy data and transmit the results of this research to the public, other users and the science-policy interface. In particular, this process has underlined the importance of regular dialogue and consultations with the governments. PEMSEA was initially supported by the UNDP and the GEF, and I had the honour to participate in its evaluation in 2006 (PEMSEA, 2006).[60]

The LME approach is another mechanism used to stimulate broad cooperation, which has made much progress and gained strong support since its inception

60 The PEMSEA vision is discussed further in PEMSEA (2013). The publication brings out the broad cooperation between all sectors that the partnership model has generated.

in the 1970s. LMEs are regions of the ocean measuring 200,000 km^2 or more, ranging from coastal zones, river basins and estuaries to the outer regions of the continental shelf or the seaward extent of a predominant coastal current (Sherman et al., 2009). The LME approach is a pragmatic, evolving concept for ecosystem-based management that consists of five dimensions: productivity, fish and fisheries, pollution and ecosystem health, socio-economics and governance. This interdisciplinary approach underlines the need for cooperation across sectors. An LME is defined based on related ecological criteria (e.g. bathymetry, hydrography, productivity and trophically linked populations). Case studies employing the LME approach evaluate the effects of perturbations on biomass yields, examine biodynamic processes and elucidate underlying patterns and processes (see, for example, Sherman et al., 1990). As of 2015, there are currently 66 designated LMEs globally.

Various LME projects have the support of several international organizations, including the GEF, the International Union for Conservation of Nature (IUCN), UNEP, the United Nations Industrial Development Organization (UNIDO), the Food and Agriculture Organization of the United Nations (FAO) and IOC-UNESCO. The whole LME programme has strong support from US-NOAA and other leading national institutions, reflecting the involvement of many sectors. Global applications of the LME concept have been reviewed by Sherman et al. (2007). The authors present the level of funding (US$3 billion by 2010) which provides the participating countries of the regions where the LME is active with the means to help implement the regional LME programme. This implies that coastal communities can benefit from the LME projects, the lessons learned and overall results. The LME programme has obtained substantial support over time due to its persistence and close association with leading national institutions, as well as the delivered results. The projects are endorsed by several governmental departments, including ministries of the environment, fisheries, energy, tourism and finance in participating countries.

One important LME project that concluded recently was the Yellow Sea LME project, in which I participated as part of the evaluation. The project generated a great deal of information about conditions, including seasonal and interannual variability, and gave rise to improved management. At the same time, the project illustrated regional conditions, which sometimes made cooperation across the whole region difficult to achieve.[61] Many comparative experiences have also emerged from efforts since around 1970 in the Baltic Sea, which has also been

61 A summary of the results regarding environmental and living resources conditions from the project is given in Kullenberg and Huber (2011).

studied as an LME. The IOC has also cooperated with the LME programme through the GEF's Transboundary Waters Assessment Programme, now renamed 'International Waters' (IW), which aims to provide a global baseline assessment of status and changes, as well as institutional arrangements for future assessments of transboundary water systems.[62] The IOC coordinates the GEF's International Waters Learning Exchange and Resource Network (IW:LEARN).

Based on experiences so far, one of the global leaders in LME research, Prof. G. Hempel (see Sherman et al., 2009), has identified the need to increase the interaction between pragmatic LME science and basic marine science, as currently conducted in universities. This would help to promote a new generation of marine ecosystem experts in areas of basic science such as taxonomy, as well as in sociology, economics and international law. The approach, which is similar to that of the International Ocean Institute (IOI) (see Chapters 13 and 20), could also improve the application of science to management, and help identify linkages that would benefit from greater attention in development and cooperation. Adopting this perspective would also lead to a more interdisciplinary oriented education system, which in turn would gradually increase horizontal communication between different sectors and promote related structural adjustments. Accordingly, the LME projects could be seen as joint enterprises that take into account the concerns and outlooks of participating countries and sectors. Their common interests could lead to the creation of cooperative coalitions involving several LMEs from different parts of the ocean, working together to achieve common goals including sustainable development and human security. This idea may be particularly relevant to the conditions and divisions characterizing the largest part of the ocean – the Pacific.

62 IOC-UNESCO (2013).

20 Ocean governance and UNCLOS: The case of the South Pacific and Small Island Developing States

The role of UNCLOS

The United Nations Convention on the Law of the Sea (UNCLOS) provides a formal foundation for achieving good ocean governance in the form of an agreed legal framework for the ocean and seas that *inter alia* promotes the peaceful uses and equitable and efficient utilization of marine resources, as well as the protection and preservation of the marine environment. UNCLOS has been supplemented by the normative rule of law in the form of Agenda 21, agreed at the 1992 Earth Summit in Rio de Janeiro, as well as several other agreements, in particular on fisheries. Chapter 17 of Agenda 21 extends the concepts established in UNCLOS to the shelf seas and coastal zones, and endorses integrated coastal area management (ICAM). Combined, these agreements constitute a code of conduct for ocean development and uses, including the coastal zone, thus providing a basis for ocean governance. Large areas of the ocean remain essentially unexplored and are not under any national jurisdiction, but are still being subject to exploitation, use and abuse. These areas are in particular need of ocean governance, and many are located in the Pacific Ocean.

Ocean governance can be interpreted as 'the means by which ocean affairs are governed by governments, local communities, industries, NGOs and other stakeholders, through national and international laws, public and private laws, policies, customs, traditions and related institutions and processes' (Mann Borgese, 1995). The report *Our Common Future* of the World Commission on Environment and Development (1987) characterized ocean governance as comprehensive, consistent, transsectoral, multidisciplinary and participatory (de Marffy, 2004). It also stated 'that sustainable development, if not survival itself, depends on significant advances in the management of the oceans' (Falk and Elver, 1999).

Three imperatives were defined for ocean management in the report of the World Commission: the need for effective global management regimes, the

importance of regional management to address shared resources, and the urgency of international cooperation to support effective national actions that respond to major land-based threats to the ocean (Falk and Elver, 1999). These are largely reflected in the Executive Messages herein. The need to strengthen ocean governance and management is linked to population increase, with rising demand for living and non-living resources from the ocean, seas and coastal areas, and a corresponding increase in pressure on marine environments related to multiple types of uses and abuses. The requirements for advancing ocean governance and management are well demonstrated through cooperative research and evaluations, and are reflected in the agreements. They are also evident in the activities of many organizations and donor agencies, including through education and training with technical assistance.

Several of these requirements were addressed by the International Ocean Institute (IOI), including through a series of intensive courses on ocean governance which lasted from a few days to several months. Topics covered in the programmes included ocean law and UNCLOS, marine affairs, sea-bed mining, the management of exclusive economic zones (EEZs), oceanography and the role of other organizations. The overall aim was to assist developing countries in implementing the Law of the Sea (Kullenberg et al., 2012). Several UN organizations, such as the International Seabed Authority (ISA), IMO, the Food and Agriculture Organization of the United Nations (FAO) and the Intergovernmental Oceanographic Commission (IOC) cooperated in the training programmes, including in partnership with IOI operational centres (hosted at universities). The professionals delivering the training programmes covered a wide array of sectors, including ocean conditions and governance, sustainable development and management. The training and education programme gradually incorporated skills upgrading, postgraduate training with scholarships and internships, awareness raising and on-the-job training. The training courses were supported by several donors and participating intergovernmental bodies, and substantial course reports were published. According to a report on a 1997 course on UNCLOS and Agenda 21 given at Dalhousie University (9 June–15 August 1997), the IOI training programme aimed 'to deepen the understanding of the ever-increasing importance of the ocean and its resources in world politics and sustainable economic development; to assist developing countries in the formation of a core of decision-makers fully aware of the complex issues of ocean management; and to maximize benefits to be derived from UNCLOS through the proper integration of ocean management into national and international development strategy' (IOI, 1997).

One particular large ocean regime which calls for proper ocean governance is the South Pacific. Large areas of the Pacific could be considered as part of the 'Common Heritage of Humankind', a concept elaborated by Arvid Pardo. It emphasizes peaceful uses, freedom of access and use, regulation for the purpose of conserving heritage and avoiding discrimination, responsibility for use and misuse, and equitable distribution of the benefits from exploitation (Pardo, 1975). These points are all inherent in the Law of the Sea. They are of particular interest in relation to governance of the Pacific Ocean, in view of its global importance, rich resources and of course large number of bordering states, including Small Island Developing States (SIDS).

Ocean governance in the Pacific

The Law of the Sea specifies the rights of coastal states with respect to merchant shipping in their territorial sea and in straits. In section VII of UNCLOS, the Law specifies the implications of the principle of freedom of the high seas (e.g. concerning the rights of navigation, the nationality and status of ships). The duties of the flag state are specified, including the requirement for a genuine link between the state and the ship. Thus, UNCLOS provides an overall legal regime for transport at sea, which is complemented by several specific legal agreements mainly managed through the International Maritime Organization (IMO). The implications are particularly important for the Pacific Ocean, where shipping is the main link between nations, as has been the case throughout modern history.

Long before the arrival of the Europeans, trade, communication and cultural exchange processes flourished in the South Pacific among the Polynesian peoples, underpinned by a strong knowledge of the ocean and navigation (Thompson, 2019). Ongoing globalization processes involving increasing trade, tourism, pressure on the environment and national populations, together with climate change, warming and shifts in weather patterns, necessitate advancing cooperation among Pacific nations in relation to their common ocean interests. This situation, in turn, highlights the need for good governance, based on science, data, exchange of information, cooperation, understanding and communication involving multiple scientific disciplines, administrations and policy-makers. There is also a need for public outreach, information, consultations and the involvement of private industry, as demonstrated in the case of East Asia through Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) (see Chapter 19).

Large areas of the Pacific are also associated with the Southern Ocean, which is home to large amounts of living resources. Krill fisheries have seen strong

development in recent decades, but again have benefited only a few nations. The importance of the Southern Ocean is demonstrated by the existence of the commission, also referred to as the Convention of 1980 for the Conservation of Antarctic Marine Living Resources, which serves as a leading platform to achieve proper ocean governance in the region. Among the notable challenges facing the commission are the increase in krill fisheries and the growing use of the Antarctic region for tourism. Recently, proposals have been put forward to establish large marine protected areas in the Ross Sea and along the East Antarctic coast. If confirmed, these proposals would prohibit fishing in these areas and aim to properly manage tourism.

The Asia-Pacific region is one of the top drivers of the global economy, but also leads in terms of carbon emissions as well as occurrence of natural disasters. In addition, the region is highly vulnerable to climate change, being home to eight of the ten countries in the world with the largest number of people living in low-lying coastal zones vulnerable to sea level rise. Flooding of Asian cities is a perennial problem but has increased since the beginning of this century, due to rising sea level and heavy weather events with rain and high winds, combined with the spread of major coastal cities where large areas covered by concrete prevent proper runoff. The classical management response to these issues is to construct dykes and walls and water pumping facilities. However, this approach is evolving to include greater use of natural protection in the form of wetlands, sea-grass beds and mangroves, which are now being restored. Over the decade 2001–10, natural disasters resulted in the highest number of deaths and the largest economic losses, with over 200 million people affected and more than 70,000 killed annually. In 2010 alone, more than 30 million people were displaced by environmental disasters. Over the period 2005–14, developing Asia lost over 400,000 lives and suffered economic losses amounting to US$436 billion. This trend led to the elaboration of the Sendai Framework for Disaster Risk Reduction 2015–2020 (United Nations) (see Chapter 28) and the SAMOA Pathway of 2014,[63] both of which aim to strengthen cooperation and action to address these issues.

This situation calls for a carefully handled regional approach to governance, including through education, preparation and assistance for highly vulnerable island states. The required cooperation has also involved the scientific community. However, the many island states of the Pacific Ocean are also associated with large EEZs. In all but six cases, these EEZs cover over 500,000 km^2, and in four cases over 3 million. These areas hold vast potential for supporting island states – on the basis of UNCLOS – which also constitutes a motivation for cooperation

63 See A/RES/69/15: https://undocs.org/en/A/RES/69/15

in developing and governing these resources by applying and implementing the Convention. The Pacific also includes large areas beyond national jurisdictions in which can be found tremendous resources both on and below the sea bed. These include metals, fossil fuels and living resources associated with hydrothermal vents, as well as fisheries resources including straddling stocks. To a large extent, it was these resources and concern for their use that triggered the negotiations for the Third Law of the Sea, through the seminal speech of Arvid Pardo at the United Nations in 1967. At the time, many of these resources were beneficial to only a few nations with the required capacities in science, technology and capital. However, the last few decades have seen efforts to ensure their governance in accordance with the spirit of UNCLOS for the benefit of the whole region.[64]

Small Island Developing States (SIDS)

Many environmental conditions, including extreme events driven by the ocean and ocean-atmosphere interactions, present large threats to human security, health and welfare, and the well-being of nations. This is particularly the case for nations bordering the Pacific, and especially the many SIDS in the South Pacific. The latter are strongly dependent on the ocean, including for maritime trade, as illustrated in the observations of the Cook expeditions, as well as the early exploratory and scientific expeditions under the Russian flag. These efforts provided an initial understanding of conditions in the largest ocean basin, the Pacific. The expansion and domination of shipping for transport of goods is a notable feature of globalization processes, as can be seen in shipping lanes and the amount of goods carried by ships throughout the Pacific – coupled with services for the increasing urbanization of the coastal zone in the form of megacities.

SIDS are defined by their historic, cultural and economic links to the ocean and seas. They continue to be heavily dependent on their marine resources, particularly for the sustainable livelihoods of coastal communities (The Mauritius Strategy of 2005).[65] Small islands are extremely vulnerable to climate

64 Overviews of ocean governance approaches, regional co-development and security, and opportunities from ocean governance are presented in Mann Borgese (1998), Mann Borgese and Bailet (2001) and Kullenberg (2002, 2010a). The development of and ideas behind the comprehensive approach in governance and human security considerations are discussed in the Ocean Yearbook vol. 18 and 26 (Terashima, 2004; Kullenberg, 2004; de Marffy, 2004; Kullenberg et al., 2012).

65 The Mauritius Strategy for the Further Implementation of the Programme of Action for the Sustainable Development of Small Island Developing States sets forth actions and strategies in 19 priority areas, which build on the original 14 thematic areas of the Barbados Programme of Action for the Sustainable Development of Small Island Developing States. In line with the Millennium Development Goals, this framework puts in place measures to build resilience in SIDS. See: https://sustainabledevelopment.un.org/conferences/msi2005

change, global warming and sea level rise, and to the increasing frequency of cyclones, storms and hurricanes (e.g. Davies and Hanich, 2012). SIDS participated actively in the negotiations for the Law of the Sea. The Convention brought large benefits to the islands, in particular through the establishment of the EEZ, which is reflected in the Barbados Programme of Action of 2004. SIDS have also demonstrated that much can be achieved through cooperation and the coordination of common efforts (see further Davies and Hanich, 2012).

The specific concerns of SIDS were brought into focus through the creation in 1990 of the Alliance of Small Island States (AOSIS) during the preparations for the United Nations Conference on Environment and Development (UNCED) 1992 – the Earth Summit – held in Rio de Janeiro, Brazil. AOSIS was an initiative of the diplomatic representatives of the Pacific Island States at the United Nations, led among others by Ambassador Neroni Slade, which followed the pragmatic Pacific approach in negotiations. The alliance was instrumental in bringing climate change to the top of the international agenda, and played a large role in the development of the United Nations Framework Convention on Climate Change (UNFCCC) adopted at the Rio Conference 1992, and spearheaded the 1994 Barbados Conference on SIDS. The Alliance then had over three dozen member countries and represented a distinct group of nations and interests. It continues to play a significant role in climate change negotiations, with a focus on the urgent need for action in view of the developing situation threatening many SIDS. It also provides strong input to the follow-up to UNCED, implementation of the Law of the Sea, the Barbados Conference and Programme of Action, and the Risk Reduction Programme. The Alliance has played a role similar to that adopted by Malta in the context of the development of UNCLOS. This represents an example of how UN actions at the global level can stimulate and drive other cooperative efforts.[66]

The SAMOA Pathway of 2014 represents a follow-up to the Barbados Conference of 2004 and the outcome of the Rio+20 UN Conference in 2012. The SAMOA Pathway stands for SIDS Accelerated Modalities of Action and represents the

66 It may be noted that in the context of preparations for the 2002 World Summit on Sustainable Development in Johannesburg, an initiative in which the IOC was involved led to the creation of the Global Forum on Oceans, Coasts and Islands, which has played a substantial role in the context of ocean governance and coastal zone management developments. Specifically, the Forum has provided a venue for multiple stakeholders other than Member States (the private sector, civil society, representatives of indigenous and local communities) to discuss and interact with each other, and with government representatives, their vision and aspirations related to the ocean and sustainable development. Prof. Biliana Cicin-Sain provided clear and effective leadership in making the Forum act and deliver as a truly multistakeholder platform for informal consultations in support of formal negotiations on ocean matters, biodiversity and climate change. The author in this connection was very honoured when she particularly expressed her appreciation for our cooperation at the conference in Indonesia in 2008.

outcome of the Third International Conference on Small Island Developing States, held in September 2014 in Apia, Samoa. Overall, the Pathway reaffirms the commitment to sustainable development, and expresses deep concern for extreme weather events, sea-level rise, coastal erosion and ocean acidification, all of which can be expected to increase over time. The SAMOA Pathway urges increased technology, finance and capacity-building assistance in the context of climate change mitigation and adaptation, calling for support to improve baseline monitoring of island systems. The Pathway affirms that international law, as reflected in UNCLOS, provides the legal framework for the conservation and sustainable use of the ocean and its resources. It also stresses the critical importance of international cooperation and partnership for the implementation of sustainable development and calls for increased coordination and support from the UN system to SIDS – as is the case for the Sendai Framework. In this respect, the IOC WESTPAC Sub-Commission could act as a facilitator and leader, and could seek to enhance cooperation with the Pacific Islands Regional Ocean Framework for Integrated Strategic Action and its implementation mechanism (see Chapter 21).

The Pacific Way

Planning and development for individual states and regions as a whole must take into consideration the uses and users of the marine environment, as well as the interdependencies and complexities of the different processes, uncertainties and reactions to change. These conditions underline the importance of regional and subregional cooperation between nations. This has been understood in many areas of the Pacific, and was evidenced by the creation of the South Pacific Commission in 1947, now the Secretariat of the Pacific Community. The need for such cooperation is further shown through enhanced trading activities, mobility, competition and economic interdependence driven by the globalization process.

Over the decades, many action plans have been developed, including through the Secretariat of the Pacific Regional Environment Programme (SPREP). Other regional bodies participating in regional cooperation include the South Pacific Applied Geosciences Commission for non-living resources and boundaries, the Forum Fisheries Agency for oceanic living resources, and the Secretariat for the Pacific Community for coastal fisheries and socio-economics. These approaches reflect sector-oriented structures which nevertheless over time have succeeded in achieving a Regional Oceans Policy which is apolitical and works by consensus – 'the Pacific Way' (Veitayaki et al., 2004). This may be seen as a partnership approach, as was also adopted for PEMSEA. Another important example of Pacific Island States cooperation is the Majuro Declaration for Climate

Leadership, which was initiated by the Marshall Islands and is supported by other countries and regions. However, the ideal approach would be to implement ocean governance for the whole of the Pacific through UNCLOS. The Convention represents a globally agreed legal order for the ocean and seas – including accountability. The Convention facilitates international communication and promotes peaceful uses, the equitable and efficient utilization of resources, the conservation of living resources, and the study, protection and preservation of the marine environment. Moreover, the Law of the Sea covers many essential human needs, including peace, economic and environmental security; parts of the ocean as a common heritage; freedom of access, equity and benefit for all; and the application of the rule of law through responsibility for use and misuse, *ergo* accountability. The paradigm of sustainable development is also reflected in the Law of the Sea, including through the Common Heritage of Humankind. The Convention can respond to changing conditions and evolve as required, as has been demonstrated through developments in the 1990s.

Changing problems require evolving international cooperation, negotiations and dialogue to reach consensus on actions. Such evolving cooperation was achieved among the Pacific Island States through the establishment of the South Pacific Commission in 1947. The Secretariat of the Pacific Community, as it is known today, includes 26 nations and territories and is associated with several other international bodies. The consensus approach, the Pacific Way, is used in decision-making to achieve good governance. The agreements are underpinned by strong international consensus, and have become difficult for governments to disregard.

The extensive cooperation between nations and institutions in the Pacific region with respect to the ocean and marine and coastal resources was highlighted at the IOI's 27th Pacem in Maribus (PIM) conference (Suva, Republic of Fiji, November 1999) (South et al., 2001).[67] An overview of developments since 1990 was presented by Ambassador Neroni Slade of Samoa, who also drew attention to the importance of financial support and cooperation among donor agencies. He noted in particular the SIDS/Donors meeting in 1999, which focused on the environment, human resources development, capacity-building, institutional strengthening, financing and technology transfer in support of the Barbados Programme of Action, as well as the Convention on Biological Diversity. A review in 1999 showed that SIDS made efforts to implement the programme,

67 The importance of the cooperation was also underlined in the context of the UN Convention on the Law of the Sea, the UN Conference on Environment and Development 1992, the UN Global Conference on Sustainable Development of Small Island States in Barbados 1994 and the Special Session five years after Rio 1997, Rio+5, at the United Nations in New York

and also highlighted the significance of the milestone Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks (1995), the negotiations for which included the participation and contributions of many island states. The IOI Conference also identified challenges for the island states, many of which lie beyond their control; but it also suggested some opportunities, which give hope for the future. Challenges included the pollution of inshore waters, overfishing, unregulated coastal development, climate change and sea level rise. These threaten livelihoods and, in some cases, the continued existence of the fragile island states.

The 27th IOI Pacem in Maribus conference

The Conference covered a range of subjects. Notable among them were the following:

- Boundary issues in the South Pacific, with EEZs representing the foremost source of future wealth and security requiring management, and in some cases negotiations for delimitations, as well as negotiations in the framework of UNCLOS on management and conservation of the South Pacific.
- Traditional marine tenure and Pacific tuna.
- Revitalization of the Regional Seas Programme, in line with major changes in the UN system and to ensure responsiveness to regional priorities with a cross-sectoral approach to incorporate sustainable development. Appropriate technology development and transfer needed to be facilitated with human capacity development and institution building, using successful regional cooperation in higher education (the University of the South Pacific Empowerment of Resource Owners), with an urgent need to put in place co-management mechanisms in which traditions have the possibility to play a major role in partnerships in conjunction with other factors, including the cash economy and new resource management systems.
- International Sea Bed Authority and deep-sea mining in the South Pacific, a major responsibility of the Authority being to help ensure that developing countries are able to participate in deep-sea mining activities, so that their people can benefit from resources within the EEZs and territorial waters, as well as areas beyond national

jurisdiction in the spirit of the Common Heritage of Humankind of UNCLOS. The importance of marine scientific research was highlighted in this regard and is also manifested in UNCLOS.

- The oceanic environment, with particular attention to ocean observing systems, their sustainability and role in facilitating forecasting climate change-related high risk and security threatening events and seasonal variations, and the need to find ways and means for SIDS to participate and benefit properly from the results emerging from observation systems.
- Regional security and disaster preparedness, as SIDS have limited capacity for surveillance and enforcement of rules and regulations in their vast EEZs, leaving them particularly vulnerable to natural and human-induced hazards, and could thus benefit from enhanced cooperation in surveillance and ocean and coastal management in relation to enforcement, risk management, preparedness and mitigation.
- Marine biodiversity and bioprospecting, with SIDS being custodians of some of the world's most important biodiversity; their obligations towards protection of this biodiversity is a priority under the Convention on Biological Diversity, with resources including tuna, coral reefs, tropical marine organisms and deep-sea vent ecosystems all requiring cooperation and consensus regarding actions in accordance with the Pacific Way.

The definition of ocean governance from Mann Borgese (1995) given in the first section of this chapter does not imply big government, but rather reflects a view that all interests must be involved and that government as one partner can delegate actions to others so as to avoid centralization. The Pacific Way can fulfil these requirements. Cooperation across the Pacific has continued to evolve in the new millennium through the adoption in 2002 of the Pacific Islands Regional Ocean Policy, approved by the Pacific Island leaders.[68] In subsequent years, an implementation strategy was developed in the form of the Pacific Islands Regional Ocean Framework for Integrated Strategic Action, achieved through a cooperation process undertaken by the Council of Regional Organizations of the Pacific. The framework consists of five interrelated thematic areas:

68 An overview of the whole related development is presented by Veitayaki et al. (2004).

- Improve governance of coasts and the ocean.
- Adopt an integrated approach to sustainable ocean and coastal development.
- Strengthen the capacity of Pacific Island communities to undertake sustainable development and management.
- Foster alliances for securing a healthy ocean.
- Establish high-level leadership on ocean and coastal issues.

Implementation of the programmes and agreements is based on cooperation among institutions, sectors, interests and nations. This underlines the importance of actions at the regional level, particularly in relation to marine research and ocean observations (as was also highlighted in earlier chapters in relation to the North Atlantic and the Mediterranean). The importance of cooperation to this process is corroborated by the efforts of the IOC in establishing and supporting regional cooperation with capacity-building and the transfer of marine technology. The fact that lack of financial means and human resources are major limiting factors underlines the need to secure the support, interest and involvement of governments. This observation is further corroborated by the early developments of exploration and oceanography. Early examples of support and stimulation from governments include the Chinese expeditions to the seas of South Asia and the Russian exploratory and scientific expeditions in the Western Pacific.

21 Cooperative developments in the Western Pacific

Cooperation in ocean research in the Western Pacific was initiated by the Intergovernmental Oceanographic Commission (IOC) with a programme on the Kuroshio Current in the 1960s. This joint investigation of the Kuroshio Current system and the flow from the tropical Pacific through the East China Sea to the North Western Pacific eventually led to the establishment of a more formalized intergovernmental cooperative mechanism in the form of a subcommission for the Western Pacific (WESTPAC), established by the Fifteenth Session of the IOC Assembly in 1989. The decision to establish this mechanism was based on developments in marine research, ocean observations and regional cooperation, together with the associated increase in capacities in the participating countries.

The first session of the subcommission was convened in Hangzou, People's Republic of China (PRC) in February 1990. In my capacity as Secretary of the IOC, I highlighted several topics drawing on previous related experiences from other regions. These included the need for active involvement on the part of Member States; growing concern for the environment, climate variability and change, the pressure of the growing human population and, in addressing these issues, the need for a holistic view of environment, activities and development of human society. The support of governments of the region was pronounced during the session, as shown by the creation of a regional secretariat, with support in particular from Australia, China, Japan and Thailand. The significant role of the ocean and its resources is undeniable in connection with most human activities. The ocean also has an immense influence on climate variability and change. However, there was no reference to the ocean in the resolution of the Governing Council of the United Nations Environment Programme (UNEP) on global climate change in May 1989. I therefore stressed that adequate and sustained ocean observations were vital to narrow down the uncertainties and improve our ability to understand and possibly forecast climate change and related effects.

The subcommission would take responsibility for facilitating the development of ocean observations in the region, and has since organized regular scientific

conferences and symposia. The tenth WESTPAC International Scientific Conference in Qingdao (April 2017) entitled 'Advancing Ocean Knowledge, Fostering Sustainable Development' addressed the implementation of the 2030 Agenda, and particularly Sustainable Development Goal 14 (SDG 14), on the ocean. The Conference attracted over 700 scientists, government officials and resources managers from 21 countries, and involved many international programmes. It was structured around four themes: understanding ocean processes and climate change in the Indo-Pacific; ensuring marine biodiversity, food safety and security; the maintenance of ocean health; and enhanced knowledge for cross-cutting and emerging issues. The participants suggested a number of areas for enhanced efforts regarding ocean conditions in the Western Pacific and adjacent regions, including: observations and forecasting; marine pollution, plastic and eutrophication; ocean acidification and its impact; atmosphere and ocean circulation; ecosystem restoration; and vulnerability assessment. This demonstrates the concerns of the participants and countries. Briefing documents published in 2017 by the WESTPAC Secretariat covered capacity development, actions in sustainable development and building blue partnerships, all of which highlight the broad outreach and cooperative efforts of the subcommission.

The desire to strengthen cooperation at all levels was also in evidence at the fourth Asia-Pacific Forum for Sustainable Development (March 2017) (WESTPAC, 2017), with respect to implementation of SDG 14 on the ocean. The Forum recommended strengthening existing regional ocean governance and scientific development mechanisms; establishing regional ocean partnerships among UN agencies, subregional and regional ocean and fishery-related organizations, NGOs, civil societies, public and private sectors, including local communities; and supporting the UN proposal for an International (UN) Decade of Ocean Science for Sustainable Development. These recommendations underline the interconnectedness between the ocean regions.

Several intergovernmental activities since the 1960s helped to address some of the environmental, security and economic problems of the Pacific as a whole. From its establishment, WESTPAC played an important role in these cooperative efforts as an ocean science organization. These activities included the establishment in 1960 of the Tsunami Warning Center in Hawaii, which in 1965 fell under the responsibility of the IOC. The importance of this cannot be overstated. It has served as a model for several other centres for tsunami and other hazards warnings established after the 2004 tsunami and earthquake in the Indian Ocean. Related actions include combined risk reduction efforts, which are of great importance for the states of the Pacific Ocean (see also Chapter 28).

WESTPAC is linked to the South Asian Seas and the Indian Ocean through two regional cooperative IOC committees for the Western Indian Ocean and the Northern Indian Ocean. The linkages between the three major ocean regimes and their significance for about half of the global population merits a balance in terms of facilitating the development of and cooperation in ocean research and observations between the regions, with respect to focus, coordination, interaction, contacts with Member States, exchange and the common use of resources at a commensurate level.

In 1998, the Perth Regional Programme Office of the IOC was established with support from the Western Australian State Government, the Australian Bureau of Meteorology and IOC-UNESCO. This was very much due to the foresight, efforts and contacts of the former Head of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Dr Roy Green, who was also the Australian Delegate to the IOC. The office coordinates IOC activities in the region, with a focus on the development of the Global Ocean Observing System (GOOS). It has helped to develop several GOOS regional alliances, including the Indian Ocean GOOS, the South-East Asia GOOS, the Western Australia GOOS and the Pacific Island GOOS, and supports the Australian Integrated Marine Observing System (IOC-UNESCO, 2006, 2009). The Perth Regional Programme Office maintains cooperation with WESTPAC. Since 2015, the office has also been responsible for supporting and coordinating the development of plans for the International Indian Ocean Expedition 50th Anniversary Initiative (IIOE-2) in collaboration with the Scientific Committee on Oceanic Research (SCOR). The development of the plans has required several meetings and the organization of related reference groups. The planning process has built on experiences from one of the first tasks of IOC with SCOR half a century ago – the International Indian Ocean Expedition from 1959–65. Emerging core priorities include: physical oceanography and atmospheric sciences, biogeochemical and ecosystem science, societal drivers, capacity-building, and data and information management. The coordinated, integrated programme is expected to examine several environmental issues of the Indian Ocean (IOC-UNESCO, 2014a). The design of the programme highlights trends in the transition of oceanography from pure natural science to the application and involvement of social and economic questions in relation to society as a whole, in harmony with the spirit of UNCLOS.

In conclusion, regional cooperation in the Western Pacific is well established and is producing results. Cooperation between regions is in place, and global programmes have been operating for several decades. Sustained ocean observations with data delivery and assimilation have proven to be operational

through GOOS and related regional alliances. At the same time, several issues of global concern are emerging and are attracting public attention (see the discussion in Chapter 22). Half a century after the launch of the first ocean decade there is again a need for ocean science and observation to pool resources to find scientific solutions to these global problems. The opportunity to launch a second ocean decade emerged from the global initiatives of the United Nations in 2015 at the launch of the 2030 Agenda for Sustainable Development and the Paris Agreement on climate change.[69]

69 Available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

22 The 2030 Agenda and the Ocean

The challenges and opportunities of the 2030 Agenda

The 70th anniversary of the United Nations saw the adoption of the Resolution by the General Assembly on 25 September 2015, entitled 'Transforming our World: the 2030 Agenda for Sustainable Development',[70] which included 17 Sustainable Development Goals (SDGs).

The Preamble of the Resolution expresses determination to protect the planet from degradation; to end poverty and hunger; to ensure that economic, social and technological progress occur in harmony with nature; and to foster peaceful, just and inclusive societies free from fear and violence. The Resolution sets out a 'supremely ambitious and transformational vision' and envisages a world 'in which consumption and production patterns and the use of all natural resources – from air to land, from rivers, lakes and aquifers to ocean and seas – are sustainable', under good governance and the rule of law. The Resolution recognizes that climate change is one of the greatest challenges of our time: increases in global temperature, sea level rise, ocean acidification and other climate change-related impacts are seriously affecting coastal areas and low-lying coastal countries, including many least developed countries and Small Island Developing States (SIDS). The Resolution further affirms the need for urgent action, noting that: 'The survival of many societies, and of biological support systems of the planet, is at risk'.

The Resolution also notes, however, that this is a time of immense opportunity. Significant progress has already been made in meeting many development challenges. The global spread of information and communication technologies has great potential to further knowledge and connect societies through scientific and technological innovations in diverse areas. The 2030 Agenda and the SDGs represent a pledge by world leaders for common action towards a broad and universal policy agenda. As the new Agenda stated, 'We are setting out together

70 See A/RES/70/1: https://undocs.org/A/RES/70/1

on the path towards sustainable development, devoting ourselves collectively to the pursuit of global development and of "win-win" cooperation which can bring huge gains to all countries and all parts of the world'. The 2030 Agenda will be 'implemented for the full benefit of all, for the generation of today and for future generations, with commitment to international law'.

The 2030 Agenda as a 'plan of action for people, planet and prosperity' represents a unifying global adventure that will last for at least a decade. This raises the question of how the ocean communities might best contribute to and help ensure the implementation of Agenda 2030 and achievement of the SDGs. As we come up to the 50th anniversary of the launch of the International Decade of Ocean Exploration (IDOE), one way to achieve cohesiveness, cooperation and coordination of our efforts is through the launch of a new international (or UN) Decade of Ocean Science for Sustainable Development (2021–2030).

The challenges and opportunities of ocean science

The ocean covers 71% of the world's surface, connecting the planet in numerous and interdependent ways – a factor that is crucial in the context of achieving sustainable development. Most countries have sea coasts and make use of the sea and the ocean waters. Their contents mix and interact without regard for human interference. The ocean has also played a leading role in the development of international cooperation and exchange. Throughout modern history these exchanges have been double-edged – health threats, plagues and epidemics have been carried by ships, as well as new food products, materials and migrating people of different cultures. These aspects have all inspired the United Nations Convention on the Law of the Sea (UNCLOS), which entered into force in November 1994, almost exactly 100 years after the *Challenger* expedition.

At this juncture, ocean science, or oceanography, had matured. Several international organizations had been created, and were working with advanced, substantial research institutions in many countries, including mission-oriented national agencies. These organizations were charged with addressing national priorities and emerging concerns with respect to marine and near-shore environments and the related resources. The IDOE and the successful completion of the negotiations for UNCLOS are ample proof of this maturity. In parallel, interest in and understanding of the need of ocean science and ocean observations had increased at the global level. The realization by governments of the need for capabilities in ocean science is reflected in the considerable increase in the number of Intergovernmental Oceanographic Commission (IOC) Member States during the last decade of the century. In addition, the results

of the marine sciences and ocean observations were being transformed into societal applications far beyond traditional applications in fisheries management (e.g. Wunsch, 1993). Carl Wunsch notes that up to this point, oceanography had essentially taken the form of basic, curiosity-driven research. The new tendency, however, appeared to represent a shift towards addressing national priorities, with an emphasis on short-term benefits rather than a longer-term perspective (Briscoe and Evans, 1993). If this is the case, mission-oriented agencies, depending upon the results of basic research, should provide some support to basic and free research in academic institutions. Such support would be dependent on cooperation and dialogue between the institutions concerned and the researchers involved.

Briscoe and Evans (1993) make the case that the best argument for the sustained transfer of basic research funding is improvement in the conversion of basic research results into applications. In other words, governments and the public are entitled to see the benefits arising from research expenditure. This implies a need to demonstrate how research results are incorporated into products, development and policies. My personal experience in international work leads me to believe that this could be achieved through demonstration projects that highlight the importance and role of upstream basic research. The contribution of scientific research occurs upstream of the whole development process, and is therefore rarely acknowledged to the extent it deserves. This has been noted in relation to the work and communication efforts of the IOC. Briscoe and Evans further note that the application of research results is limited by the capability of users to understand the research results, and be able to modify them to solve applied problems. Increased understanding is needed on both sides to address this point. Training is needed for users and others engaged in applying the results of basic science, while scientists require training to communicate and cooperate with the users of their results. Such need for training both sides creates opportunities for dialogue.

The IOC, as part of UNESCO, plays a role in this context which could possibly be strengthened, for instance, through greater cooperation with the social sciences. Being part of UNESCO, the IOC can facilitate and initiate dialogue between the different branches of science (e.g. social and cultural) with the aim of deepening cooperation and understanding between the sectors. However, the process also requires basic research institutions to allow their scientists sufficient time for training and interdisciplinary dialogue. In my own experience, leading research institutions do not always encourage or facilitate this process. For example, in some cases, scientists who were invited to take part in and devote time to the work of GESAMP were either not available or were not incentivized

to participate. In this context, it should also be noted that the time needed for new inventions resulting from research to be disseminated as applications is often quite long (e.g. Rogers, 2003), depending on the need and the time taken to develop the innovation into a tested application, and obtain its acceptance by users and the public. A good example of quick acceptance and general use is the chronometer tested by Captain Cook (see Chapter 3).

Scientific exchange and training resulted in a mutual understanding that students from academic research institutions would enter mission-oriented agencies employing the research results. The more students and graduates that moved into industries and government agencies, the greater the likelihood that their knowledge and insights would become part of applications. The Royal Navy and the Royal Society applied this thesis in the planning and execution of the exploratory expeditions of Captain Cook as well as the *Challenger* expedition. However, this thesis also implies that the academic educational system must accept that academic research is not the only successful end point for graduates, and that transfers to industry, governmental institutions and national agencies form an important part of the system (Briscoe and Evans, 1993). Transfer of graduates to user agencies may provide critical people who have access to emerging research results either through publications, interactions with researchers or personal involvement in the research process.

Coordination, cooperation and communication between the various agencies are also essential elements – and ones that often seem to be missing. In my own experience, this is exemplified by differing messages on the same subject from national representatives to governing body meetings of different organizations. This mismatch may be the result of a lack of coordination and communication between the various national agencies, their status, competition, and different levels of access to decision- and policy-makers. However, experiences from global research programmes and management of priority needs by national mission-oriented agencies involved in the first IDOE demonstrated good coordination and interaction between the different agencies and research institutions. Examples include climate and global flux research programmes, the development of sustained ocean observations, and work on the various pollution and waste problems. Accordingly, it can be argued that additional research and assessments should not be implemented before existing research results have been transferred into proper applications and policy. For example, climate and fisheries are both areas where sufficient research results exist to support policy decisions and implementation to help address problems of overfishing and climate change. Basic research, observations and monitoring must of course

continue; we do not yet fully understand the climate system, and there may well be some further surprises.

Briscoe and Evans (1993) concluded that oceanography has matured and has produced remarkable advances. The coming decades should see an evolution towards using these advances in ways that treat research and applications on an equal footing, with stronger cooperation and deeper trust between researchers, and those who adopt and wish to apply their results, and the practitioners who can put them into practice. These observations are highly relevant in the context of launching an ocean science decade for sustainable development. Ocean science, including basic and applied, has still much to achieve and to contribute through applications to address current issues of major concern. We should also expect new problems to emerge and possibly also surprises as to the consequences of ongoing changes. Experiences have shown that achieving the SDGs – and possibly in particular SDG 14 related to the ocean – requires close cooperation with the social sciences and greater communication with the public, in accordance with the spirit of Agenda 2030.

The Sustainable Development Goals

The situation described above is well reflected in Goal 14 of the 2030 Agenda for Sustainable Development: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'. The Goal specifies several targets to be achieved during the decade 2021–2030. These target direct attention to specific management and use aspects of ocean areas and the resources therein, including the following:

- preventing and reducing marine pollution (Target 14.1);
- sustainably managing and protecting marine and coastal ecosystems, and strengthening their resilience and restoration (Target 14.2);
- minimizing and addressing impacts of ocean acidification (Target 14.3);
- regulating harvesting and ending overfishing as well as illegal, unregulated and destructive fishing, and implementing science-based management plans to restore fish stocks, to achieve at least maximum sustainable yields determined by the biological characteristics (Target 14.4);
- conserving at least 10 per cent of coastal and marine areas based on best available scientific information (Target 14.5);
- prohibiting and eliminating certain forms of fisheries subsidies (Target 14.6);

- increasing the economic benefits to SIDS and least developed countries from the sustainable use of marine resources including fisheries, aquaculture and tourism (Target 14.7);
- increasing scientific knowledge, developing research capacities and transferring marine technology to improve ocean health and enhance the contributions of marine biodiversity to the development of developing countries, in particular SIDS and least developed countries (Target 14.a);
- providing access for small-scale artisanal fisheries to marine resources and markets (Target 14.b); and
- enhancing the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS (Target 14.c).

In addition to these targets, several other SDGs include targets and actions of high relevance for the ocean and coastal conditions and are influenced by these conditions, thus also influencing the situation on land. In particular, the issue of climate change, covered by SDG 13 and the Paris Agreement, is of great concern for ocean conditions, and, conversely, the role of the ocean as an integral part of the climate system. Society now depends on the ocean more than at any time in history, underlining the importance of these targets and actions. In fact, the ocean has a decisive influence on our climate (SDG 13), constitutes a source of critical resources for survival (e.g. high-grade animal protein – SDG 2), provides a dominating transport route for our goods and is a leading tourism stimulator (SDG 9), and forms the largest and mostly unexplored and shared ecosystem of the planet (SDG 15). The ocean provides a large proportion of the oxygen we breathe and is the origin of life on our planet. However, many of its functions are being threatened from natural and human-induced changes and their various interactions.

The ocean is a vital source of nourishment, supporting the livelihood of about 500 million people, especially in the poorest nations. Food from the ocean is vital to human health and brain development. Recent economic assessments assign to the Gross Marine Product an annual value of US$2.5 trillion, which represents about 3% of global gross domestic product (GDP), not including much of coastal areas. Marine and coastal resources and industries account for over 5% of global GDP. For many nations, ocean-related economic activities such as tourism and artisanal fisheries are major contributors to the national economy and development. Over 90% of world trade is carried by sea, amounting in the 2000s to about US$13 trillion, having increased from about US$7 trillion in the early 1990s (see, for example, Mann Borgese, 1998; Chua et al., 2008; Hudson and Glemarec, 2012). Ocean economies are among the most rapidly growing in the world, and provide benefits to many sectors of great economic

value. These include fisheries and food, energy, tourism and transport, climate change regulation, carbon sequestration, habitat, biodiversity, and influence on human health and well-being. Additionally, the oceanic biological system offers exciting opportunities for the development of new drugs to treat many human ailments, such as asthma, tuberculosis and cancer. Marine biotechnology is a rapidly growing industry, and the financial benefits from worldwide sales of marine biotechnology-related products constitute a multi-billion dollar market (see, for instance, Mann Borgese, 1998).

The ocean is also a source of human history and cultural development through the large number of ships, infrastructure constructions and various other artifacts preserved in the sea floor sediments after sinking or burial by rising sea levels, and discovered by means of exploration, technological developments and archaeological sciences. The technological developments (see also Chapter 15) with deep sea diving, drilling and precise positioning made it possible to study the sea floor at depth in detail, and identify with eco-sounding, side-scan sonar and photography irregularities, changes in shape and objects partly hidden by the sediments. It became possible to extend studies of submerged shipwrecks and other hidden treasures found in shallow water to the deep sea. This led to the combination of archaeological and oceanographic sciences into the hybrid science of underwater archaeology. It came of age in the 1980s, even if a number of studies of this nature had been accomplished since the end of the 1950s (e.g. Hohlfelder, 1990).

Underwater archaeology studies submerged sites, artifacts, human remains and landscapes. It is to be seen in the larger context of maritime archaeology, which studies human relations with oceans, lakes and rivers and is complemented by nautical archaeology, which studies vessel construction and use.[71] Many shipwrecks and remains of historical constructions, as well as traces of human living sites as debris, have been located, protected and preserved in the sediments. Famous examples of such sites which have been studied include Port Royal, Jamaica and Caesarea Maritima, Israel (e.g. Hohlfelder, 1990, presenting studies by Link), and shipwrecks of the *Mary Rose* from 1545 in Portsmouth harbour, the *Vasa* from 1628 in Stockholm harbour and the *Titanic*, located in 1985. Access to sites requires diving equipment and diving skills and advanced logistics. The activity is multidimensional, a truly interdisciplinary, cooperative team effort involving experts from many fields, practitioners of diving, precise

71 http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/protection/underwater-archaeology

navigation and logistics, knowledge of the ocean and weather conditions. It combines natural and technology sciences with history, humanity and culture.

Treasure hunting has always been a tempting human occupation. Experience soon showed that the artifacts which had been found needed protection from treasure hunters. This challenge was taken up by UNESCO in context of its 1972 Convention concerning the Protection of the World Cultural and Natural Heritage. Since the 1980s, 50 marine sites have been included in the World Heritage List in recognition of the conservation challenges.[72] On this basis, acknowledging the importance of underwater cultural heritage as an integral part of the cultural heritage of humanity, and realizing the need to codify and progressively develop rules relating to protect and preserve this cultural heritage in conformity with international law and practice, the UNESCO 2001 Convention on the Protection of the Underwater Cultural Heritage was adopted by the General Conference in November 2001.

Underwater cultural heritage includes all traces of human existence – submerged partially or totally, periodically or continuously – which are one hundred years or more old and have a cultural, historical or archaeological character. The Convention aims at preventing the destruction and looting or loss of historical and cultural information, helping to protect the underwater cultural heritage through an international legal forum. The Convention is harmonized with UNCLOS, where articles 149 on Archaeological and historical objects, and 303 on Archaeological and historical objects found at sea (in parts XI The Area and XVI General Provisions, respectively; United Nations, 1983) provide its legal framework.

The interaction between marine archaeology and oceanography is based on several recent technological developments, perhaps in particular as regards diving, but also precise navigation, positioning and mapping by means of various sonar and photography techniques. It also provides a fine example of how interaction, exchange and cooperation between different pursuits of knowledge can lead to enlightenment and development in many disciplines, here including our history, means of exploration, culture, constructions, nutrition and health care.

72 See World Heritage List at: https://whc.unesco.org/en/list/?search=&themes=7

Major issues and research needs with respect to the ocean today (2010-2015)

The major issues concerning the marine environment include: overfishing, warming and oxygen depletion, acidification, pollution, waste and contamination. There is also great concern, including among the public, about changes in the ocean currents, for instance of the Gulf Stream, the melting of sea-ice, sea level rise, coastal flooding, extreme weather events and changes in their frequency, the environmental impacts of aquaculture, the effects of marine invasive species, habitat destruction and coastal erosion. Public perceptions also show a strong connection to marine and coastal environments affected by aesthetics, identity, practical considerations of access, livelihoods, assessment of impacts on marine wildlife and clean energy production. However, international evaluations of human impacts on the marine environment do not assess public awareness and perceptions, concerns and priorities (Gelcich et al., 2014). Such public attitudes and understanding are key to the successful implementation of management changes. They need be taken into account when developing national programmes, making management decisions and designing interventions, and in the implementation and actions of the Ocean Decade (see Chapter 23).

Based on a broad survey of scientists covering 94 countries, the leading marine research issues facing the scientific community are as follows (Rudd, 2014): cumulative stressors, ocean productivity, ocean acidification, monitoring cumulative effects, oceanographic data, biodiversity contributions to ecosystem function, greenhouse gas flux, climate change mitigation and manipulation, global biodiversity and ecological functions, benthopelagic coupling, science communication, contaminants, top predator decline, climate change-induced species dispersal, ecosystem structure to service linkages, thermohaline circulation, coral reef management strategies, cross-disciplinary ocean science and management, and energy development. Five of the top ten research priorities were shared by respondents globally. Seven of the top ten priority questions were shared by physical and ecological scientists (the global ranking is given in parentheses): cumulative stressors (1), ocean productivity (2), ocean acidification (3), monitoring cumulative effects (4), oceanographic data (5), greenhouse gas flux (7), and climate change mitigation and manipulation (8). However, only the cumulative stressors issue was among the top 10 priorities for social scientists. Many of the high-priority questions for social scientists ranked lower in order for natural scientists. Meanwhile, many social scientists top-ranked science communication (1), risk assessment for governance (2) and ocean literacy messages (4). All this points to an interest in the purpose of environmental management and the normative aspects of our relationship with the environment, and of interpreting, integrating and advocating science

by engaging in the policy process. There were also differences in rankings between regions. Furthermore the rankings do not reflect the research priorities of society as a whole or of government policy-makers. It would be valuable to systematically compile and compare existing ocean research priorities among governments and other bodies.

Reports from the World Bank and the European Commission (Rudd, 2014) have pointed to an increasingly accepted view of the ocean as the driver of economic and social well-being, as well as understanding of its importance for safety and security – all of which are influenced by ocean conditions. This acknowledgement inevitably leads to recognition of the need to restore and maintain the health of the ocean (Rudd, 2014). The European Environment Agency (2014) states that 'Our seas are rapidly changing while our dependence on them is growing. We do not fully understand the complex interactions of natural and human-driven changes. But we do know that we are not yet on the path to achieving healthy, clean and productive seas'. Rudd (2014) concludes that his results 'provide insights as to how research scanning results can be synthesized and used to target ocean research on questions that, if answered, would be central to achieving ocean sustainability'.

It should be noted that the possible role of the ocean as the driver of socio-economic development and well-being was also previously proposed by the founder of the International Ocean Institute, Elisabeth Mann Borgese (1997, 1998, 2000). Her analysis was based on the application of the Law of the Sea and in particular the possibilities offered by the Common Heritage of Humankind idea, together with the economic potential of ocean-dependent and ocean-related goods and services. It should also be recalled that the 1992 UNCED recognized the critical role of the ocean in maintaining conditions of life on Earth; that without a healthy ocean there is no healthy global or regional environment; and that the present understanding of interactions between the ocean, the land and the atmosphere is insufficient for adequate forecasting of changes and consequences of human actions. Subsequent developments have corroborated these observations.

The results of Rudd were supported by a Nordic Study (Boonstra, 2015) in which marine scientists identified overfishing as a top concern, followed by elevated temperature, contamination and waste, and ocean acidification. Differences depended upon the scientific background: natural scientists stressed the symptoms of global change driven by human impacts, whereas social scientists tended to focus on the human causes of the threats.

The silent services of the ocean

The ocean provides a number of crucial services of worldwide significance. In the context of global transformations and climate change, these 'silent services' include (Stocker, 2015):

- the ocean uptake of over 90% of the excess energy in the climate system, confirmed by observed warming on a worldwide scale to depths over 2,000 m;
- the ocean as a receiver and global distributer of excess water from melting land glaciers and ice sheets of Greenland and Antarctica, together with the warming driving sea level rise;
- ocean absorption of up to 30% of the carbon dioxide emitted by society and about 28% of the cumulative anthropogenic carbon dioxide emissions from 1750 to 2011, which are now stored in the ocean and are roughly equivalent to the amount taken up by the land biosphere.

The price for ocean uptake of this heat is ocean oxygen depletion and carbon dioxide ocean acidification, which has reached great depths. The implications of this include gradual calcium carbonate undersaturation, the critical threshold of which can be predicted, probably with the smallest uncertainty of all projections of future change related to the climate issue. Model simulations suggest that this threshold will be crossed first in the Arctic. Possibly the most important issue is ocean acidification. Sustainable Development Goal target 14.3 calls for minimizing and addressing impacts of ocean acidification, including through enhanced scientific cooperation at all levels. However, oxygen depletion – de-oxygenation – is also emerging as a top priority, while the multiple, cumulative stressors constitute a priority research area. The first World Ocean Assessment (United Nations, 2016) confirmed this assessment and concluded that we are running out of time to effectively protect the world ocean from multiple interactive stressors. This in itself seems to justify a consolidated global effort such as the United Nations Decade of Ocean Science for Sustainable Development 2021–2030.

23 Original proposal for an Ocean Science Decade

Over the last few decades, ocean science has demonstrated that we are facing multiple problems with respect to the conditions of the ocean and coastal areas, their resources and uses, and the resulting consequences for our society and livelihood systems. This has also been certified through our increased understanding of the functions of the ocean in our climate system.

The situation calls for a global, cooperative, coherent and coordinated effort over an extended period to identify science-based solutions to the problems of the ocean, to establish necessary links between ocean science and sciences concerned with social, human health and economic conditions, and to deliver outcomes in a manner that is understandable to policy-makers and society at large. Agenda 21, the Millennium Development Goals and the 2030 Agenda now provide a value-chain enabling framework and the opportunity to launch such an effort in the form of an international ocean science decade for sustainable development 2021–2030. This possibility was discussed at the brainstorming meeting of the Intergovernmental Oceanographic Commission (IOC) Officers and senior staff members of the IOC Secretariat in Gilleleje, Denmark in January 2016, in which I also participated as a consultant. It was agreed that the idea should be elaborated in a discussion paper by the IOC Officers and presented to the forthcoming IOC Executive Council. As a consultant, it was my responsibility to prepare a report of the brainstorming meeting, including a draft of the discussion paper for the Officers.

The first draft proposal for an ocean science decade is summarized in the framed text below.

> The uniquely ambitious and transformative vision of the 2030 Agenda provides a great opportunity and a rationale for another 'historic and unprecedented adventure' as the International Decade of Ocean Exploration (IDOE) (see Chapter 15) in the form of an International Decade of Ocean Science for Sustainable Development. The main goal of this Decade could be to support the achievement of Sustainable

Development Goal 14 and the vision of securing a healthy ocean – 'The Ocean We Need for the Future We Want'. This implies an emphasis on science and integration as well as international cooperation. The science drive is motivated by the fact that the ocean is far from fully explored or mapped although regular observations now relate more to sustained monitoring than exploration.

Since the creation of the IOC in 1960, science and marine technology and related capacities have developed such that many societal goals of ocean science can be achieved through concerted, cooperative actions. These actions can be guided by the Convention on the Law of the Sea in combination with related international agreements and conventions – including the Sendai Framework on risk reduction, the SAMOA Pathway, the Outcome Document of the United Nations Conference on Environment and Development in 2012, the Paris Agreement of 2015 under the UN Framework Convention on Climate Change, and possible future agreements on areas beyond national jurisdiction. Over recent decades, it has been increasingly accepted that an integrated, holistic approach is needed to find solutions to the main problems we face, even if they appear to be different. This was also the motivation from leading scientists behind the creation of the Scientific Committee on Oceanic Research (SCOR) and the IOC.

The overall goal for the proposed Ocean Science Decade could be to support implementation of the 2030 Agenda and the achievement of Sustainable Development Goal 14, as well as ocean-related elements in several other SDGs.

Specific goals or objectives of the decade could include the following:

- completing the science base for ocean governance, a sustainable ocean economy and good ocean stewardship, based on sustainable development practices;
- obtaining a more complete baseline (picture and inventory) of the ocean, the ocean floor and the ocean resources;
- addressing major ocean science issues, including the enhancement of interdisciplinary ocean research;
- revisiting selected programmes of the IDOE to elucidate changes in the ocean;

- enhancing participation in, use of, and support to sustained ocean observations;
- strengthening the science base and use of marine protected areas;
- enhancing economic benefits for Small Island Developing States (SIDS) and least developed countries from marine resources and technology;
- strengthening the implementation of capacity development and transfer of marine technology;
- enhancing trust, cooperation, coordination, exchange of information and communication between various institutions and bodies dealing with or responsible for marine affairs and related policy, including ocean research and observations.

Several other objectives can of course be identified and will be expected in the course of further development of the decade programme and solicited proposals.

The Rio+20 Outcome Document *The Future We Want* (United Nations, 2012) recognizes the importance of building the capacity of developing countries to benefit from the conservation and sustainable use of the ocean and seas and their resources. The document emphasizes the need for the transfer of marine technology taking into account the *IOC Criteria and Guidelines on the Transfer of Marine Technology* (IOC-UNESCO, 2005). The proposed Decade would support education and enhance awareness about sustainable development, and the contributions of research, technology and observations, together with the need to care for the ocean and marine resources. The Decade could aim to make ocean science and ocean policy-making act together, for the common good of society as well as the ocean itself (see, for example, Holland and Pugh, 2010). The Decade can inspire cooperation and exchange of human experiences and marine technology, thus contributing to the diffusion of equality, human rights and related matters in support of and conformity with the United Nations Convention on the Law of the Sea (UNCLOS). In line with the overall goal of the UN Decade of Education for Sustainable Development (UNESCO, 2005), the spirit of the new International Decade could focus on the integration of the principles, values and practices of sustainable development into ocean governance,

and the utilization and management of marine resources and the ocean as a whole, in conformity with UNCLOS.

The efforts of the Decade should support the free flow of data, of scientific and technological information, and exchanges by means of modern technology. The programmes should enhance knowledge about international law and the need to abide by it – in particular UNCLOS – a requirement which is essential for sustainable development of the ocean economy.

Following debate on the paper prepared by the Officers, the Executive Council decided that the proposal be pursued, leading to the document IOC/INF-1341 Rev. Prov.[73] Following further discussions and refinements at the IOC Assembly in mid-2017, the proposal was presented to the UN General Assembly in the autumn of 2017, and on 5 December the UN General Assembly in its 72nd Session adopted Resolution 72/73[74] proclaiming a United Nations Decade of Ocean Science for Sustainable Development 2021–2030. The successful completion of this effort by the IOC should be seen as proof of the maturity and level of acceptance of the IOC as an organization by its Member States and the United Nations.

The idea for a new decade on ocean science and exploration presented here are based on the initial discussions in 2015 and brainstorming in 2016. An overview of further developments of the idea is given in IOC-UNESCO (2018).[75] However, while the proposal serves to provide the main motivations and goals of the Decade, it is also important to create a vision for the desired results, some suggestions of which are indicated in the following chapters.

73 Available at: http://legacy.ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=19559

74 A/RES/72/73 available at: https://undocs.org/A/RES/72/73

75 A conceptual overview of the spirit of the planned Decade is included in IOC-UNESCO (2018).

24 Desired results: Science-based solutions delivering oceanographic products and ocean services

Social and environmental motivations

The interdependence and global interconnectedness of the ocean has been well recognized in the context of achieving sustainable development. Looking ahead, in the context of global interconnectedness and sustainable development, 'governments need to work together with greater urgency to address the many natural and man-made issues concerning the ocean … to understand better the role that ocean science can play and to develop much stronger ocean governance mechanisms to profit from the knowledge obtained' (Holland and Pugh, 2010). Strengthening cooperation is vital in this regard.

The UN Secretary-General's Scientific Advisory Board has identified eight 'grand challenges', which it categorizes as serious problems affecting the entire world community. First among these is 'improving ocean science and governance for the development of sustainable ocean knowledge-based economies', while the fifth challenge concerns 'averting human disasters through prediction of extreme environmental events'. The Board recommends that nations press for greater collaboration among international science networks, including professional societies and academies, and indigenous and local knowledge holders (UNESCO, 2016).

The First Global Integrated Marine Assessment: World Ocean Assessment I (United Nations, 2016) concludes that 'many parts of the ocean have been seriously degraded' and that 'the general threat to the ocean comes from a failure to deal quickly with the manifold problems described in the assessment'. These include ocean and coastal seas pollution, coastal and island erosions, the effects of climate change, sea level rise, warming, acidification and de-oxygenation, overfishing, and species and biodiversity changes and loss. The failure is due largely to a lack of integration of scientific results into management. If this failure continues, there is a strong risk that these problems will combine to drive a destructive cycle of degradation in the ocean life-support system, undermining

its capacity to provide many of the services from which our society currently derives benefits. This would seriously limit our ability to achieve the objective of sustainable development. The first World Ocean Assessment concluded that we are running out of time to effectively protect the world ocean from multiple interactive stressors. Addressing these cumulative stressors must therefore become a priority research area. This in itself provides ample justification for a consolidated global effort. The problems and priorities are known and documented; we now need to orient ourselves towards providing science-based solutions.

Evaluation of the seriousness of these problems depends largely on science; finding the solutions will also depend upon science and technology, and will involve several science disciplines, including the social sciences, economics and engineering. However, most of the problems are a result of our actions and uses of the environment. Human behaviour is a major factor and society as a whole must be involved in addressing the issues and applying solutions that include behavioural change. This implies the involvement of policy- and decision-makers, industry, the public and private sectors, and the public, in what must be a truly holistic approach. The scientific community has an additional responsibility to communicate scientific data and results in a timely and understandable fashion to all these sectors. This will require a communication strategy that takes into account pride, prejudice and the perceptions of governments, as well as the public.

Scientific and technological motivation

Scientific and technological developments (including sustained ocean observations, data transmission and assimilation, modelling and communication of results to users) and international and intergovernmental cooperation and coordination, along with the pooling of resources, have led to the maturity of oceanography as a discipline. Oceanography is now able to provide oceanographic products and science-based ocean services for a wide range of sectors and interests, including ocean space planning, for a multitude of activities and needs, such as integrated management approaches and warning and protection from natural hazards. These services *inter alia* concern fisheries for food and food security, aquaculture, resources extraction, pollution, waste management, human health, tourism and recreation, coastal zone development and protection, sustainable development of the ocean economy, tsunamis and other ocean-generated natural hazards or those induced by society, and social processes such as transport, insurance and reinsurance. These services provide scientific knowledge and tools to support the protection of the ocean

and the Common Heritage of Humankind, with a view to maintaining a healthy ocean and building a sustainable future. However, there is a need for an intergovernmental mechanism to ensure cooperation and coordination, responsibility and adherence to international legal instruments, and to make sure that data, models, and the transmission and communication of forecasts and their use are properly achieved, managed and accounted for.

Institutional needs

Ocean research and observation activities cover a wide range of interests – some of which may conflict – and involve most sectors, users and uses, disciplines, transfers of technology and skills, technology development, industrial development and, most recently, biotechnology. All of these activities are of great socio-economic relevance, and ensuring that their benefits are shared in a fair way is a defining feature of UNCLOS, the Convention on Biological Diversity (CBD) and its Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization. Large economic interests and developments, including risk reduction, are coupled to and dependent upon ocean research, sampling (e.g. in the case of pharmaceuticals and other commercial applications of the findings of marine research), sustained observations and data retrieval. Observations of the ocean and coastal seas so far largely rest on scientific communities and involve several disciplines and institutions. Nevertheless, a gradual shift in the methods of observing the ocean is underway, from exploration to more sustained monitoring, with the aim of providing ocean services in forms that will eventually match meteorological weather services. Sustained ocean observations through the water column are also necessary in order to identify, confirm and trace possible changes, including to ocean circulation, which may be related to climate change.

The statutory role of the Intergovernmental Oceanographic Commission (IOC) is to promote coordination and cooperation in ocean research, services and capacity-building. Over the first three decades of the IOC, the number of institutions and other organizations that have recognized the marine environment or parts thereof as within their sphere of interest doubled (see, for example, Lie, 1990). This is reflected in the increase in the number of marine scientists, research and education institutions, as well as significant infrastructure investments for ocean observations. This trend is also reflected in the shift of ocean sciences from exploration by means of research vessels to permanent establishments of large distributed facilities (Field et al., 2002).

The diversity of interests – including the fast-growing development of ocean technology and an ocean economy, fragmented and essentially sector-oriented management (in spite of UNCLOS and the Sustainable Development Goals) – call for a unifying proposal to mobilize new resources from government and industry, as presented in the original proposal for an ocean science decade in Chapter 23. This is necessary to stimulate broader multistakeholder cooperation and to build partnerships in support of marine science and its applications and links to policy-making, alongside sustained observations and services with related capacity development and technology transfer, in order to meet the goal of sustainable ocean development.

The International Decade of Ocean Exploration 1971–1980 and the International Year of the Ocean 1998 generated substantial support for ocean-related activities at the local, national and global levels – in governments, civil society and scientific communities. On the occasion of the International Year of the Ocean, the IOC Secretariat prepared a dedicated programme covering a wide range of actions, including an ocean education kit, a press kit for public information and the launch of postal stamps commemorating the International Year. A website was prepared which included an Ocean Charter for signature by visitors to the site. The UNEP Regional Seas Programme launched a Musical Celebration of the International Year of the Ocean 'Save the Ocean for Life on Earth' (Merchán, 1998). National governments were willing to provide additional resources for research and infrastructure, while local governments supported local awareness-creating actions. An example is the 1998 publication by the National Oceanic and Atmospheric Administration (NOAA) *Year of the Ocean Discussion Papers*. This included contributions from a wide range of US Federal Agencies covering the role of the ocean for all essential sectors of society. These experiences are very positive and support the idea of launching another ocean decade to address current issues, priorities and uncertainties, and to promote the delivery of results in a timely fashion to users, in particular governments and concerned national agencies. The year 1998 also saw the publication of *The Ocean Our Future* – the report of the Independent World Commission on the Oceans, chaired by Mario Soares. During the International Year of the Ocean, the Sixth International Congress on the History of Oceanography was held in Qingdao, China, from 15–20 August 1998. It had very wide international community support, confirming the broad cooperation in oceanography (see Morcos et al., 2004).

The International Year of the Ocean 1998 brought further attention to the role of women in the development of ocean science, related cooperation, communication and public awareness.

Women in ocean science

For many years, oceanography was dominated by men. In a group photo from 1957 taken in Gothenburg on the occasion of a meeting on the oceanographic programmes of the International Geophysical Year 1957–58 and a SCOR Bureau meeting (see also Wolff, 1990 and 2010; Chapter 8), one can clearly see only two women with about 50 men. That group included most, if not all, leading oceanographers at the time: far from gender balance. This was despite the fact that major efforts in providing information in an accessible form and raising public awareness about the processes, conditions and importance for society of the ocean and coastal zone on basis of available scientific results were contributed by women.

Dr Rachel Carson was an initial leader in this context. Although she is best known for her *Silent Spring* published in 1962 (see also Chapters 8 and 14), she also published several books on the ocean and coastal zone, including *Under the Sea Wind* (1941), *The Sea Around Us* (1951) *and The Edge of the Sea* (1955). Dr Carson brought out the ecological relationships of ocean life and provided a guide to explaining the coastal zone using parts of the USA's Atlantic coast in *The Edge of the Sea*. In *The Sea Around Us* she gives a presentation of the evolution from the start, the grey beginning, the surface of the sea, the seasons, the air-sea interaction, the wind, the sun, the rotation of the Earth, the deep sea and the processes in the ocean. The book was a great success, presented in abbreviated form in the *Reader's Digest*, and a basis for a film which won the 1952 Oscar for Best Documentary Feature.[76] The book reached out globally through translations and adaptations. In Swedish it is entitled *Havet* (meaning 'The Sea'), with a large number of illustrations and references, showing cooperation in its preparation (Carson, 1959).

Rachel Carson did not discuss changes in the ocean related to actions of the human society; she considered that 'Man cannot control or change the ocean (…) as he has subdued and plundered the continents' (1950/1951). This relates to the statement by Dr Thomas Huxley in the 1880s that 'All the great sea fisheries are inexhaustible' and 'Nothing we can do can seriously affect the numbers of fish' (quotes from Simon, 1984). However, over the subsequent decades, science demonstrated that the sea is changing due to our actions.

Important, comprehensive, readable, awareness-creating accounts of these changes and their effects are given by Dr Anne W. Simon in several books, including *Neptune's Revenge: The Ocean of Tomorrow* (1984). This may be seen

76 See: https://awardsdatabase.oscars.org

as a follow-up to Rachel Carson's research. Anne Simon provides an overview of what is happening to the ocean on basis of available scientific information, together with identifications of actions needed to save the ocean. It was threatened by release of waste materials, sewage, toxic chemicals, radioactive wastes, oil spills and overfishing, e.g. of cod, flounder, herring and mackerel. The Atlantic salmon was threatened – the effects of acid rain could lead to its extinction. The accumulation of toxic chemicals in fish and shellfish, including PCBs, heavy metals and radioactive wastes, threatened human health. These points are also raised by Goldberg (1976) in the first review of the health of the ocean. Dr Simon managed to identify trends of changes by integrating information from several research disciplines, bringing out the multidimensional complexities of change and uncertainties in quantifications. She also noted that the changes are occurring over short timescales compared to the natural changes and the stability of the ocean, including the sea level since the end of last ice age. In the context of actions to save the ocean, Dr Simon brings out the political and legal problems of reaching the global agreements and the cooperation required to deal with the issues. This is evidenced in the process of reaching agreements on UNCLOS and the time-span from its signature in 1982, without the United States, and entering into force in November 1994. She nevertheless presents UNCLOS as the possible mechanism for saving the ocean. She credits Ambassador Arvid Pardo of Malta for initiating the comprehensive process through his appeal to the United Nations in 1967 (Simon, 1984, and here Chapters 10, 12 and 20).

This connects very well to the leading role of another woman scientist and communicator, Dr Elisabeth Mann Borgese. She provided strong support to Ambassador Pardo and the initiation of the UNCLOS negotiations in 1973 through organizing several interdisciplinary meetings in Malta, including participants from all relevant sectors and disciplines. These also led to the creation of the International Ocean Institute (IOI) (see also Chapter 13). Her legacy book *The Oceanic Circle: Governing the Seas as a Global Resource* was first published by the United Nations University during the International Year of the Ocean 1998. The book was launched by the Club of Rome in Canada on the occasion of the 26th Pacem in Maribus Conference, Halifax, November 1998. Dr Mann Borgese gave an explanation of the title in her speech when receiving an honorary degree at Yokohama City University, on 8 December 1998. It is related to the changes which are going on in the ocean and the socio-political order (elucidated further in Box 8). The life and contributions of Dr Mann Borgese are presented in the commemorative *Ocean Yearbook* volume 18 (Chircop and McConnell, 2004).

The Director of the UNEP Regional Seas Programme (see Chapter 17) in 1998 was Dr Terttu Melvasalo. She was also serving as the Chairperson of the Administrative Committee on Coordination Subcommittee on Oceans and Coastal Areas (SOCA, see also Chapter 25). Dr Melvasalo had contributed over several years to the development and implementation of the Helsinki Convention (see Chapter 17) and cooperation in relation to problems of the Baltic Sea environment, as well as to activities under the purview of the International Council for the Exploration of the Sea (ICES). It was possibly her experience from efforts to reach out and create public awareness in these contexts that triggered the idea of creating the Ocean Songs for the 1998 International Year of the Ocean. This is just one example of the contribution of women in raising the issues of the ocean and coastal areas in order to stimulate actions and cooperation on the basis of available scientific information.

The year 2002 was the period of preparation for the World Summit on Sustainable Development (WSSD) held towards the end of the year in Johannesburg, South Africa. During the preparations, some concerns emerged that the ocean issues might not be sufficiently addressed. This challenge was taken up by Dr (Prof.) Biliana Cicin-Sain. With the support of the IOC and its Executive Secretary Dr Patricio Bernal, she initiated the creation of the Global Forum of Ocean, Coasts and Islands to present the Ocean Agenda at WSSD (see also Chapter 20). This became a multistakeholder forum involving many participants from the required scientific and legal disciplines and user sectors, with strong civil society associations and support from a number of organizations. The forum succeeded in increasing the profile of the ocean and coasts in the conference – see, for example, Bernal (2010). It has since continued the efforts to address ocean issues through preparing overviews of processes and changes in the marine environment, often called policy briefs, together with an analysis of the related effects on the conditions, functions and impacts on society. Regular conferences and workshops involving a wide range of participants have been organized. Dr Biliana Cicin-Sain led the forum until the spring of 2021, when she passed away. She was an inspiring driver – very engaged, demanding and hardworking, and the author of many publications. The IOC provided support for her and her husband Dr Robert W. Knecht to complete their book *Integrated Coastal and Ocean Management: Concepts and Practices,* which was appropriately published in early 1998, the International Year of the Ocean.

The participation of women in ocean studies and marine research has steadily increased since the middle of the last century. Christina Reed (2009) in her review of the development over the century names two women as scientists of the decade: Lieutenant Mary Sears, who served as the editor of *Deep Sea*

Research, for the decade 1941–1950 and Dr (Prof.) Rita Colwell for the decade 1991–2000. The IOC has also matured into electing its first woman Executive Secretary in 2010: Dr Wendy Watson-Wright, who served until 2014. In the context of history, development and change, it seems appropriate to also recall the great contributions of another woman, namely Dr Margaret Deacon, who presented the history of oceanography over several books, in a scientific and comprehensible manner. This includes her contribution to *Ocean Sciences: Their History and Relation to Man*, which covers the history of ocean sciences and oceanography from 1650 to 1900, wherein she points out that ocean studies were carried out long before the *Challenger* expedition (Lenz and Deacon, 1990). She notes that 'if the history of oceanography has shown anything it is that ever since the modern era of scientific activity began in the mid-seventeenth century there have usually been plenty of ideas and observations around, even though would-be students of the ocean were all too often frustrated in carrying them beyond a preliminary stage by lack of adequate technical expertise and by the indifference of much of the scientific community and society at large. This dependence on external support and understanding affected oceanography at a much earlier stage in its development than most if not all other sciences and must be the main reason why its formal development occurred comparatively late in the last quarter of the nineteenth century'. This observation seems well reflected in the establishment of international institutions and cooperation in ocean sciences, including at the congress, which dedicated a special symposium to the subject. The congress elucidates the institutional developments from around 1850s, including references to Maury and the First International Conference on oceanography in Brussels 1853. Through that, the first international cooperation towards a worldwide oceanographical and meteorological data bank was settled with the related institutional framework (Houvenaghel, 1990). The respective roles of the three international institutions the ICES, SCOR and IOC are analysed in the context of the development of UNCLOS (Wooster, 1990); the requirement for institutional developments in this context is further highlighted in the ocean governance model of Dr Mann Borgese (see Box 8).

The sequence of developments also underlines the need to find appropriate ways of creating dialogues, building the necessary trust, understanding and strengthening cooperation, including by sharing responsibilities, data and results, as well as costs, investments and the maintenance of equipment. None of this is new, but the importance, urgency and scale are increasing, and there is much at stake. All sectors of society need be involved. Such approaches have been found and developed in the context of meteorological and hydrological services, and often in relation to fisheries, hydrographic services and sea level observations. Private weather, water, fisheries, insurance and reinsurance institutions use the

services provided by related intergovernmental and governmental institutions. In some cases, ocean-related institutions are involved, but in a more limited fashion. Attempts have been made to link with and provide services to the private sector, for instance by the IOI in the context of reinsurance and tourism – as well as by Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) in the context of coastal area management uses and port developments. What role could the IOC play? Examples exist that could be further analysed and used to build upon and expand the links between intergovernmental ocean institutions and the private sector; these are presented in the following chapters on mechanisms and the ocean economy. The ongoing changes in the ocean (summarized in Chapter 27) corroborate the need for increased cooperation and dialogue, the whole of which links to institutional development needs. An overview of applications to date (as presented in Chapter 28) might give some clues to possible ways forward. These applications confirm a broad institutional partnership involving multiple experiences and scientific disciplines in regional and global programmes, with support from governmental, private and global UN-related organizations. The analysis of trends in Chapter 29 indicates a further increase in the coming decade of applications, and possibly support for marine research and ocean observation-related applications, confirming the need to deal with associated institutional requirements. This issue is highlighted in the concluding chapter.

BOX 8. Ocean governance structure: The Oceanic Circle model

During Dr Mann Borgese's speech on the occasion of receiving an honorary degree at Yokohama City University (8 December 1998), she emphasized that the problems of ocean governance and management are multidimensional and, consequently, so are the needed instruments of change. An integrated approach is required; the dimensions of changes work on different timescales – legal, institutional and economic instruments may be established in a relatively short time, but changes in attitudes or ethics take much longer. It is, however, exactly these dimensions of human behaviour that will have to drive the whole development. The required changes, in particular in Western cultures, Dr Mann Borgese notes, concern equity, eradication of poverty, cooperation rather than competition and conflict, and relationships between humans and nature. The instruments of change need to be comprehensive. The primary legal instrument of change is UNCLOS, but there is a lack of institutions capable of enforcing – or willing to enforce – this comprehensive legal instrument. It is, however, supplemented by the institutional framework envisaged in Agenda 21 of UNCED 1992, particularly in Chapter 17 (see here Chapter 10). Both UNCLOS and Agenda 21 are global in outreach. Dr Mann Borgese then gives an overview of available or possible instruments of change, from the local to the global scale, which may function within the global framework of UNCLOS and Agenda 21.

At the local level, the 'co-management' system of governance is identified. This can include all major users of ocean and coastal space and the resources in planning, regulation and decision making. This system also provides a mechanism or framework for cooperation and responsibility sharing between local, provincial, federal and State authorities with a combination of top-down and bottom-up approaches. In order to be effective, the system of co-management at community level needs corresponding changes and instruments at the national level. Many instruments of change and innovative structures have emerged, including interministerial committees and commissions. Many of the 'closely interrelated problems of ocean space' transcend the boundaries of national jurisdiction. Hence, corresponding instruments of change are needed at the regional level. Several such instruments have emerged; Dr Mann Borgese in particular recalls the development of the Mediterranean Commission on Sustainable Development associated with the Barcelona Convention and the Mediterranean Action Plan

(see also Chapter 13). The commission involves the governments of the contracting parties and representatives of users, coastal communities and nongovernmental organizations, all having the same rights as the representatives of the governments. Dr Mann Borgese considers that by providing a direct link between the coastal communities and an international, intergovernmental body, the commission is an instrument of democratization.

Many of the interrelated problems of the ocean are also of a global nature and can be dealt with only at that level by the United Nations. There, the corresponding instruments are needed, and were emerging at the time. Dr Mann Borgese thus sees a system of ocean governance moving from the smallest to the widest circle, each depending on and needed by the other in what she refers to as 'the Oceanic Circle'.

Some applications

After leaving UNESCO in 1998, I had the honour of working closely with Dr Mann Borgese in the position of Executive Director of the IOI, based at its headquarters in Malta. Unfortunately this lasted only a few years. She passed away in early 2002; a great loss for us all.

Dr Mann Borgese had accepted the invitation to give the keynote address at the opening of the international conference 'Sea and Human Security', convened by the United Nations Institute for Training and Research (UNITAR) Office in Hiroshima under the direction and leadership of Dr Nassrine Azimi, in March 2002. In my capacity as Executive Director of the IOI, I was called upon to act as substitute for Dr Mann Borgese and deliver the keynote address. This I did, feeling both honoured and sad, using her draft as a basis. She had mentioned to me that she found the place of Hiroshima very appropriate for the subject of the conference. The event was a great success, even without her presence; in the published proceedings, Azimi et al. (2002) note that 'This conference and its proceedings are dedicated to Prof. Elisabeth Mann Borgese in honour of her life and her tireless work for the oceans'.

My participation in the conference gave me an additional reward in that I got the chance to work with Dr Azimi in her capacity as the Director of the UNITAR Hiroshima Office in a series of follow-up workshops on 'Sea and Human Security' in 2007, 2008 and 2009. These were all great experiences with participants from the global level (although mostly from Asia), all very dedicated and interested. The success of these

actions was mainly due to the tireless work of Dr Azimi, in cooperation with her staff and all the lecturers at the month-long workshops. I am indebted to Dr Azimi for inviting me to not only lecture but also lead the workshops.

It has also been my honour to work with several other very dedicated female ocean scientists and professionals. At the regional level, I wish to mention Dr Janet Pawlak, who served as the Environment Officer of ICES for many years. She was instrumental to the work of the ICES-SCOR Working Group on the Pollution of the Baltic (see Chapter 16). She has also contributed substantially to the reviews of the conditions of the Baltic prepared under the auspices of the Helsinki Convention with support of the ICES, and more recently to studies of conditions in the Arctic Basin. During my period at the IOC Secretariat, I worked very closely with Ms Natalie Phillippon, who was the head of the financial section of the secretariat. She also served as the Secretary of SOCA (see Chapter 25). Ms Phillippon was very dedicated and reliable and I was very happy that we worked so well together. A number of younger staff worked in the IOC Secretariat during my period there, such as Dr Helle Ravn and Ms Ksenia Yvinec, who is still there now as the head of the operational support unit. The number of women in the secretariat has steadily increased – in 2020 there were 28, constituting 48% of the total IOC-UNESCO workforce.[77]

77 Total IOC-UNESCO workforce (headcount) includes staff at headquarters and in the field in 2020, holding a contract within one of the following categories: fixed-term position, project appointment, temporary post, loan, secondment or service contract. Consultants and short-term contracts are not considered.

25 Modalities of cooperation and experiences from the IOC

Cooperative regional investigations

Cooperative regional investigations were the initial mechanism used by the Intergovernmental Oceanographic Commission (IOC) to generate ocean studies and build international and national cooperation in ocean science and observations – as well as to provide support at national level for the IOC-UNESCO programme on Training, Education and Mutual Assistance (TEMA). These projects were co-developed mostly with scientific communities and often in cooperation with the Scientific Committee on Oceanic Research (SCOR). The IOC ensured governmental cooperation with associations, and agreements, support and links between the associated countries and governments. The projects were essentially science-driven, but responded to national and regional needs and priorities. Well-known examples include the international tsunami warning system and the (first) International Indian Ocean Expedition, both initiated in the 1960s. The projects generated both interest and involvement among governments. In several cases, the initial projects were continued, expanded and led to the establishment of regional cooperative mechanisms of a more permanent nature. These later became IOC regional subsidiary bodies, committees and gradually subcommissions (see, for example, Roll, 1979; Kullenberg, 2016). Both the mechanism and the approach proved very successful, and the IOC, accordingly, invited other UN and regional intergovernmental bodies to cooperate and participate in regional projects and subsequent developments.

A formal mechanism

A growth in collaboration and the emergence of new bodies at the global and regional levels highlighted the need to establish a more formal foundation for interagency cooperation. In 1969, the Executive Board of UNESCO authorized the Director-General to negotiate with other interested UN agencies to establish a suitable mechanism to this end. The result was the Inter-Secretariat Committee on Scientific Programmes Relating to Oceanography (ICSPRO).

The objective of the new body was to contribute to the development of effective forms of cooperation among UN organizations concerned with ocean-related programmes, and to avoid duplication and overlapping in the planning and implementation of the expanded programme of international marine science (Roll, 1979). The founding members were the United Nations, the Food and Agriculture Organization of the United Nations (FAO), UNESCO, the World Meteorological Organization (WMO) and the International Maritime Organization (IMO, then IMCO), with the agreement signed by the executive heads of the agencies. ICSPRO was also open to participation by other UN agencies in the work of the committee.

The ICSPRO mechanism was created to provide support to the IOC for the development and implementation of a long-term study of the ocean (LEPOR), which the IOC subsequently decided to initiate through by the International Decade of Ocean Exploration (IDOE) programnmes; conversely, the IOC was expected to provide help to develop and implement projects and programmes of the member organizations of ICSPRO related to ocean science and observation. This cooperative mechanism was also established with the purpose of using the IOC as a joint specialized mechanism for member organizations and, possibly, other bodies with responsibilities for ocean studies and conditions. The IOC provided secretariat support for ICSPRO and the Secretary of the IOC participated in ICSPRO meetings. In addition, the partners were expected to contribute to the Secretariat of the IOC, to sustain its work through the relevant programmes of their respective organizations, and to call on the IOC for advice and review in the area of marine sciences (Roll, 1979).

The committee, as a formal mechanism, broadened the base of the IOC, thereby enabling it to fulfil its functions as an effective joint specialized mechanism for intergovernmental marine research. The importance and attention accorded initially to ICSPRO is reflected in the frequency of meetings, as well as the development of the IDOE. At its sixth session in December 1972, the committee considered revised terms of reference which specified the composition, purposes and functions of ICSPRO, as indicated above. These included that members should be prepared to contribute to the Secretariat of the IOC, to sustain the work of the commission through relevant parts of the programmes of their respective organizations, and to use the commission as appropriate for advice and review in the area of marine sciences. Any member who ceased to fulfil these conditions was expected to withdraw from the committee. The Principles and Procedures concerning the mutual relationship between the IOC and organizations participating in ICSPRO identified the operational parts of commitments expected to be fulfilled by the members. These principles specified

how the IOC would function as an effective joint specialized mechanism by assisting members with their functions in marine science. The principles also referred to the IOC Statutes; in particular, Article 3 of the Statutes reads: 'The organizations participating in ICSPRO shall endeavour to supply the commission, at their expenses, with personnel for the Secretariat, as needed by the commission to fulfil its task as a joint specialized mechanism'. The same article noted that the appointment of the Secretary of the IOC would be made by the Director-General of UNESCO, 'in consultation with the Executive Heads of the organizations participating in the Inter-Secretariat Committee'.

In the first decade the agreement functioned very well. In 1974, approximately one-quarter of staff salaries and operational funds spent by the IOC Secretariat came from the partners (Roll, 1979). The committee met regularly, at least once per year. This period was characterized by good economic conditions, the expansion of ocean science (including the IDOE) and a positive spirit underlying the negotiations for the United Nations Convention on the Law of the Sea (UNCLOS). However, problems gradually emerged relating to policy, resources and institutional issues, which proved difficult to handle. Despite these problems, ICSPRO agencies seconded staff and funds to the IOC Secretariat throughout the 1980s, with the last seconded senior staff member returned to the supporting agency in 1989. An evaluation prepared for the 11th Session of the Executive Council of the IOC in 1979 noted that, although IOC collaboration with a large number of organizations had overall been fruitful and effective, three main limitations had been identified: (i) the IOC Secretariat was too small to interact extensively with a large number of international organizations; (ii) the interests of the IOC and collaborating organizations did not coincide perfectly; (iii) the limited budget of the IOC and often collaborating organizations prevented the fulfilment of potential collaboration (IOC/EC-XI/17). Subsequent developments seem to basically confirm these observations. At the 27th Session of the IOC Executive Council, Paris, April 1989 (IOC/INF-779) each member organization, as well as the IOC itself, made reference to extreme financial limitations. The resulting severe austerity measures led the last two ICSPRO agencies to withdraw outposted staff members from the IOC Secretariat, despite the fact that cooperation with the agencies concerned – the FAO and IMO – was in fact increasing. Cooperation between the United Nations Environment Programme (UNEP) and the IOC was also very good and quite extensive during this period, and concerned programmes of clear benefit to both partners. At the Council meeting, it was noted that ICSPRO agencies were prepared to reconsider outposting staff members when financial conditions improved. The IOC could therefore continue to develop programme components of common interest to ICSPRO member organizations, thereby enhancing the role of the

IOC as a joint specialized mechanism. It should be noted that UNEP attended the 1989 meeting as an observer for the first time in ten years. This was an important development in view of the notable cooperation between the IOC and UNEP, and the related financial support to IOC programme implementation provided by UNEP. Although the mechanism was considered to be useful, the difficult financial situation placed serious limitations on direct support to the IOC Secretariat from partner agencies and fundamentally contradicted the idea behind the creation of the formal mechanism.

The working procedure of the committee included reviewing programmes of interest to several members. These concerned climate research, El Niño, the marine pollution programme GIPME, cooperative regional studies, the tsunami warning programme, the development and implementation of International Decade programmes and TEMA. The ICSPRO agencies were also included in the biennial programme forecast of the IOC. The committee was concerned about the continued development of the IOC and was invited to provide their views on the work to a review group concerning its future and functions. Some of the members and UNEP, which participated but was not a formal member of ICSPRO, raised the question of protection of the IOC budget, which was related to the status of the IOC within UNESCO. The view was expressed that contributions from ICSPRO agencies, as well as UNEP, should not, in accordance with the ICSPRO agreement and the statutes of the IOC, be subject to the authority of the General Conference of UNESCO. Interpretation of the status of the IOC within UNESCO, in particular relating to its 'functional autonomy', became an impediment to the IOC receiving support from ICSPRO agencies other than UNESCO. As an example, projects approved by the Governing Council of UNEP and contracted to the IOC as a 'joint specialized mechanism' for the ICSPRO agencies should and could only be subject to additional scrutiny by the IOC governing bodies and not by those of UNESCO. The committee in this context expressed an urgent need for clarification to all members already at the 17th Session of ICSPRO, held at the FAO in 1978. The committee also indicated the need to strengthen exchanges of information about its work and existence with other UN mechanisms concerned with the environment. In particular, representatives of member agencies to other groups or bodies needed to be properly informed and aware about the existence, objectives and work of ICSPRO, and its role and activities. This observation and the underlying situation constitute one important example of unsatisfactory information exchange and dialogue between UN organizations and among different sectors, as well as at the national level.

Overall, it can be concluded that the ICSPRO mechanism served its purpose very well during the first two decades (1969–1989), and in particular during the IDOE 1971–1980. However, in view of subsequent and recent developments, it does not appear logical or realistic to put much effort into revitalizing the committee. Some legal references and experiences, including logistical elements, could be drawn upon for the creation of a mechanism dedicated to the provision of ocean services and related products – on the basis of science, ocean technology with sustained ocean observations, dynamic modelling with data assimilation, related training, communication and transfer of marine technology, all in harmony with UNCLOS. The stakes involved seem to call for the establishment of an intergovernmental organization independent of others and with sufficient resources and authority, charged with addressing ocean needs as a whole. This should of course build on the IOC's experiences.

Strategic follow up to UNCED 1992

The year following the United Nations Conference on Environment and Development (UNCED) saw the creation of the Subcommittee on Oceans and Coastal Areas of the Administrative Committee on Coordination (SOCA), in part through an initiative of the IOC. SOCA was charged with guiding and supporting the implementation of Chapter 17 of Agenda 21: 'Protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their living resources'.[78] The IOC provided the Secretariat for SOCA,[79] delivering services to the committee through senior staff member Natalie Phillippon, whereas the role of chair was rotated among participating organizations. The committee fulfilled its role over the decade, but was abolished as part of the restructuring of UN governance at the beginning of the new millennium.

The adoption in 1995 of the Global Programme of Action on the Protection of the Marine Environment from Land-Based Activities aimed to address the related problem raised in Chapter 17, and UNEP was requested to lead the effort. Implementation of the programme is dependent on cooperation between many

78 See: https://www.un.org/Depts/los/consultative_process/documents/A21-Ch17.htm

79 Members and collaborators of the subcommittee included the Food and Agriculture Organization of the United Nations (FAO), the International Atomic Energy Agency (IAEA), IOC, the International Maritime Organization (IMO), the United Nations, United Nations Department of Economic and Social Affairs (UN-DESA), the United Nations Office of Legal Affairs/Division for Ocean Affairs and the Law of the Sea (UN-DOALOS), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), UNESCO, the United Nations Industrial Development Organization (UNIDO), the World Meteorological Organization (WMO), the World Bank, and the secretariats of the UN Convention on Biological Diversity and the United Nations Framework Convention on Climate Change (UNFCCC).

international agencies. However, no well-defined forum for such coordination existed, and SOCA could not fulfil this task. The needed mechanism was created by the General Assembly in 1999, following a proposal from the Commission for Sustainable Development, in the form of an open-ended informal consultative process on the oceans, for which UN-DOALOS was called to serve as the secretariat. The coordination of all activities was crucial and required the commitment of Member States and staff serving at intergovernmental organizations. This includes following a consistent policy at the national level in the various international bodies.

Co-sponsorships

An important mechanism for cooperation used extensively by the IOC is the co-sponsorship of programmes. This mechanism implies joint programmes and partnerships, and involves interested and like-minded partners who share costs, management and responsibility for programme formulation, support and implementation. This approach was a natural consequence of the original regional cooperative programmes and activities related to ICSPRO and the IDOE. The related projects were often co-sponsored and developed in cooperation with other bodies from the UN system, or other intergovernmental bodies. Accordingly, recalling some examples: the living resources programme was co-sponsored by the FAO; the marine pollution programme by several UN partners, including UNEP; the climate programme by SCOR (ICSU) and then, by the decision of the 16th Session of the IOC Assembly 1991, after negotiations with the WMO and ICSU leading to an agreed MoU signed by the co-sponsors in 1993, the IOC became a co-sponsor of the World Climate Research Programme (WCRP), together with the WMO and ICSU. The co-sponsorship mechanism supported the association of the ocean science and engineering communities with various ocean-related specialized global programmes. Evaluations of the environmental conditions, referred to as 'assessments', are frequent and mostly involve many contributing partners. These efforts may also be seen as co-sponsorships, with all partners sharing the responsibility. The IOC is contributing as a partner to many such assessments, as indicated here in the context of several programmes.

The co-sponsorship mechanism also provides for pooling of resources, joint support and specifications of actions, and broadening of participation in implementation, outreach and use of results. However, one serious problem concerns the presentation and application of results, whereby the origin and contributions from different sectors may not be adequately reflected in the presentation and explanation of results to users, including governments and decision-makers. It is essential that all sources of scientific information are

properly noted and acknowledged. This is particularly important in the case of scientific contributions, the importance of which is often forgotten or not properly acknowledged. This supports the need for an ocean science and observations organization with authority and independence – as well as sufficient means, status and government support – to take the lead on components dealing with science, observations and the communication of related results. This conclusion is corroborated by economic developments, especially the emergence of the blue economy.

26 Ocean economy: Increasing need for cooperation between sectors

The concept

Economic development, and economic growth in particular, are priorities for most governments and populations. The ocean plays a large role in the global economy, and the most advanced countries have demonstrated a clear interest in developing the potential of the ocean to support economic growth. The 'blue economy' concept, elaborated and presented by Gunter Pauli to the Club of Rome in 1994 and later published as a book (Pauli, 2010), is a further development going beyond the green economy concept. It argues for an integrated, holistic, system-oriented approach to economic development that takes into account the various interrelationships between processes in the environment and between human society and the environment. The blue economy approach incorporates ecosystem services, notably the provisioning, supporting, regulatory and cultural roles of the ecosystem. The goal is to achieve an ecosystem-based and sustainable way of using these services, the environment and resources, and – possibly – sustainable development. The basic principles of the blue economy are based on physics, the preservation of natural systems, matter and energy, and aim for no emissions and no waste. Gravity and solar radiation are the basic energy sources and water the primary solvent. An essential feature of the blue economy model is a focus on working at the community level and the local scale.

The rationale for adopting this approach here is linked to confirmed changes in the ocean and coastal environments, together with estimates of related costs in monetary terms (see Chapter 27). The changes, including with respect to sea level, erosion, warming, freshwater distribution, circulation, acidification and de-oxygenation, primary and food production, are paralleled by changes in human society and global conditions. There remain considerable uncertainties and gaps in our knowledge about how the system functions, and surprises may well emerge. However, what we know is that the uncertainties highlight the need to adopt a system-oriented and ecosystem-based approach to economic development, and to internalize ecosystem services and environmental costs

and implications. In addition, the uncertainties and gaps confirm the need to avoid large-scale engineering interventions in the life-supporting system of the ocean on the basis of short- and medium-term timescale observations and possible economic gains. Instead, considerable focus should be given to new technological developments, the recirculation and use of discarded material to supplement existing sources of material in short supply, or avoiding productions requiring high energy consumption and known high release of carbon dioxide.

Observations and reliable data over time are necessary elements for good decision-making, including with respect to the economy. Ocean observations can enable substantial economic and social benefits, which form part of the motivation for the Global Ocean Observing System (GOOS). Recent developments in European oceanography have been driven by community support for the development of a regional ocean observation network – EuroGOOS.[80] The services cover ecosystem-based management, advancing coastal oceanography integration, modelling and forecasting, and the further development of the European Ocean Observing System for multiple purposes (She et al., 2016).

Overall, developments in ocean research cooperation have advanced significantly in just over 100 years since the first initial cooperative ventures in the North Atlantic. The continued cooperation of the European states in the European Union and the European Commission is of great – probably critical – importance in this respect.

Interpretation of the ocean blue economy

The concept of the ocean blue economy refers to a form of economic management that aims to ensure the sustainability of marine resources and the marine environment. This implies sustainable development of marine resources and the ocean economy. Here, I make no distinction between marine resources, the marine environment or marine industry economics. Sustainable development may be understood to constitute a set of development programmes that meet basic human needs without violating long-term natural resources capacities or standards of environmental quality and social equity. However, this interpretation does not specify basic human needs. In relation to ocean policy and ocean economy, the United Nations Convention on the Law of the Sea (UNCLOS) specifies several basic human needs: peace, economic and environmental security, conservation of human heritage, freedom of access under responsibility, equity and benefit for all, application of the rule of law through responsibility for

80 Priorities and potential services are presented in She et al. (2016).

use and misuse, and accountability and transparency. The Law of the Sea meets the need for sustainable development and comprehensive human security, understood as the prevention of armed conflict, the promotion of peace and the fulfilment of basic human needs (e.g. Kullenberg, 2010a). The law provides for a code of conduct in developing the ocean blue economy version – an ecological code.[81]

A system-oriented approach to development in this context takes into account the various interrelationships between processes in the ocean and coastal seas, as well as between society and the environment – in other words, socio-economic implications. The size of blue ocean economy operations, even at local level, makes a system-oriented and ecosystem-based approach desirable in analysis and management. The goal must include sustainable use and maintenance of marine ecosystem services and internalization of the economic contributions of these services. They include provisioning (through primary and secondary production), supporting (e.g. through protections against coastal erosion or pollution), regulating (e.g. through maintaining a balance between producers and predators) and cultural-related services (through maintaining an attractive, healthy and aesthetic environment together with growth, in which maintenance of the life-supporting system is inherently included). This means that the economy must operate within the boundaries imposed by the ecosystem.

Ideally, the role of ecosystem services should be incorporated into the economic and socio-economic evaluations, and the costs of using ecosystem services should be integrated into economic valuations. There are various ways of doing this without knowing the precise value of the services in monetary terms. The price we are willing to pay for the services will always depend upon the circumstances and the quality of life the society in question demands or expects from a medium-term perspective. This could constitute an ecosystem-based approach depending on its feasibility, level of development and expectations. A chief focus is to maintain a healthy ocean and coastal sea for a healthy life – a blue ocean. This would constitute a system-oriented approach to organizing economics. The whole complex could form a basis from which to generate research as part of the new United Nations Decade of Ocean Science for Sustainable Development (2021–2030).

The basis for the interpretation of the ocean blue economy presented here is the confirmed changes in the ocean and coastal seas, including their size and scale in space and time, as presented in the following chapter. Comprehensive

81 The difficulties and differences in defining sustainable development are discussed in relation to ocean governance by Kullenberg et al. (2012).

international cooperative research programmes and reviews have firmly established that human activities are substantially impacting the total environment, including the ocean and the climate system. Human activities are also triggering global and regional changes in physical, chemical and biological conditions, affecting ecosystems and human societies. Various pressures on the marine environment have increased markedly over recent decades. These include offshore oil and gas exploration and exploitation, the expansion of fisheries into new areas (e.g. krill fisheries in the Southern Ocean), growing global transportation and shipping (including cruise liners), offshore and onshore extraction of renewable energy, aquaculture/mariculture production, enhanced uses of coastal areas for urbanization and increasing population density, land reclamation, infrastructure installations, ports, and recreation and tourism. These pressures can also lead to violence between communities, conflicts and competition between groups and interests, and a serious lack of security.[82]

82 For more detail on these points see, for example, Kullenberg (2001) and Goldberg (1994).

27 A brief overview of changes in the ocean and social and economic transformations and their assessment[83]

Changes in the marine environment

Warming. It is evident that the Earth is getting warmer. The planet's temperature has risen regularly over the last several decades, even taking into consideration natural variability. In high latitudes, the increase is stronger, with rises of up to 5–7 °C in Arctic areas. The ocean plays a significant role in this warming. The global mean sea surface temperature increased by 0.67 °C over the last century, and the mean temperature in the 0–2,000 m layer increased by 0.09 °C from 1955 to 2010. Warming in large marine ecosystems (LMEs) ranges between 0.08 °C (in Patagonia) and 1.35 °C (in the Baltic). Over the past 25 years, warming of above 0.96 °C has been observed in the North Sea, the East China Sea, Newfoundland and Black Sea. The rise in heat content is much greater in the ocean than in any other compartment of the Earth, accounting for about 93% of the overall increase. Storage and transport of heat in the ocean are central drivers of the global energy budget, affecting climate variability on timescales of months and seasons and their appearances, such as El Niño and the North Atlantic Oscillation. Heat inputs also influence the path of storms and flux of moisture (water vapour) across the oceans.

Salinity and freshwater. Our understanding of the freshwater budget of the ocean has increased significantly over the last decades due to the Argo programme, an array of profiling floats that measure temperature and salinity year-round in the upper 2 km of the ice-free ocean. These floats confirm that ocean salinity and, hence, freshwater content are changing on gyre- and basin-wide scales. These changes can have major implications for water mass composition and circulation patterns. The global hydrological cycle has intensified over the last 50 years, as evidenced by increasing salinity in areas dominated by evaporation and decreasing surface salinity in areas dominated by precipitation. Water

83 Data as of 2015, from the Intergovernmental Panel on Climate Change (IPCC) reports and studies, and policy briefs by the Global Forum on Oceans, Coasts and Islands.

transport from low to high latitudes and from the Atlantic to the Pacific has also increased. These changes are global in scale and are reflected in basins: subpolar surface and intermediate waters have freshened in the Atlantic and the Pacific, becoming less saline due to changes in the hydrological cycle; the intermediate water in the Southern Hemisphere has freshened in both the Atlantic and the Pacific; and freshening has occurred in the North Pacific, with an associated decrease in oxygen content there due to decreased vertical exchange, decreasing the ventilation. This process can also lead to a decrease in nutrient transfer to the surface productive layer, the euphotic zone. Freshening observed in the surface layer of the northern North Atlantic areas may be related to land runoff from melting ice in Greenland.

Ocean circulation. Changes in heat and salt content are linked to changes in ocean circulation. Salinity changes are consistent with an increase in the hydrological cycle over the ocean, and will generate changes in ocean advection. In the North Atlantic, warming has penetrated well below 1,000 m, and is particularly pronounced under the Gulf Stream and the North Atlantic Current at 40° N. While we know a great deal about the upper layer circulation which is largely wind-driven, we know less about the deep water circulation. This represents a serious gap in our knowledge of the ocean and the climate system. Observations from Argo floats may provide quantitative information about changes in ocean currents. There are also indications that deep water circulation and deep water formation in the North Atlantic is slowing. This may have significant consequences for weather conditions and the distribution of precipitation. Furthermore, there are concerns around changes in the western boundary currents, for instance the Gulf Stream, and the rates of the interior upwelling, and at the Antarctic continent.

Sea level rise. Over the last century, the sea level rose about 20 cm. The global mean sea level increased by 1.7 mm per year during the period 1900–2009; however, sea level rise for the period 1993–2009 was 3.2 mm per year. Recent satellite measurements of changes in the ice sheet mass balance allow for improvement in projections of sea level change during this century, related to temperature rise. Estimates for 2007 IPCC scenarios give a range of 75–190 cm for the period 1990–2100. However, it should be noted that there can be large spatial variations and differences in the rate of sea level change, as shown by the Atlantic coast of North America (Sallenger et al., 2012). Over scales of decades, the rate of sea level rise could be three to four times higher in certain hotspots along the coast than the global average. Furthermore, an increased rate of continental ice loss, e.g. on Greenland, will increase the rate of sea level rise.

Biogeochemistry. The ocean plays a key role in global biogeochemical cycles, and the confirmed changes summarized below will affect the marine biogeochemical cycles, including carbon, oxygen and nutrients. The ocean has always been a large reservoir for carbon dioxide. However, the net additional uptake since the industrial revolution has led to a gradual acidification of the ocean. The fraction of carbon dioxide emissions from fossil fuel and cement production taken up by the ocean has decreased from about 48 ± 9% during 1800–1994, to 34 ± 6% during 1990–99, to 30 ± 7% during 2002–11. However, the estimated mean uptake has increased from 1.5 ± 0.5 GtC per year in the 1960s to 2.5 ± 0.5 GtC per year for 2002–11.

When carbon dioxide enters the ocean, it divides into dissolved carbon dioxide gas, bicarbonate and carbonate ions, becoming carbonic acid. This process of division is guided by the pH of the sea water. As more carbon dioxide enters the ocean, the pH decreases, which increases the fraction of dissolved carbon dioxide and reduces the fraction of carbonate ions. The partial pressure of carbon dioxide increases accordingly, decreasing the uptake from the atmosphere. The decrease in carbonate ions implies difficulties for organisms to form calcium carbonate, impacting phytoplankton and zooplankton and corals, and other animals with calcium carbonate skeletal structures. Acidification thus has very serious consequences for life-supporting systems. It damages coral reefs, decreasing their protection of islands against erosion and sea level rise. Continued increase of carbon dioxide uptake may lead by 2100 to a decrease in pH by 0.4 units, compared to the present observed rate of 0.1 unit, and an increase in the amount of hydrogen ions by about 150%, compared to the present rate of 26%. This would result in a level of ocean acidity higher than at any other time over the last 130 million years. This change is occurring over several decades – a period that is very short compared to geological and evolutionary timescales. Observations in the Pacific indicate that the rate of acidification is greater than initially suggested.

The International Geosphere-Biosphere Programme (IGBP) investigated ocean acidification in cooperation with the Scientific Committee on Oceanic Research (SCOR) and IOC-UNESCO. The programme presented a summary for policy-makers (IGBP et al., 2013), which noted that ocean acidification research is growing rapidly, with 540 experts and 37 countries attending the 3rd Symposium on the Ocean in a High-CO_2 world (September 2012). It also stated that the acidification process has the potential to affect food security, limit the capacity of the ocean to absorb carbon dioxide from human emissions and provoke substantial economic impacts. Both research on and observations of ocean acidification are organized through the IOC led Global Ocean Acidification

Observing Network (GOA-ON) (for requirements and a governance plan, see Newton et al., 2014). The Intergovernmental Oceanographic Commission (IOC) was appointed as the custodian agency responsible for developing the methodology and collecting the data underpinning SDG indicator 14.3.1, which deals with ocean pH and acidification.

Eutrophication, oxygen levels and biodiversity. Nutrient enrichment of marine systems, in particular through excess use of nitrogen fertilization, has been well documented in many coastal areas and shelf seas. This process has resulted in an increasing spread of dead zones with dissolved levels of oxygen below 2 ml/l since the 1960s, a condition known as hypoxia. Confirmed examples include the Baltic Sea, the Black Sea, the Gulf of Mexico and the East China Sea. Changes in land runoff have also influenced the ratio and balance between nutrients. This may lead to complete changes in dominant primary producers, with consequences up the food chain and for biodiversity. Since the 1960s, the number of dead zones has approximately doubled each decade. The warming leads to higher rates of oxidation of organic material and thus faster use of available oxygen. In conditions of slow water exchange or stagnation, this can lead to oxygen depletion and complete lack of oxygen, as observed in the bottom and deep water areas of the Baltic Sea. Habitat requirements and resilience are also impacted, but these processes have not yet been clarified. Habitat compression and loss of fauna as a result of hypoxia have very serious implications for ecosystem functioning, energy and biodiversity. In addition, shifts in plankton biomass have been observed in the North Atlantic, the North Pacific and the Southern Indian Ocean, and decreasing chlorophyll a and primary production have been documented in LMEs since 1978. Breitburg et al. (2018) provide an overview of present knowledge regarding the decline in oxygen in the ocean, including its effects and implications, based on research and findings of scientists of the Global Ocean Oxygen Network (GO_2NE) established by the IOC in 2016. The review also represents an example of interdisciplinary scientific analysis and communication to policy-makers and the public, made possible through global cooperation.

High latitudes. The high latitudes play a major role in the global climate and life-support systems. Changes occurring in the Arctic have significant implications for the climate and the ocean ecosystem. They also have serious consequences for society, including for boundary limitations, marine industries and technological developments, including shipping, fisheries, oil and gas, tourism and the blue economy. Temperature has increased measurably at these latitudes with a decrease in the extent, thickness and duration of ice cover. The albedo – the reflection of incoming sunlight – has changed accordingly, influencing

the temperature, which is also affected by warmer inflowing Atlantic water. A freshening is occurring due to change in runoff from land and an intensification of the hydrological cycle. This may influence the deep water formation in the area and, as a consequence, the inflow of warm Atlantic water. Changes are also occurring in the Southern Ocean and the Antarctic regions, including greater presence of people, industries (fisheries and tourism) and shifts in temperature. The Antarctic ice cover does not appear to be decreasing from above; however, the West Antarctic ice shelf seems to be melting from below, which will have serious implications for sea level.

Conclusion. Human activities are influencing ocean conditions in ways and at a speed and intensity that seriously threaten the Earth's life-support system. These changes are compounded by climate change and climate variability, which influence weather patterns and seasonal conditions. Slow climate variability phenomena such as El Niño, the monsoon and the North Atlantic Oscillation are also likely affected, and increased occurrence of extreme weather events seems to be confirmed. The occurrence of natural disasters has increased in all regions of the world over the last three to four decades. In South Asia, the annual average has increased from two to three natural disasters between 1981 and 1990 to five between 2001 and 2010, and in East Asia from two to four over the same period. We have to prepare for these risks and build our capacity to deal with their consequences. The same dilemma is faced in relation to the range of warming – mitigation or adaptation – although adopting both approaches is preferable. The social cost of warming can be very high: higher temperatures influence human health and weaken our resistance to various health issues and diseases. It is therefore vital to explore adaptation and mitigation possibilities and to make adjustments in life styles. Ocean and climate science can provide a range of options. However, policy will ultimately determine which level of risk is acceptable, and public acceptance will play a major role in terms of solutions, taxation and changes in the supply of basic resources.

Social changes and globalization

In parallel, the world is undergoing large social changes. Chief among these are population increase, migration to coastal zones and urbanization, including the growth of numerous coastal megacities. These trends all lead to concerns for the availability of food, freshwater and energy, as well as for waste production, security, social justice and equity. Managing these problems will require the use and further development of communication tools to reach and warn large parts of the populations. In some cases, this can be achieved well in advance.

The other trend of significance is globalization. This ongoing transformation implies greater mobility of goods, people and capital, as well as diseases, pollution, organized crime and terrorism. Boundaries are becoming more diffuse and closer with increasing need for cultural understanding, solidarity and cooperation. Globalization also leads to increased competition, potentially marginalization, and drives expansion in economies, policy and regions. The same trend is apparent in the context of the ocean economy, including through the establishment of exclusive economic zones (EEZs), vast land reclamations, river diversions and regionalization (see, for example, Kullenberg 1999b regarding the role of EEZs). All of these changes influence economic development and lead to a shift in the perception of security. An all-embracing approach to security management is needed: comprehensive infrastructure and human security (e.g. Kullenberg, 2002). To achieve this, we need a reasonable understanding of the system with which we operate, as well as its interactions and interdependencies across natural, social, economic and political environments. This highlights the need for cooperation between sectors, disciplines and users as well as authorities, management and managers. Crucially, this means cooperation with transparency and communication, which help to build trust.

The economic potential of ocean services

At the end of the last century, the economic impact of global marine industries was estimated at approximately US$7 trillion per year. The most significant factors in this estimate are seaborne trade and cruise tourism, followed by the submarine fibre optics cable industry (Mann Borgese, 1998). Other estimates give values in the range of US$2–4 trillion, not including the value of transported goods. Current developments in science and technology will increase the value of marine industries considerably. This potential includes marine biotechnology. Thousands of bioactive substances have been identified and the financial rewards for the development of anti-virus and anti-cancer drugs are large. Microbial genetic resources found in the deep sea also offer significant potential for industrial development (Aricò and Salpin, 2005; Leary et al., 2009; Mann Borgese, 1998).

The potential to extract renewable energy from the ocean should also be noted. Tidal plants have long been operational, but may have negative consequences for the coastal environment. However, extraction of wave energy in near-shore and coastal areas is increasing in many regions, and can provide clean renewable energy. Wind farms at sea are also being established, although the placement of such installations needs to be evaluated in the light of other uses including shipping transport, fishing, tourism and recreation. Coastal constructions

could possibly be used for storing energy in dams using sea water. Other energy sources include ocean currents, such as the Florida Current, and ocean thermal energy conversion. The latter could be particularly useful for parts of the Pacific, including Small Island Developing States. The costs of many forms of renewable energy production have decreased over the last decade, and are comparably very low when the implications of fossil fuel energy for human health and security, the environment and the climate are taken into account – which they should be.

Fossil fuel sources in the form of methane hydrates in or below the sea floor have been estimated to roughly double terrestrial sources. However, it must be noted that if we wish to achieve the goal of preventing global warming from exceeding an average of 2 °C – at most – we can burn only 1 trillion tonnes of carbon, and over half of that amount was already used in 2013, according to IPCC evaluations. Moreover, the global average temperature increase in 2018/2019 was 1.2 °C. Furthermore, the ocean has the potential to deliver hydrogen to support the nuclear fusion process – the ultimate energy source, as found in the Sun. Methane hydrates may conceivably be used at the bottom of the ocean to drive fuel cells generating hydrogen, which can be transferred to land use. Attempts have been made to estimate in monetary terms the value of the ecosystem services provided by the ocean and other ecosystems, including protection against storms and floods, nitrogen fixation and plant-derived pharmaceuticals, from biomes such as oceans, estuaries and tropical forests. The figure from one research group, which included 17 categories of goods and services, was US$30 trillion annually. Of this, the ocean and coastal systems provided US$21 trillion (Costanza et al., 1997; also Mann Borgese, 1998). However, these estimates contain a large measure of uncertainty. With such a large range, can these evaluations have any practical value? If we accept the need for sustained performance of the system, then the functions and values of maintenance activities performed by the ecosystem are of critical importance and need to be factored in – perhaps by designing a system that allows risks to be spread in an optimum manner.

To put the above values in perspective, the gross domestic products (GDP) of the United States, the European Union and China in 2014–15 were about US$15.7 trillion, US$12 trillion and US$8 trillion, respectively. The world GDP for the same period was about US$80 trillion. The ocean economy is of the same order as the examples of national domestic product, and amounts to about 10% of the world GDP. In China, the ocean economy accounted for about 10% of GDP, in the European Union about 5%, and in the United States 1–3% (not including the coastal zone). However, in many small island states, the contribution of the ocean to the economy can be up to 80%, including fisheries and tourism. In

these states, the costs of natural disasters are estimated through insurance losses and possible losses in tourism revenue. Data from the Asia Pacific Economic Cooperation (APEC) show that the Asia-Pacific region accounts for 40% of the global population, 55% of global GDP and 44% of world trade. Trade has grown by a factor of seven over 1990–2010, reaching US$11 trillion in 2011, and the ocean played a sizeable role in this development.

However, the region also leads in the occurrence of natural disasters (see Chapter 20). In order to cope with such risks, governments need to put in place not only strategies for response and recovery, but also for preparedness, warning, and cooperation and communication. In 2011, the tsunami and earthquake that struck Japan and flooding in South-East Asia generated economic losses of US$294 billion, accounting for 80% of global losses that year due to natural disasters. These global losses were equivalent to about 0.5% of world GDP.

The costs of changing our energy sources from fossil fuels to alternatives – thereby addressing at least in part emissions related to climate change by limiting the temperature increase to 2–2.5 °C – have been estimated to be in the range of 1–2% of world GDP. At present, the contribution of the ocean economy to the global economy is estimated at about 10%, as shown above, highlighting the significance of the ocean economy and ecosystem services. The potential of ocean services can be further elucidated by providing some additional details about the ocean economy and the contribution of ocean science.

The ocean economy and the contribution of ocean science

Forecasting and the ocean economy. The ocean holds the key to many things, including the timing and amplitude of human-induced climate change. Through ocean observations of large parts of the water column and ocean areas, by means of drifting buoys delivering data on temperature and salinity in near-real time, it is possible to deliver reasonable forecasts of climate variability and conditions over timescales of months to seasons. These include predictions focused on El Niño and the Indian Ocean monsoon. Such forecasts can significantly help populations prepare for droughts, flooding, freshwater shortages, and disruptions in transportation, fisheries and food supply, as well as agriculture management. On most continents, river transportation is strongly influenced by precipitation distribution as it impacts water levels. Disruption of transport routes can have very serious economic consequences. At the global level, the impact of changing precipitation patterns, together with variation in the extent and occurrence of droughts, is of great importance. For example, the recent decrease in the water level of the Panama Canal during the rainy season makes the passage of large

container vessels uncertain (*The Economist*, 2019). It is therefore clear that adequate seasonal forecasting is of great economic and social importance.

Improved and extended forecasts of extreme weather events are likewise obtainable, allowing for a higher degree of preparedness than before. Rapid and widespread means of electronic communication allows these warnings to reach large parts of the population. This requires training in their use, as well as their limitations, and knowledge of which sectors and communities need to be reached. Ocean observations can play a critical role in the success of preparedness. They enable forecasting over longer time periods than weather forecasts – stretching over a season or half a season. This can help with planning for agriculture, transport, construction, social conditions (including human health), in particular in areas where extremes occur. These developments are also highly significant in the context of the insurance and tourism industries, both of which play an increasing role in the global service economy. However, ongoing climate change makes weather forecasting more difficult and uncertain compared to more stable climate conditions. Nevertheless, the linkages between environmental, social and economic processes and conditions are well demonstrated and documented. It is thus possible to evaluate the implications in relation to the development of the blue economy. Notable challenges will include finding the right balance between economic growth and ecological sustainability, avoiding disturbances beyond the ability of the ecosystem to self-repair, and ensuring the involvement of high-level representatives of government and the private sector, with a view to promoting understanding, participation and constructive leadership – in short, cooperation for the benefit of all.

Cooperation and the ocean economy. The United Nations Convention on the Law of the Sea (UNCLOS) was achieved through persistence, global cooperation and consensus, including necessary compromises. The development of the blue economy will also necessitate the involvement of all stakeholders and institutions, agencies, ministries, industries and public bodies, as well as the scientific community, in order to seek consensus and achieve the right balance. This process will involve cross-sector exchanges, dialogue, cooperation and trust, both nationally and internationally, so as to avoid tensions, and address conflicts of interests through dialogue and negotiations. Participating parties will need to be able to negotiate and address potential multiple conflicts, and be proactive in terms of outreach and dialogue. Furthermore, the process will require enhanced dialogue and communication between the sciences (natural, social, nutrition, health and economy), the public, management, political decision-makers and government. Training and capacity-building will be essential to ensure success, including adequate research to achieve understanding and acceptance. This is

also necessary in order to build public awareness, trust and participation, in particular at the local community level.

The development of oceanography over the 150 years since the *Challenger* expedition confirms the idea that wealth is created through a combination of knowledge and cooperation (see, for example, Pinker, 2018). This is reflected in the emergence of the ocean economy. It is also mirrored in the early establishment of the mutual insurance mechanism for shipping by the island of Rhodes in 800 BC (see Chapter 7) (Chua et al., 2008). Under present conditions, the costs of natural disasters and climate change, which can exacerbate disasters, constitute strong motivations for using our much improved understanding of the natural system to enhance security against such disasters. Combining knowledge with experience, cooperation and networking will help enhance security and create improved livelihoods and associated wealth.

The ocean economy and the role of the IOC

The *IOC Biennial Report 2014–2015* (IOC-UNESCO, 2016) notes that growing pressure on the ocean from a multitude of uses, users and waste inputs underscores the need to 'move from single-sector approaches to a multisector ecosystem approach' in providing scientific support to ocean development and maintaining valuable ocean ecosystem services. The IOC has made progress in this direction, for instance by assisting Member States in implementing integrated coastal zone (area) management and marine spatial planning. The increasing interest in ocean areas beyond national jurisdiction makes this approach even more desirable. The limited knowledge about these vast areas of the ocean highlights the need for international and intergovernmental collaboration on science and observations – both to increase our knowledge and ensure its dissemination in accordance with the spirit of the Common Heritage of Humankind.

The IOC has an opportunity to fulfil these aspirations through the Ocean Decade, linking together the tasks defined in its strategy for 2014–21 – sustained ocean observations, data exchange, research, decision-making, assessment, governance, capacity-building and services – and by capitalizing on the results and experiences obtained in ongoing IOC programmes and subsidiary bodies. This could lead to the consolidation of IOC activities around the core requirements of Member States, notably through the creation of oceanographic products in support of sustainable development and research seeking solutions to current issues. The desire to follow this path is underlined by enhanced national interest in deep ocean resources, living and non-living, for instance those associated with the deep sea thermal vents of the Area of UNCLOS. Such an approach would

also match the multispecies approach in fisheries management and provide for sustained interest in and support for ocean observations and research. It is the task of IOC to facilitate these activities through intergovernmental cooperation and coordination. This approach will also help to improve 'ocean science and governance for the development of sustainable knowledge-based economics' (UN Secretary-General's Scientific Advisory Board, see UNESCO, 2016). Until the end of the last century, ocean science issues, the contributions of ocean research and observations to society, management and governance were dealt with in a very fragmented manner (see Kullenberg, 1999a). However, present efforts, as shown in the following chapter, related to the development, use and applications of ongoing ocean science and observation services, suggest increasing interest in benefiting more comprehensively from their contributions.

28 Examples of ongoing cooperative service programmes in ocean science

The development of oceanography and its relationship to social, technological and economic developments in recent decades is reflected in most of the ongoing programmes involving the Intergovernmental Oceanographic Commission (IOC) and many other bodies associated with, or part of, the UN system. These are all cooperative efforts.

The Global Ocean Observing System (GOOS)

The initial development and subsequent experiences of coordinated ocean observations over several decades – including the Integrated Global Ocean Station System, sea level observations and marine pollution monitoring efforts as well as associated technological developments, evident for instance in the World Ocean Circulation Experiment, the Tropical Ocean Global Atmosphere Experiment and the programmes of the International Decade of Ocean Exploration (IDOE) – together with the growing need for sustained ocean observations, provided the basis for the establishment of GOOS. The formal decision to establish GOOS was taken by the IOC Assembly in June 1989. The World Meteorological Organization (WMO) and the International Council for Science (ICSU) became co-sponsors. Calls for systematic global ocean observations at the second World Climate Conference in 1990 reinforced support for GOOS. The Conference furthermore proceeded to confirm the establishment by the WMO of the Global Climate Observing System (GCOS), co-sponsored by the IOC and ICSU.

The Millennium implementation arm of GOOS – established in 1999 through the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology – mostly addressed open ocean needs. Strategic priorities included: disaster risk reduction; a global framework for climate services; an Expert Team on Operational Ocean Forecast Systems, to develop standards for intercomparison and related guidelines; and the Cross-cutting Task Team on Integrated Marine Meteorological and Oceanographic Services within the WMO Information System. Additional activities included an *in situ* Observing Programme Supporting Centre in Brest, France, and the new Centre for Marine-

Meteorological and Oceanographic Climate Data based at the National Marine Data and Information Service, Tianjin, China.

Management of GOOS is based on *A Framework for Ocean Observing* (Task Team for an Integrated Framework for Sustained Ocean Observing, 2012). Over the period 2015–19, it focused on the operation of the Physics and Climate Panel (OOPC) and the coordination of existing *in situ* observing networks, reflecting the limitations of resources, despite contributions from Australia, the European Commission and the United States. The development of the coastal and shelf seas aspects of GOOS were generated through a regional approach, with Member States sharing a common sea area working together in GOOS Regional Alliances (Holland and Pugh, 2010). Cooperation through the Global Coastal Network has helped to ensure interaction and clarify variability and change from global to local scales. The global component is required to capture the linkages of global conditions to regional impacts. These in turn are influenced by teleconnections between different areas and regions.

Ocean observations organized through GOOS contribute to the implementation of the United Nations Convention on the Law of the Sea (UNCLOS) (United Nations, 1983). In particular, they meet needs related to the following sections of the Convention: EEZ (V); the Continental Shelf (VI); the High Seas (VII, mainly Section 2); Enclosed and Semi-enclosed Seas (IX); the 'Area' (XI); Protection and Preservation of the Marine Environment (XII); Marine Scientific Research (XIII); and Development and Transfer of Marine Technology (XIV); as well as elements of Settlement of Disputes (XV) and General Provisions (XVI). GOOS involves floats, satellites and ships, the operation of which also depends on the implementation, interpretation and application of UNCLOS provisions.

The structure and scope of GOOS were reformed at the 26th Session of the IOC Assembly in 2011, creating the GOOS Steering Committee (GSC), which met in 2012 and 2013 to review progress. The challenge remains to achieve the agreed global targets. The JCOMM Observing Programme Support Centre in Brest, maintained by voluntary contributions over the period 2008–13, served as a platform of cooperation for technical coordination and support to operators of the GOOS *in situ* networks. This includes time series stations and ship hydrography. The tracking system then showed a 62% implementation level for GOOS and a below 50% real-time data return for the tropical Pacific moored array due to a reduction in cruises for controlling and exchanging moorings. This has gradually been rectified in subsequent years. At the same time, the Argo profiling float network delivered its millionth profile in 2012. The overview given in the *IOC Biennial Report 2014–2015* (IOC-UNESCO, 2016) showed an increasing trend in coverage and numbers of floats.

Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM)

The Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) was formally established in May/June 1999 through agreements signed between the Governing Bodies of the WMO and IOC. The background, conditions and negotiations leading to this new cooperative venture are presented and analysed in detail by Peter Dexter (WMO, 2020), along with lessons learned from the process. The author notes differences in the prevailing attitudes of meteorologists and oceanographers in the decades prior to the agreements, which began to evolve in the late 1970s and 1980s. He concludes that 'the active support of the oceanographic community was essential to the establishment of JCOMM. The support involved the ocean research community, and crucially also the associated intergovernmental ocean community through the IOC. It is critical that the IOC has, and is seen to have, a real ownership of the collaborative activities in equal partnership with WMO'. Peter Dexter explores the work of JCOMM over two decades up to 2019. He notes that it is 'equally important for the successors to JCOMM to facilitate, assist and even drive closer relationships between the meteorological and oceanographic communities at the national end'. The new structure for management of joint ocean observing ventures 'should lead to development of greater synergies between the work on oceanography and marine meteorology'. This will all depend on the work of the new Joint WMO-IOC Collaborative Board, which should greatly expand the active collaboration between the two organizations. Furthermore, 'the Collaborative Board should enhance the ability of WMO and the IOC to encourage and support the increased cooperation and collaboration of the meteorological and oceanographic communities at national level, which was always a focus of JCOMM'. The Joint Commission was terminated in 2020 in context of restructuring of the WMO.

Having been involved in discussions from the start of the initiative and throughout the 1990s, I can fully concur with the analysis of Peter Dexter. Cooperation and trust between the oceanographic and meteorological communities at national, governmental, international and intergovernmental level will also be essential to the success of the United Nations Decade of Ocean Science for Sustainable Development 2021–2030, particularly in relation to delivering services to society and identifying solutions to ocean-based problems.

The International Ocean Carbon Coordination Project (IOCCP)

Time series of observations are necessary to confirm changes in the ocean. In order to make comparisons among different time series produced around the world, it is essential to agree upon the method used. This subject was the focus of the International Ocean Carbon Coordination Project (IOCCP) workshop in 2012, which discussed common standards and methods for comparisons of specific time series. In addition, the surface ocean CO_2 database of IOCCP recorded over 6 million datasets in this year. The IOC is compiling existing biogeochemical time series and has put together 33 sites from the workshop with others from the North Atlantic. In total, 125 such time series were compiled by 2014, constituting a key contribution of the IOC to standard setting. The time series supported the development of a monitoring network for standardized observations of ocean acidification. The partners involved in the development of the network – the IOC, the National Oceanic and Atmospheric Administration (NOAA) and IOCCP – have established a Global Ocean Acidification Observing Network (GOA-ON). The 3rd symposium on the Ocean in a High CO_2 World stressed the need to combine CO_2 observations with other stressors such as temperature, nutrient availability and hypoxia.[84]

Hazard warning systems and risk reduction

The transformation to multi- and interdisciplinary, system-oriented ocean research is an ongoing process. Observation technology has advanced significantly, allowing for improved early warning possibilities, with integrated coastal area management (ICAM) becoming the norm. The vulnerabilities of many coastal areas and islands are self-evident, and risk-reduction, preparedness and training in the use of early warnings for hazards originating at sea are now considered vital to saving lives and property. However, it was the Indian Ocean tsunami in December 2004, caused by an earthquake off Indonesia, that generated the political will to support the establishment of tsunami warning systems in regions beyond the Pacific Ocean, despite several warnings and calls for action by the IOC in previous years.[85] On the basis of its experience with the Pacific tsunami warning system, the IOC was asked to lead intergovernmental cooperation within the United Nations for the creation of other similar warning systems. This has led to the establishment of three additional tsunami warning

84 An initial *Ocean Acidification Summary for Policy Makers* was published in 2013 (IGBP et al., 2013).

85 In a chapter on hazards and warnings in the book *Troubled Waters* (2010), David Pugh discusses the motivation for and operation of some of the warning systems developed by governments in response to coastal flooding disasters, and gives an overview of related activities of the IOC.

systems, with Intergovernmental Coordination Groups, in 2005. The first of these to become formally operational was the Indian Ocean System in June 2006.

Other hazards resulting from the ocean include storm surges and flooding driven by sustained ocean waves and swells from distant storms, all of which are exacerbated by rising sea levels, also leading to inundation. The International Decade of Natural Disaster Reduction (IDNDR) 1990–2000 led to the creation of the International Strategy for Disaster Reduction. The IOC has supported this process by incorporating other hazards into the tsunami warning system, thereby establishing the Global Tsunami and other Ocean-related Hazards Early Warning System. Over the period 2005–15, the compilation of scientific information on storm surges, flooding, tsunamis, sea level rise and coastal erosion has resulted in the formulation of guidelines by the IOC ICAM programme on coping with such hazards – and for establishing integrated coastal area management, adapting coastal environments to climate change and undertaking marine spatial planning.[86]

The agreement on the Sendai Framework for Disaster Risk Reduction 2015–2030 resulting from the risk reduction intergovernmental UN programme and conference, in Sendai, Japan, highlights the need for international, subregional, regional and transboundary cooperation, while also calling for a broader people-centred preventive approach to disaster risk reduction. The Sendai Framework for Disaster Risk Reduction 2015–2030 identifies several targets and priorities to prevent new and reduce existing disaster risk, including understanding risk, strengthening related governance, and investing in reduction and resilience enhancing preparedness (United Nations, 2015). It was adopted at the Third UN World Conference on Disaster Risk Reduction in March 2015. It covers themes such as climate change, the environment and ecosystems, risk identification and assessment and disaster risk management. The framework also specifies a number of national and local actions including:

- the collection, analysis, management and use of relevant data and practical information;
- the use and strengthening of baselines and periodic assessment of disaster risk and vulnerability and exposure;
- the promotion of real-time access to reliable data;
- the promotion and improvement of dialogue and cooperation among scientific and technological communities, other stakeholders and policy-makers;

86 See IOC-UNESCO/WMO, 2009. See also IOC Biennial Reports (2014, 2016), and UNISDR, 2007.

- the creation and facilitation of dialogue between science and policy for effective decision making;
- the strengthening of technical and scientific capacity to capitalize on and apply existing knowledge to develop and use models to assess disaster risks, vulnerabilities and exposure to all hazards.

The regional intergovernmental cooperative platforms of the IOC could help and support most of these activities at national and local levels, in particular through the involvement of their scientific and technical communities and practitioners. They could also help increase the availability of and access to multihazard early warning systems for people and provide disaster risk information and assessments to communities.

Training and data exchange

Regional activities have increasingly focused on the development of regional networks to promote training and data and information exchange and management. The first such network was created in Eastern Africa in the 1980s. In 1997, the Ocean Data and Information Network for Eastern Africa extended its coverage throughout the region while a similar process was undertaken in Western Africa. This led to the creation of the Pan-African Ocean Data and Information Network. The success of these activities over the last decade has triggered the creation of similar networks in several other regions. Cooperation and coordination have been essential to these developments, with regional cooperation supporting the co-development and integration of sustainable development with regional security (e.g. Kullenberg, 2002).

Another information initiative rooted in international cooperation is the IOC International Oceanographic Data and Information Exchange (IODE) system, which 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 system forms a worldwide service oriented network consisting of DNAs (Designated National Agencies), NODCs (National Oceanographic Data Centres), RNODCs (Responsible National Oceanographic Data Centres) and WDCs (World Data Centres – Oceanography). During the past 50 years, IOC Member States have established over 80 oceanographic data centres in as many countries. This network has been able to collect, control the quality of, and archive millions of ocean observations, and make these available

to Member States.[87] The importance of IODE's work is demonstrated through the establishment of 14 Associate Data Units and 67 National Oceanographic Data Centres, as of 2015. Training and education forms an ongoing and substantial part of the work, and has resulted in the creation of a Global Ocean Teacher Academy, which supplements existing ocean data information networks. Over 50 years of IODE activities have seen the continued growth of regional Ocean Data Information Networks, the Ocean Teacher Training system and the Global Ocean Teacher Academy, all guided from the IOC Project Office for IODE in Oostende, Belgium, supported by the Government of Flanders. The office has understood the need to increase cooperation through partnerships with other organizations in its training and outreach activities.

Harmful algal blooms and eutrophication

The problems associated with the eutrophication of coastal waters (see Chapter 27) require an interdisciplinary approach, as reflected in the Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) initiative (Pitcher et al., 2005). This is an interdisciplinary programme of the IOC and the Scientific Committee on Oceanic Research (SCOR), dedicated to developing effective management of and scientific research into harmful algal blooms (HABs) to understand their causes, predict their occurrences and mitigate their effects. GEOHAB uses a comparative system analysis approach to enhance understanding of mechanisms of population dynamics of harmful algae, and increase modelling and forecasting abilities. GEOHAB and IODE jointly compile data on HAB events and species biogeography using the Ocean Biodiversity Information System (OBIS),[88] a 'web-based access point to information about the distribution and abundance of living species in the ocean' with a secretariat housed at the IOC Project Office for IODE in Oostende. These activities assist IOC Member States in dealing with the detrimental effects of HABs. The range of actions include: building regional networks, capacity-building and organizing working groups (mainly through the IOC Science and Communication Centre on Harmful Algae at the University of Copenhagen), the publication of newsletters, guides, manuals and such as the *Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters* (Anderson et al., 2001) and the IOC *Manual on Harmful Marine Microalgae* (Hallegraeff et al., 2004).

87 See: https://www.iode.org/index.php?option=com_content&view=article&id=385&Itemid=34

88 See: https://obis.org

Capacity-building

In 2015, the IOC Assembly adopted a new Capacity Development Strategy for 2015–2021,[89] building on early experiences from the Training, Education and Mutual Assistance (TEMA) programme (see Chapter 11), later referred to as the Capacity Development Programme. The new strategy included the IOC's Principles and Strategy for Capacity-building, which were adopted in 2005, and a review of previous capacity-development activities from 2011. The strategy refers extensively to the IOC's role in conjunction with UNCLOS, and the necessity to address in particular the growing needs of Africa, and Small Island Developing States, as well as some other regions. The aim was to ensure that all Member States could cooperate and participate effectively, and benefit from all of the IOC's work. This includes research on maintaining healthy ocean ecosystems and transfer of knowledge on marine science as a contribution to capacity-building. The whole strategy also provides inputs to the *Global Ocean Science Report* (UNESCO, 2017; 2020), which aims to provide an overview of national investments, resources and scientific productivity, and to stimulate the development of human and institutional capacities among IOC Member States.

The need for capacity-development is apparent in the Sustainable Development Goals (SDGs), in particular SDG 14, target 14a: 'to increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the *IOC Criteria and Guidelines on the Transfer of Marine Technology*, to improve ocean health'. A related strategy is presented in the IOC document *Transfer of Marine Technology: Knowledge Sharing and Capacity Development for Sustainable Ocean and Coastal Management* (IOC-UNESCO, 2015). The IOC has been designated as the custodian agency for indicator SDG 14.a.1, for which the *Global Ocean Science Report* provides the underpinning methodology and data repository.

The concept of an ocean blue economy also gives rise to the need to boost scientific, technological and observational capabilities, including at local and subregional levels. The ocean-based economy, which is also referenced in the TEMA Strategy of 2015, generates incentives in many developing countries for focusing economic development plans on the exploitation and management of marine resources. The IOC needs to align its activities in capacity development with national priorities, including greater use of partnerships and local knowledge, rather than pure assistance. The IOC could take the lead in

89 IOC-XXVIII/2 Annex 8 Corr. Rev. (see: http://legacy.ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=15579); IOC/INF-1332 (see: http://legacy.ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=16788); IOC-UNESCO, 2016.

integrating existing capacity-development programmes from UN organizations and NGOs with a view to optimizing capacity development on a global scale. This would harmonize well with SDG 14 (Life below water) target 14a, SDG 17 (Partnerships for the Goals) and the spirit of SDG 6 (Clean water and sanitation).

In the context of training, education and marine technology transfer, the IOC has established working relations with national and international donor organizations through regular consultations and cooperation. This has included workshops involving donor organizations, experts, IOC officers and staff, and IOC regional subsidiary bodies, generating substantial support from a number of donors, often over extended periods of time, up to over a decade. At the regional level, several such workshops have brought out the benefits of cooperation and coordination, for instance in the context of responding to the recommendations of Agenda 21. For example, donor workshops active in the Western Indian Ocean focused on marine coastal management and related research development plans for regional capacity-building in East Africa, including with the support of the Swedish Agency for Research Cooperation (SAREC), which formed part of the Swedish International Development Cooperation Agency (SIDA) (IOC-UNESCO, 1992).[90]

A workshop on the benefits of improved relationships between international development agencies, the IOC and other multilateral intergovernmental organizations in the delivery of ocean, marine affairs and fisheries programmes was convened in Sidney, BC, Canada in September 1995, in cooperation with the IOC, the Canadian International Development Agency (CIDA) and SIDA/SAREC (IOC-UNESCO, 1995). One particular aim of this workshop was to increase the involvement and knowledge of local management, so as to enhance the effectiveness of limited financial and other forms of support, and to reach out to users. The objectives included identifying the possibilities for using existing regional intergovernmental mechanisms to implement donor-sponsored programmes, formulated through the donors for bilateral or multilateral purposes; and encouraging donors to adopt, or cooperate with, national and regional development programmes, formulated through existing regional intergovernmental mechanisms on the basis of priority problems and needs in the region. The latter workshop was global in its scope, whereas the workshops organized in cooperation with SAREC in 1991, 1992 and 1993 were regional, covering the Eastern Africa-Western Indian Ocean. All these initiatives highlight the possibilities of ocean services, achievable on the basis of

90 SAREC then evolved into SIDA's Programme for Development Research, FORSK.

the combined efforts of science, technology, education, training and proactive public information.

The coastal area

Coastal zones are also key areas for cooperation in ocean science. Coasts have long supported human survival and development, feeding populations as they migrated from one region to another. The coast remains the richest zone on Earth in terms of resources, ecosystems and services (e.g. Mann Borgese, 1998). Coasts account for 40–50% of the global population – a trend that is increasing – as well as the largest urban centres, transport hubs, recreation and tourism in the form of cruise liners and a diverse set of uses. However, coasts are also vulnerable to serious environmental degradation, resulting in damage to resources, poverty and conflict (Goldberg, 1994).

The development of an integrated and adaptive approach to address and manage these problems was first initiated in the 1960s to 1970s, which led to the establishment of Integrated Coastal Management (ICM). The United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 endorsed the concept as a paradigm for addressing coastal area concerns. There are various definitions, including that proposed by Dr Thia-Eng Chua (2006): 'ICM is a management framework for coastal governance that utilizes the capacity of local government to work across economic sectors through sound planning and better management of human behaviour in all sectors. In this way it balances the competing uses of coastal resources'.

This definition underscores the need to involve all sectors and ensure that local interests are both the main concern and the principal driving force. It also acknowledges upland influences as well as those of the connecting estuarine and ocean areas. Dr Chua also notes that over 70% of the population in the East Asian Seas live in the coastal zone – covering 100 km – underlining the importance of ICM services. The countries in the area, which mirror more or less those of the IOC Sub-Commission for the Western Pacific (WESTPAC), present large differences in financial means and technical and management capacities. The need for TEMA-oriented services is also evident, as is the need for regional cooperation and education.

The importance of education was stressed by the UNCED in Chapter 36.3 of Agenda 21 as a component critical for promoting sustainable development and improving the capacity of people to address environment and development issues. Education on the basis of reliable information is also vital to prevent

conflicts and political unrest in coastal areas (see Aricò et al., 2015). Furthermore, capacity development in studying and managing coastal zones should be driven by local priorities, as has been shown in the work of PEMSEA (Partnerships in Environmental Management for the Seas of East Asia) (Chua, 2006).

The importance of coastal services is increasing globally, especially with growing populations; however, such services are also vulnerable to the consequences of climate change and the associated risks of economic losses. Many, if not all, of the IOC's activities are relevant to coastal services. For example, the IOC's integrated coastal management programme developed *A Guide on Adaptation Options for Local Decision-Makers* as part of the GEF Project on Coastal Adaptation in West Africa (IOC-UNESCO, 2012). This guide brought together experiences from coastal managers, scientists and engineers from five countries of the West African region in a participative process that ensured local-regional ownership of the guide, and also brought to light the existence of extensive local and regional capacity. Similar situations relating to capacity exist in other regions.

Protection and management of the ocean part of coastal zones is also vital for the sake of coastal ecosystems and the services they render. These services extend beyond the local environment, with coastal ecosystems being critical to the maintenance of human well-being and global biodiversity. Key examples include mangroves, tidal flats and marshes, and sea-grass beds, which provide coastal protection. Coastal ecosystems support protection against storm surges, coastal erosion and sea level rise, and ensure water quality conditions, nutrient recycling and sediment trapping. They also provide habitats for numerous marine species, as well as food for human consumption. Crucially, coastal zones help to mitigate climate change by sequestering and storing large amounts of carbon from the atmosphere and the ocean. This 'blue carbon' (Howard et al., 2014) is stored in the soil, the living biomass above and below ground, and the non-living biomass, where it can remain for a long time due to prevailing anaerobic conditions which prevent oxidation.

Despite the vital services these ecosystems provide, they are among the most threatened on Earth. This situation calls for coordinated cooperative action to gather information about the conditions, extent and amounts of blue carbon, so as to facilitate regional and global inventories and evaluations, and direct further action. To this end, Conservation International, the IOC and the International Union for Conservation of Nature (IUCN) have jointly prepared a guide to provide managers, scientists and field practitioners with standardized recommendations and techniques for carbon measurement and analysis in blue carbon systems to support global assessment and accounting of blue carbon

(Howard et al., 2014). This work forms part of the Blue Carbon Initiative and represents just one example of the growing cooperation between numerous organizations, involving many disciplines, scientists, practitioners and sectors of society from the local to the global level.

Looking ahead

The GOOS strategic mapping, endorsed by the GOOS Steering Committee (IOC-UNESCO, 2016), has provided a basis for the further advancement of ocean services, which encompass the themes of climate, ocean services and ocean health (with related essential ocean variables). The Biennial Reports (IOC 2014 and 2016) also presented positive developments in GOOS coverage since 2013, including up to 80% sustained capacity in the Tropical Pacific Ocean provided by moored instruments, as of 2015, and full, core coverage provided by Argo floats of *in situ* networks at the time maintained through JCOMM. The development of a 'sustainable, efficient and fit-for-purpose Integrated Atlantic Ocean Observing System' as a contribution to GOOS has been underway since 2015, with support from and in cooperation with a European Commission Horizon 2020 project. GOOS has developed a set of essential ocean variables to be measured on a regular basis through the combined efforts of *in situ* and *ex situ* observations. A harmonized set of variables at the regional level (e.g. through the Copernicus effort of the European Commission) is also of the essence. The interaction and cooperation between these global and regional efforts has made possible the sharing of data compatible with the International Oceanographic Data and Information Exchange (IODE).

All these developments, together with advances in dynamic modelling and data assimilation, support the continued evolution of an ocean forecasting portal for socio-economic use by Member States and other organizations, including industry and the private sector, in regular need of ocean information and forecasting. Such developments will also help improve weather forecasting. Their potential is closely linked to the development of the IODE programme established over the decade 2005–15 through the IOC Project Office in Oostende, Belgium.

The IODE programme, in accordance with the *IOC Medium-Term Strategy, 2014–2021* (IOC-UNESCO, 2014b),[91] focuses strongly on providing data and information support to other IOC programmes, thus matching the TEMA strategy. The Ocean Biogeographic Information System (OBIS), adopted as

91 Available at: https://unesdoc.unesco.org/ark:/48223/pf0000228221

an IODE programme in 2009 and recently renamed the 'Ocean Biodiversity Information System', facilitates the provision of data through a worldwide network of 500 institutions connected via 20 national, regional and thematic OBIS nodes. The OBIS Secretariat, co-hosted with the Project Office for IODE, provides training and technical assistance to data providers, helping to ensure the strict application of internationally agreed standards, as required for this level of data integration. The need to be able to link biological observations with physical and chemical data is being addressed by IODE through the development of procedures and guidelines for managing and sharing combined datasets. In fact, obtaining, providing and exchanging data has been a primary motivation for cooperation throughout the history of ocean science development, dating all the way back to the early explorers, including Captain Cook.

The challenge now is to determine how best to organize these services, including their delivery, control and reliability. Governments must be involved in this process to guarantee their operation, as well as their reliability, quality control and sustainability, and to ensure that the services are properly used and accounted for. To this end, there is a need for an intergovernmental organization with national counterparts. The organization and provision of meteorological and hydrological services can provide some guidance in this regard. Ideally, the service compartments could form a whole, but this may not be feasible or practical. Several elements and programmes for the creation of an ocean sciences and services organization are in place and could be further developed through new communication technologies. An analysis of certain current trends in marine research and related industrial developments may provide further motivation for such a creation.

29 Broadening cooperation: Trends in ocean research and industrial applications – towards the third decade of the millennium

The need for further cooperative ocean research

Predictions made in the early 1970s regarding the ecological limits to growth have turned out to be surprisingly accurate. Increases in food and energy prices and freshwater scarcity have negatively affected resource availability, and must be treated as a priority (Jackson, 2009). These problems are exacerbated by a drop in the assimilating capacity of the planet as a whole, demonstrated by the increasing level of carbon dioxide in the atmosphere, the decreasing oxygen content and increasing acidification of the ocean, large biodiversity losses, the decline and partial collapse of fish stocks, and increasing pollution of the open ocean. About 60% of ecosystem services have been degraded (Millennium Ecosystem Assessment, 2005), aggravating existing problems with nutrition and human health in the context of an increasing global population.

Assessments in the 1980s recognized the significant potential of the ocean to address these problems, but emphasized the limits of this strategy (Simon, 1984). Open ocean resources are not owned but are subject to open access. As a result, markets have failed to develop them in a sustainable manner. In the context of globalization and regionalization, the ocean has assumed an increasing role in support of international cooperation and law through the United Nations Convention on the Law of the Sea (UNCLOS), in particular with regard to trade, economic development, and scientific and technological cooperation. This underlines the need for a new economic order of non-ownership based possibly on a stewardship or trusteeship model. Application of the principle of the Common Heritage of Humankind, which form part of UNCLOS, meets some of these requirements, as well as those relating to sustainable development. The same principles apply with respect to sufficiency, equity and inclusiveness, and are in line with the concepts of the green and blue economy. However, these principles have not yet become part of the mainstream economy and efforts to

implement them have failed to arrest environmental degradation (Johnston, 2012; Mathai and Parayil, 2012).

Ocean-based economies operate in conditions of great uncertainty, require high levels of investment, and face large risks and potentially significant losses in monetary as well as non-monetary terms. As a result, these economies depend on science and technology, as well as cooperation between sectors and industries within and across national boundaries. Accordingly, there is a desire to define the requirements for achieving stability and security in contexts where the environment and climate, food production, water availability, human health and the economy all fluctuate. Such requirements would include obstacles to be overcome; the identification of necessary instruments, technologies and capacities; and the elaboration of a plan. Further requirements include the identification of partners who can contribute or are crucial for collaboration – including in the sciences, technological, services and industrial sectors, as well as entrepreneurs. Over the decades, cooperative ocean research has demonstrated a proven ability to meet such requirements.

Financing and upscaling cooperative ocean research

Results from research and observations over long periods reflect trends in ocean changes and marine research and technological developments. They also underline the need for global cooperation. Large-scale cooperative and multidisciplinary research programmes necessarily involve many countries, institutions, and intergovernmental and NGOs – pooling human and financial resources, infrastructure and technology. Programmes developed over several decades, including large marine ecosystems (LMEs), and river-basin and basin-wide fisheries projects, have received grants from the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) and the World Bank. Such support can also catalyse significant additional financing (Hudson and Glemarec, 2012) from participating countries, other organizations and institutions, and generate collaboration – including public-private partnerships. These research programmes also contribute to addressing the socio-economic concerns and issues noted here.

A contributor to financing ocean cooperation is the UNDP-GEF programme 'Catalysing Ocean Finance'. The programme builds on experiences from the large number of activities supported by these bodies and aims to transform markets with a view to restoring and protecting the ocean. Previous experiences have highlighted the efficiency of three instruments to address and promote long-term, science-based integrated planning for market transformation

(Hudson and Glemarec, 2012): i) a transboundary diagnostic analysis/strategic action programme (TDA/SAP); ii) an integrated coastal management (ICM) framework for the sustainable development of coastal areas; and iii) global or regional ocean legal frameworks.

Losses due to poor ocean management are estimated at US$200 billion annually and are projected to rise to US$350 billion by 2050 due to additional pressure from climate change, if no action is taken. These losses are of the same order as costs due to natural disasters. The failure of the present market economy to use open-access resources sustainably leads to lack of investment in required management actions. Instead, the free market seems to lead to subsidies and other failed policies. Similar problems seem to create obstacles for marine industry developments.

Case studies which provide lessons in this respect include the Yellow Sea LME, the Seas of East Asia, Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) (see Chapter 19), the Global Ballast Water Management programme, and the West and Central Pacific Fisheries programme (Hudson and Glemarec, 2012). On the basis of these studies, the following lessons can be drawn. It is important (i) to make in-depth prefeasibility studies and dedicate adequate public resources to this end, (ii) to combine all three major instruments identified above, and (iii) to anticipate a timeframe of 5–20 years. Cost estimates for future actions on the basis of catalysing experiences are of the order of US$5 billion over the next 10–20 years. This approach would help upscale activities considerably, including achievement of the Marine Protected Area (MPA) target of 10% coverage under strict protection, specified by the Convention on Biological Diversity.

The timeframe for developing and implementing these research programmes is 10–20 years. An example in this respect is provided by the development of climate change research and assessment. The First World Climate Conference in 1978 addressed issues related to climate variability, droughts and floods, and established the World Climate Programme[92] to collect knowledge and data for dynamic modelling and forecasting of climate variations (Clarke, 2010). The research programmes studied four areas: (i) north-south heat transport by the ocean-atmosphere system; (ii) global ocean circulation, which came to include observations of carbon dioxide in the ocean; (iii) long-term monitoring of ocean variability and an associated ocean observing system; and (iv) tropical ocean-

92 As mentioned earlier, the co-sponsors of the World Climate Research Programme (WCRP) are the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the IOC and the International Science Council (ISC, formerly ICSU).

global atmosphere interactions triggered by the El Niño phenomenon. These programmes concluded in the first decade of this century with the publication of results, evaluations and associated conclusions, which along with the timeframe serve as strong motivations for the United Nations Decade of Ocean Science for Sustainable Development 2021–2030, as part of the 2030 Agenda.

The ocean observation system mentioned above developed into the Global Ocean Observing System (GOOS) (see Chapters 21 and 26), which was formally launched by the Intergovernmental Oceanographic Commission (IOC) in 1989, in cooperation with the WMO, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the International Maritime Organization (IMO) and ICSU. GOOS provides information necessary to address problems related to issues concerning climate change, food security, ocean acidification and ecosystem services.[93] In 2013–14, the system expanded with the creation of an open ocean GOOS focusing mainly on weather and climate issues, and a coastal GOOS which encompassed pollution and living marine resources. The global system comprises several regional systems, including observation technologies such as satellites, voluntary ships, repeated sections, and moored arrays of buoys and floats, reflecting a trend towards operational oceanography with sustained observations. The most noticeable array of observations encompasses the Equatorial Pacific line, providing data for El Niño forecasts, and has been extended into the Atlantic and Indian Oceans.

The combination of all these observations in near-real time makes long-range forecasting possible by means of advanced dynamic modelling, high power computers and data assimilation. The entire development process constitutes a significant combined scientific and technological achievement reached through persistent global cooperation towards a well-defined goal. Its importance is a reflection of the investments made by countries, research institutes and industry, as well as the commitment made by countries to participate in the Argo float programme (see Chapter 28), including Australia, China, Japan, France, Germany, India, New Zealand, the Republic of Korea, Spain, the United Kingdom, the United States and the European Commission. One outstanding issue, however, concerns coverage of exclusive economic zones (EEZs) and remote areas. This is being addressed through cooperation with regional bodies, such as the South Pacific Geosciences Commission (SOPAC) in the Pacific. In Europe, several regional bodies are involved through EuroGOOS, including the International Council for the Exploration of the Sea (ICES), the Baltic

93 Kullenberg et al. (1993) present a module to help assess the health of the ocean.

Marine Environment Protection Commission (HELCOM), and the OSPAR Commission, the secretariat of the combined Oslo and Paris Convention.

An important trend in global change research and technology is the combination of paleoclimatology, using isotope records in sediments and ice to identify warm and cold periods, with studies of present day climate variability and predictability. An early example of this approach is the analysis of sediment cores from a Swedish expedition in the Mediterranean in 1946 by Emiliani (1955). Isotope studies, which apply various technologies to tree rings, sediments and ice cores, can identify anomalies associated with warm and cold periods, including the warm Bronze Age (around 2700–760 BC) followed by a cold period, the warm Medieval Climatic Anomaly (around 900–1200) and the Little Ice Age (around 1350–1850). These periods are characterized by several temperature variations that demonstrate the difficulties inherent in identifying trends within a very complex system. One such study by Kabel et al. (2012) evaluated the impacts of climate change over the period from the Medieval Climatic Anomaly through to the Little Ice Age and the present Modern Warm Period in the Baltic, by means of reconstructed surface temperatures from sediment cores through a technique known as TEX 86 palaeothermometry. The study identifies changes in the ecosystem, with blue-green algae production during the warm Medieval Climate Anomaly leading to hypoxia in bottom waters. This finding is of particular relevance in the context of present changes in the Baltic, which are of a similar nature.

The examples of research-related programmes presented here reflect two trends – upscaling from essentially regional programmes within a limited timeframe to global programmes with long-term perspectives, and broad financing based on extensive cooperation. These trends have been made possible by globalization, as well as recent revolutions in information and communication technologies. These kinds of combinations may also make it possible to address the major challenges referred to above, as the problems facing us require active cooperation between different branches of science and technology. In particular, there is a need for stronger partnerships between the social sciences and the natural sciences and technology. Such cooperation and links are required to reach policy and decision-makers as well as the general public, in order to explain the technology involved and the scientific proposals – and to help communicate the knowledge and implications, and encourage acceptance. This is demonstrated by the arguments surrounding the use of nuclear technology and various issues related to contamination or pollution, including plastics and fossil fuels. The time required for acceptance and dissemination of a new technology – or a new understanding – can be long, with new technologies sometimes facing active

opposition to implementation (see Rogers, 2003). In addition to cooperation between branches of science, there is also a need for active dialogue with the science-policy interface (see Pinker, 2018).

Further upscaling trends have been noted in the more recent research programme 'Future Earth'.[94] The programme provides a global platform for scientific collaboration built around three main themes – a dynamic planet, global development and transformation towards sustainability – supported by a focus on modelling, data management and infrastructure, and theory development. Programme aims include building a knowledge base to confront risks posed by global environmental change and identifying opportunities to advance the transition to sustainability (OPRF, 2013). The trend towards increased risk preparedness through knowledge is visible in the growing use of forecasting and warning systems (e.g. tsunami warning systems, training in hazard preparedness, cyclone and flooding warning systems). Their use in combination with instantaneous and widely available communication technologies has heightened their efficiency, in combination with training and education to widen the applications of forecasts and generate awareness raising and acceptance. Research needs in this context are coupled with the refinement of models and data retrieval to achieve increased reliability.

Global assessments developed on climate and ocean conditions have noted the impact of globalization.[95] The World Summit on Sustainable Development (WSSD) 2002 called for a regular process of global reporting and assessment of the state of the marine environment, including socio-economic aspects. The first result of this effort, published in 2009, reviewed existing processes, provided regional summaries covering 23 regions and defined the way forward. This led to the first UN Global Integrated Marine Assessment (United Nations, 2016), which emphasized the lack of time left to properly address the issues identified in the report and reflected here. The IOC is actively involved in these efforts.

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was created with the support of UNEP and the WMO to assess climate conditions. However, the IOC was not invited to co-sponsor the IPCC, despite growing understanding of the important role played by the ocean in the climate system. This understanding was the result in part of research undertaken during the

94 Future Earth derives from the merging of the International Geosphere-Biosphere Programme (IGBP), Diversitas (an international programme on biodiversity science), and the International Human Dimensions Programme (IHDP).

95 Notably, the Health of the Ocean reviews initiated in the 1980s by the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP).

International Decade of Ocean Exploration (IDOE) and by the WCRP, which the IOC has co-sponsored since 1993.

Aspects of marine industry development

The annual economic impact of global marine industries has been estimated at US$3–7 trillion by the end of the last century. Leading industries comprise sea-borne trade, submarine telecommunication and fibre optics cabling, ocean mining of aggregates and placers, ocean-related tourism, fisheries, oil and gas, and naval defence (Mann Borgese, 1998). Other industries include ports and harbours, coastal and environmental activities, renewable energy and freshwater production. In the United States, the annual economic impact of ports and harbours amounts to approximately US$800 billion in GDP with sales of about US$1–2 trillion. The total economic impact of marine and ocean technology is difficult to estimate due to lack of data on (marine) equipment; however, the sector generates billions of dollars globally. The costs and risks are extensive, highlighting the need for cooperation, trust and mutual insurance. A key service sector for marine enterprises and coastal activities and protection is the insurance industry. For many nations and regions sea-borne trade is a dominant industry and delivers over 90–95% of all exports and imports. In the case of many small nations and territories, national wealth is directly dependent on port activities (e.g. Singapore, the Netherlands and Hong Kong, China) (Mann Borgese, 1998). Without ocean trade, wealth would be significantly reduced, free trade agreements would be useless, and many benefits of international specialization and globalization would be lost. The potential benefits of ocean resources in the present century encompass food and freshwater, transport, minerals (e.g. nickel, copper, cobalt and manganese), diamonds, hydrocarbons, biodiversity, sulphate deposits, energy sources, cabling, pipelines, recreation and, finally, tourism – the largest global industry accounting for about 10% of the global economy. The ocean also contains the largest reservoir of hydrogen on the planet and fossil fuel reserves, as well as genetic resources with potential for pharmaceutical developments.

There are many new, emerging and futuristic marine industries. One such industry is ocean biotechnology, a fast-growing field that is generating many patents, including for pharmaceuticals and bioactive resources, with thousands of substances having been identified. The economic returns for successful products such as antiviral and anti-cancer drugs are very high, but so are the associated investment risks.

The deep sea is also the largest reservoir of genetic resources, including for commercial and industrial applications. Industrial utilization of genetic resources from the deep sea bed, such as thermopile bacteria, is increasing rapidly. Such uses concern waste treatment, food processing, paper processing, mining and oil exploration services, and pharmaceutical applications. Hyperthermophilic bacteria constitute one example of industrial development based on the potential of microbial genetic resources from the Area (as designated under UNCLOS). Many other potentially useful organisms are also being discovered (Vierros et al., 2012).

Patents cover a wide range of products, from the development of enzymes for industrial processes to pharmaceuticals for skin cancer protection and the development of biofuels. For example, Antarctic and deep water sponges are used as sources of pharmaceuticals, including for cancer treatments.

In addition to its potential economic value, the high level of biodiversity in the deep sea underpins ecosystem functioning and the provision of ecosystem services and system resilience. The Census of Marine Life – a 10-year international effort undertaken to assess the diversity, distribution and abundance of marine life – estimated that species range from 500,000 to 10 million, with new species continually being discovered (cited in Vierros et al., 2012). Most of these organisms have adapted to life under extreme conditions and have unusual molecular and metabolic adaptations. This is true in particular for bacteria found in hydrothermal vents.

The deep sea and the Southern Ocean have also been the site of major fisheries development, with increasing industrialization targeting krill in the Antarctic region and many other species of fish such as sharks and ray, and shellfish such as crab and shrimp. It is imperative to control this development and ensure that it is sustainable. While current fishing subsidies are of the order of US$35 billion, illegal and unreported fishing is worth US$2–10 billion, representing about a quarter of the total catch. According to World Bank estimates, the mismanagement of fisheries costs about US$83 billion a year (World Bank, 2017). Additionally, the protein input from fisheries is more important than that of meat. The removal of subsidies and the registration of all fishing vessels have been agreed as priority actions, but have not yet been fully implemented. Here, as elsewhere, the best scientific advice should be followed – guidance that has now been embedded in EU fisheries agreements.

Marine industry is likely to provide important sources for the production of renewable energy. Strong candidates include an increase in tidal energy extractions, turbines powered by ocean currents, ocean thermal energy

conversion (the market value of which is estimated at about US$20 billion in 2015–20) and wind energy parks at sea. Tides have long been used as a renewable and cheap energy source, although this has in some cases resulted in significant environmental impacts. Methane hydrates are beginning to be explored and exploited, and could provide enormous amounts of fossil fuel, but they also pose a potential threat to the climate and possibly the ocean. In addition to considerations related to the use of methane to generate hydrogen, there are also other ways of using the hydrogen. Nuclear energy technology based on fission could presumably lead to nuclear energy based on the fusion process. This would rely on the combination of two light nuclei into one with a firmer attachment, resulting in a decrease in total mass. This difference in mass results in the energy release. The most suitable nuclei for fusion are deuterium and tritium. Seawater contains deuterium in a ratio of 1 to about 6,000 ordinary hydrogen atoms. Techniques to achieve thermo-nuclear reaction and plasma exist but further scientific-technological developments are required to make this energy source viable and publicly acceptable. If it could be achieved, this ultimate energy source could be made available with clean fuel from the ocean.

However, IPCC estimates suggest that the ocean is relatively expensive as a renewable energy source, due to the technological requirements and the relatively high risks. Marine technological development is expensive, as is the exploration and exploitation of marine resources, which requires significant infrastructure, human skills and resources, and considerable investment. Those involved need to operate internationally under an adopted trusted rule of law, with insurance and reinsurance options. However, the inability of markets to handle open access to ocean resources, together with the lack of an adequate institutional structure for ocean research, technological development and reporting, implies difficulties for mainstreaming marine economy and industry. In order to achieve this, public support is required along with the establishment of an institutional structure able to help generate the necessary government and public acceptance. There is also a need for a focal point, a single coordinating and responsible institution at the national level that will allow the sector to speak with one voice. The institutional structure would need to connect the public sector with technology development bodies capable of providing innovative solutions to identified needs. This could ensure that a phased development programme is put in place, for instance using competition with financial support to obtain solutions to given problems and involving leading laboratories. The proposed solutions can then be nourished into fruition, and investments secured. The responsible body could also help create strategic partnerships between various parts of the whole sector. This would allow for the achievement of a national strategy and a shared vision on marine industry development, which could be

adopted at the government and industrial level, and gain public approval. The proposed mechanism could help implement economic evaluations and seek to support the required skills development, filling related gaps while taking into account that the developments in the sector are strong and fast. The related actions could lead to an increased public awareness and understanding of the ocean and its various roles and importance for our society.

Towards the ocean we need for the future we want

Technological developments are often driven by theory. Assessments can help identify further scientific needs and provide support to theoretical developments. The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) introduced a new framework for analysing socio-ecological systems, and has inspired the scientific community to address challenges in basic sciences coupled to the management of ecosystem services (Carpenter et al., 2009). Sustainability science aims to illuminate the interactions between nature and society and, in so doing, provides evidence that management interventions can improve ecosystem services and human well-being. Particular issues that need addressing include: food security; the decline in fish stocks and unsustainable fishing practices, with higher prices creating incentives for investments in industrial fishing; land-based sources of marine pollution; the need to quantify the impact of losses of coastal wetlands, habitats, mangroves, coral reefs and other protective ecosystems; invasive species; the implications of acidification and de-oxygenation; and plastic pollution.

Studies of ocean acidification have included efforts to quantify the impacts of geological carbon storage in the context of carbon capture and storage technology using sub-sea bed storage. Recent research has investigated the outcome of carbon dioxide leakage into sediment and water (Plymouth Marine Laboratory, 2013), with findings showing that in cold bottom water, carbon dioxide may lead to increased acidification. Field experiments have been carried out in Europe by the Plymouth Marine Laboratory in cooperation with the Norwegian Stat-Oil company, as part of a European-wide project entitled ECO2. Laboratory and field experiments have aimed to quantify how the benthos[96] reacts to acidification. This research may be supplemented by experiments in enclosures to ascertain how acidification influences the growth of fish larvae. At present, concern around this issue is growing among the food producing industry, although acidification is still considered a future problem.

96 The collection of species that make up the ecosystem on the sea bottom.

Long-term observations of trends in plankton production over basin-wide scales have been carried out to establish possible changes in blooming time, species composition and level of production. Observations by means of the continuous plankton recorder, which has been operating since the 1960s, have shown the close link between the North Atlantic Oscillation, slow climate variability at decadal time scales and populations of plankton species. Changes in species composition have been observed and related to increases in sea surface temperature in the North Sea area, and to changes in balances between nitrogen and silicate in the Yellow Sea LME. The changes affected species ranging from diatoms to dinoflagellates, potentially impacting the next level of production, zooplankton, and the transfer of carbon to the sea bed. Continual observations are obtained through repeated sections run from north to south across the Atlantic, with participants from several countries. Hydrographic sections have long been a part of oceanography but are now multidisciplinary and relate also to the passage of satellites to obtain sea truth data.[97] Repeated ocean sections were also conducted during 1972–78 to study the carbon cycle in the ocean as part of the Geochemical Ocean Sections Study (GEOSECS), a programme of the IDOE (Clarke, 2010). These sections also helped initiate the Joint Global Ocean Flux Study, which began in the early 1990s and continued into this century.

The need for cost-effective and economic continuous subsurface observations of large ocean areas with regular data transmission drove the development of various drifting and oscillating floats in the 1970s. The Argo float programme, referred to earlier, now has in the range of 2,000 to 3,000 floats covering most parts of the ice-free ocean. These observations are supplemented by satellite mapping of sea surface conditions over large areas. Ocean-colour mapping, in particular, has developed into a powerful tool to obtain information about phytoplankton distribution and related blooms. An early example of its use is given by the detailed mapping of various features of the North Sea presented by Holligan et al. (1989). The occurrence and timing of blooms may also indicate the conditions of the pelagic environment. Mapping of sea surface temperature, chlorophyll and radiation data have been combined to identify periods and amplitudes of phytoplankton growth in tropical and high latitude waters. These show low amplitude but extended periods in tropical areas, related to the availability of nutrients, and shorter periods with high amplitude in high latitude areas, related to seasonal variations of light. The Green Seas project, which involves several countries from north to south, aims at elucidating how

97 These data are obtained when the sea surface conditions are recorded by the ship at the time when a satellite is passing in the space area above the ship. This process is called sea truth and consists of satellite calibration of the position at which the ship collects the data.

the plankton communities may be affected by climate and other changes. Studies are pursued to clarify relations between plankton growth, primary production and harvestable marine organisms, resulting in advice for the food industry. Satellite observations are also used to study net sea-air fluxes of carbon dioxide in the Arctic region. This area functions as an important carbon dioxide sink, possibly accounting for 5–14% of total oceanic uptake, although it accounts for only 1% of the global ocean volume (Kullenberg et al., 2015). However, increases in temperature imply a decrease in uptake. Satellite observations of ice coverage in the high latitudes have provided invaluable information about ocean variability and need to be continued.

The ocean research community is attempting to better clarify the value of the seas, including with respect to renewable energy production, recreation and tourism. Benefits obtained from ecosystem services include oxygen production, water purification and other intangibles. This research has involved the public, for example by seeking to ascertain their willingness to pay to reduce ecosystem losses due to various constructions and the use of coastal and shelf sea areas. European research (reported in Plymouth Marine Laboratory, 2013), which combines climate change predictions, estimates of productions from marine ecosystems and fisheries, the expected size of the human population, price estimates of fish meal, and projections of technological developments in aquaculture and dynamic modelling, has suggested that an increasing contribution from aquaculture to the volume and stability of seafood supplies would provide the growing population with sufficient protein, and meet increasing demand in an economically and ecologically viable way. The keys to success are efficient management of fisheries and the sustainable growth of aquaculture with efficient technology. This underlines the need to protect the water quality of the coast and shelf seas, and for proper marine spatial planning. Ecosystem-based marine spatial planning aims to sustain resources and ecosystem services (Ehler and Douvere, 2007), and has been developed as a tool to enable integrated, forward-looking and consistent decision-making on the human uses of the sea.

This tool can be implemented as part of the integrated coastal management approach endorsed by the United Nations Conference on Environment and Development (UNCED) in 1992 as part of Agenda 21. However, experiences from applications have been mixed. PEMSEA (2013) represents a success story, but there are many failures which have led to the development of alternatives. These alternatives include the integrated catchment area management approach applied to river management, the LME approach which produces a good geographic and oceanographic framework, and the integrated coastal and

ocean management approach which has been incorporated into the Sustainable Development Goals (SDGs).

The LME concept (see Chapter 19) was developed in the 1970s and now represents a leading trend in shelf seas research and management (Sherman and Alexander, 1986; Sherman et al., 2009). One notable example is the Yellow Sea LME presented earlier. As of 2014–15, about 110 developing countries are partners in 16 joint international LME projects supported by GEF, the World Bank and participating countries. However, the complexity of the ecosystem approach has led to recognition of the need for a new type of professional able to address sustainability issues in a broader sense (Sherman et al., 2009). Scientists and technologists are needed who can communicate across sectors and disciplines, as well as with legal experts and economists, as indicated above, in the context of the need for links with social sciences. There is also a need for increased interaction between applied science and the basic sciences in order to develop a new generation of generalists and specialists.[98]

Another important trend which demands input from research and technology is increasing uncertainty. Addressing these challenges requires risk management and a capacity for adaptation among management – an approach developed in the 1970s by Charles Hollings (Mee, 2010). This involves several steps which result in a well-defined shared vision without specifying how it will be achieved. The emphasis on adaptation allows new scientific, technological and socio-economic insights, information and data to be taken into account. The approach can be designed to address key environmental SDGs related to pollution, disasters, loss of livelihoods, freshwater shortages, loss of biodiversity, overexploitation of resources and coastal areas, and threats from climate change. In several cases, the approach has led to the agreement of regional visions, notably at an early stage in the Blue Plan for the Mediterranean, in the seas of South-East Asia through PEMSEA, and in Europe through the European Marine Strategy Framework Directive.

The increasing acceptance of ocean research as a major scientific discipline, together with the need to obtain a solid baseline of life in the ocean, is manifested in the Census of Marine Life programme, mentioned earlier. This programme was initiated in the late 1990s by scientists in the United States who contacted the Alfred P. Sloan Foundation, a philanthropic non-profit organization. This global effort, which was made possible by the support of the Foundation in association with ICSU,[99] the Scientific Committee on Oceanic Research (SCOR)

98 See the discussions on this topic in Briscoe and Evans (1993) and Wunsch (1993) for further details.

99 Now International Science Council (ISC).

and the IOC, has generated an enormous amount of information and a valuable and necessary baseline for the future. Further research is still needed, however, to understand adequately the functions of the ocean for life on Earth and the associated role of the ocean in the circulation of water, energy and different substances, and how these are transformed and biologically influenced. It is also vital to comprehend how the functions of the ocean are changed by and respond to our interventions as well as management, and to be able to distinguish between natural and human-induced processes and changes.

30 Concluding remarks

Much of the progress in ocean science and observations over the decades has had a bearing on socio-economic development, as indicated through the role of the ocean in our economy, food security and social development, as discussed above and in other chapters. The first hundred years or so of dedicated ocean research from the *Challenger* expedition onwards may be divided into three phases (Roll, 1979). The beginning of the first phase can be traced to the *Challenger* expedition of 1872, which set the pattern for long, wide-ranging research cruises making single point observations, mostly on the basis of random distribution. The second phase started after the First World War and yielded more systematic information of a defined ocean area, but still consisted mostly of single ship operations (Smed, 1990, 2004), even after the Second World War. Expeditions such as the Swedish *Albatross* (1947–48) and the Danish *Galathea* (1952–53) introduced new technologies and equipment, yielding significant breakthroughs and encouraging further research. The third phase of oceanographic development began towards the end of the 1950s, and was characterized by international cooperation, with several nations pooling their resources, on the basis that coordinated observations covering a region were necessary to obtain a realistic picture of ocean conditions, including ocean circulation. An initial effort organized by the International Council for the Exploration of the Sea (ICES) in 1958, within the framework of the International Geophysical Year (IGY) (1957–58), covered the Atlantic Polar Front and included 22 research vessels from 8 countries, highlighting the complexity of the operation. The effort and results provided further incentives for the development of global cooperation in ocean science and observations during the International Decade of Ocean Exploration (IDOE). Roll's sequence can be extended further with a fourth phase covering the last two decades of the twentieth century. These years saw the development and implementation of global, interactive programmes of science and observation, addressing specific problems or issues of interest to society and science, with much support provided to sector organizations. In parallel, the scientific and technological communities were putting in place sustained ocean observations, based on new technologies, including *in situ* observations in the interior of the ocean and remote sensing from space. Interactions between physical, biological, chemical

and geological processes were also being addressed. Ocean science, together with sustained ocean observations, had now matured to the point where they were able to provide useful ocean services over a wide range of sectors and uses.[100] Key developments included marine technology transfer and capacity development, with the potential for further expansion through the provision of more resources.[101]

The ocean sciences and observations are now in the early decades of the Millennium, coming into their fifth phase of development, with some focus on the role of the ocean for sustainable development, climate change, or global changes, and global economic development. An important driving force in the process is the continued development of technology (Scientific American, 1969; Field et al., 2002), influencing observations, mapping, data retrieval and transmission, and their use and integration with other disciplines and parts of society. The entering into force of the United Nations Convention on the Law of the Sea (UNCLOS) in 1994 and subsequent developments of international concern regarding ocean conditions, climate change and the environment, together with limitations on resources, including freshwater and the needs of the global economy, have also provided driving forces. These developments are all manifested in the UN Pillars of Work, including the Sendai Declaration,[102] the Samoa Outcome on Small Island Developing States, and the 2012 Outcome Declaration of the UN Conference Rio+20, together with the Sustainable Development Goals and the 2015 Paris Agreement, as well as several other conventions. It is also necessary to emphasize here the importance and comprehensiveness of UNCLOS. This includes the notion of treating the ocean as a whole, and at least some areas as the Common Heritage of Humankind in relation to accountability, responsibility and the social acceptance of activities. The totality of this development has placed oceanography in a position to provide a wide range of services to society. The key to being able to provide such services is sustained ocean observations, notably through the Global Ocean Observing System (GOOS) and the International Oceanographic Data and Information Exchange (IODE) programme. These efforts are managed by the IOC. These services are of increasing importance, as practically all sectors of society are influenced by the ocean and the seas, their resources, ecosystems and services.

100 See the Synthesis of IOC Development, Work and Results: Opportunities and Coincidences 1960-2015 (IOC/INF-1337 Rev.; Kullenberg, 2016): http://legacy.ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=20009

101 This is demonstrated through several programmes of the IOC and its partners, some of which are indicated above. See also Melvasalo (2008b), Kullenberg (1986, 1998, 2010b) and Kullenberg et al. (1993).

102 See A/RES/69/283, Annex I: https://undocs.org/en/A/res/69/283

One important lesson that emerges from the experiences presented here is the important role played by individual leaders and personalities in stimulating and guiding the development of institutions, cooperation and, in many cases, large cooperative programmes and building institutions. Their contributions include the sharing of ideas, the willingness to involve colleagues, and the ability to delegate responsibility and leadership for specific actions. They have worked to build trust and engage with political decision-makers and donor organizations, and create a new generation of leaders and others willing to participate in meaningful international cooperative development. Such experiences and lessons can be drawn from the creation of numerous international ocean-related institutions such as the International Maritime Organization (IMO) and the World Maritime University (WMU), the IOC of UNESCO, the ICES, the International Ocean Institute (IOI) and the Scientific Committee on Oceanic Research (SCOR) of the International Council for Science (ICSU).

However, science is a free profession; it cannot be contained or directed. Each scientist needs the freedom to pursue truth and the explanations behind observations and processes. Each scientist may be able to contribute a small part of the puzzle – while others may be able to put it together.

The major contributions of the IOC may be seen as crucial in this regard and include the implementation of several regional and global programmes: the Training, Education and Mutual Assistance (TEMA) programme (see Chapter 11), the framework and generation of some support for the IDOE 1971–1980 (Chapter 15) and, of course, the International Oceanographic Data and Information Exchange (IODE) and GOOS (see Chapters 11, 21 and 28). In this broad context, success in obtaining the involvement and support of governments is critical for research and education, observations, data exchange and analyses over an extended period of time. During the decadal process, initial suspicion towards the IOC on the part of several governments was gradually overcome.

Regional programmes initiated by the IOC prior to the IDOE 1971–1980 to some extent laid the foundation for these later achievements. The establishment of GOOS depended upon research results, technological developments and experiences from several dedicated ocean observation efforts over time. The need for GOOS was brought out through the negotiations for and adoption of UNCLOS and concerns for climate and other global changes. The creation of GOOS built on the cooperation over previous decades in laying the foundation for a global system of ocean observations. In parallel, the IOC, with the support of ICSU and SCOR, created a partnership between ocean research and the climate research community, with the IOC acting as a co-sponsor of related programmes. In the context of other concerns of global reach, the IOC created

research and training programmes for marine living and non-living resources, and established studies on marine pollution, including marine debris, through extended cooperation with other organizations. Crucially, TEMA was integrated as a component in most of these programmes.

These programmes collectively contributed towards the implementation of Chapter 17 of Agenda 21,[103] as well as subsequent actions in the contexts of pollution, protection of the ocean against land-based sources, a programme addressing the marine debris problem, and a dedicated programme on harmful algal blooms. These challenges and initial programmes led gradually to a more integrated approach in the form of coastal zone management, marine area planning, sustained observations, integrated data exchange, training and the transfer of marine technology, as well as the provision of services through warning systems. There have been obstacles and sometimes failures, due in part to the situation of the IOC, including its lack of independence and clout, and its limited resources in terms of funds and staff at the secretariat. In some cases, conditions have necessitated sunset clauses and the subsequent closure of programmes. Over the period discussed here, several working groups have analysed the development of the IOC and suggested actions for its further strengthening as an intergovernmental organization.[104] These findings and recommendations can be used for the further development of the institution, through the support and involvement of Member States of the IOC.

An important constraint on the IOC is its situation as a body within a much larger mother organization, UNESCO, with many other substantial areas of interest. While this arrangement provided initial benefits, the IOC's responsibilities have widened with an increasing number of Member States, programmes, actions and support needs. The situation has become correspondingly more complicated. The current structure hinders further growth and acknowledgement of the major role of scientists and ocean science and observations in addressing several key issues of importance for society. This situation can become counter-productive in competitive environments, with a large number of institutions addressing matters related to the marine environment. Such competition leads to conflicts and turf-fighting and can become debilitating.

In 1995, when I was serving as Executive Secretary, the position was accorded the level of Assistant Director-General. Thereby UNESCO, and of course its

103 Protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their living resources. See: https://www.un.org/Depts/los/consultative_process/documents/A21-Ch17.htm

104 IOC/INF-1337 Rev. (Kullenberg, 2016).

Director-General, acknowledged the importance of the ocean and the IOC. This change brought greater access within UNESCO and strengthened both access to and cooperation with other organizations. However, resource limitations and budget constraints still constituted serious challenges for the IOC, hindering satisfactory fulfilment of its mandate and obligations – an issue that has been acknowledged by the Member States. This situation is particularly difficult in view of the IOC's responsibilities to address major problems affecting the ocean – the most important compartment of our environment. The need for research and sustained observations to identify science-based solutions to known issues is increasing. Moreover, surprises may well emerge with respect to global changes, both in the environment and social conditions, which together with related uncertainties need be taken into account in governance and management. The time scales for action may also be shrinking. This all demands communication between sectors, including the science community, as well as adaptive management, and underlines the need for a strong intergovernmental organization to ensure coordination and timely delivery of results.

How can this be achieved and how can these challenges be overcome? Orderly, regular communication with Member States is crucial, accompanied by reporting of results and transparency regarding the use of resources. The Member States need to acknowledge the role of the IOC and their priorities need to be addressed. But are these priorities the same as those of UNESCO or other organizations cooperating with the IOC? If not, then who acts as the arbiter? This complex situation seems related to the status of the IOC. The time has come to re-establish the IOC as a separate, independent, acknowledged intergovernmental organization of the UN system, with responsibility for integrating, coordinating and reporting on a multitude of programmes. For the sake of our ocean and our society, let the new UN Decade of Ocean Science for Sustainable Development bring about this change, to let us ensure the ocean we need for the future we want.

Ocean research and observations can provide highly valuable services to society and can help address serious environmental problems and issues. The vision of the founders of SCOR and the IOC for a planet-wide perspective has been confirmed. Over six decades, cooperation has expanded from national institutions in a few countries to multiple nations across the globe with links to regional partners, including the 150 IOC Member States. In parallel, the IOC's focus has widened from serving mainly one major sector of society to encompassing almost all sectors. However, despite these advances in understanding the marine environment and resources, and their importance for us, assessments show that the deterioration of many ocean areas and coastal

zones continues. This underscores the need for humanity to address and change its own actions and behaviour.

The first visit of humans to the deepest part of the ocean occurred almost at the same time as President John F. Kennedy launched the programme that would land humans on the Moon. Deep sea vents were discovered in the 1970s, with deep sea remotely controlled vehicle technology playing a large role in further exploration and now exploitation. Now, more than two decades into this century, we are facing the biggest challenge of real ocean development. It is to be hoped that this will be done with care and thought. As Anne Simon said, 'To risk the ocean is to risk ourselves, our children, our world' (Simon, 1984).

Despite this warning almost half a century ago, a major conclusion from this book and several other reviews based on ocean science findings is that we are in fact risking the ocean. However, science alone cannot help us retrieve the ocean Captain Cook experienced.

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Paying tribute

This is not a life story. However, throughout my life I have so far been very lucky, thanks to many people. I feel a need to express my thanks and appreciation through some personal tributes. First, I was very lucky with my parents, who gave me a good education and supported me in my various choices, and provided help when needed. I was equally lucky in finding my wife, with a little bit of help from very special friends, including her father and brother. I wish to thank my wife in particular for her support and help, remaining with me in different places, keeping the home base warm and taking care of our two children. She also accepted my travels to participate in many expeditions at sea, and much travelling during my work at the IOC of UNESCO. For all this I am extremely grateful. This also goes to our children for their participation and support, which has continued and become even more important after retirement.

I am extremely grateful to Prof. Nils Jerlov for accepting me as his research and teaching assistant at his new institute for physical oceanography at the University of Copenhagen, where I started in April 1965. The new institute specialized in optical oceanography; the specialization was one method of institution building and training.[105] In most cases, we worked in frontal zones as in straits or upwelling areas, in coastal currents, in estuaries and outflows from regional seas, where the water masses were characterized by their content of different substances, suspended or dissolved, organic or inorganic. This broad but still focused approach was thanks to our leader, Prof. Nils Jerlov. His leadership stimulated us; he had a great international network of contacts; he shared his ideas and experiences with us, and encouraged us to develop our own, giving guidance and advice; he encouraged cooperation and interaction with others. Many others at the Institute should also be remembered, as well as colleagues from the other small institutes on meteorology, geophysics, ice, isotopes and climate change, housed in the same building. This stimulated cooperation, exchange and a series of seminars. However, I owe a special tribute to our

105 We applied optical techniques for tracing Baltic Sea water outflow into the Kattegat- Skagerrak and the North Sea through its content of humus, called yellow substance; river outflows through the same characteristic and through the content of suspended particles by measuring the light scattering; in coastal upwelling areas to follow the migration of the productive water offshore through the colour of the surface water and the light scattering through indicating the amount of suspended particles; to identify and follow the presence of bottom boundary layers by means of their light scattering signal; using fluorescence to follow the spreading of a dye tracer in experiments to study the mixing in the upper layers of the sea.

institute's experienced and clever secretary, Mrs Elin Hallden. She welcomed me when I first arrived, helped introduce me to the Danish way, and remained very helpful and supportive throughout the whole period. I also wish to express my thanks to lecturer Mr Kjell Nygaard, who gave much advice and help in context of electronics. Special thanks and also admiration goes to our research engineer Mr Henning Hundahl, who participated with me in many ocean expeditions, from the Southern Ocean to the Arctic Basin, always very professional, willing to work and able to solve problems with most equipment. We also cooperated with other Danish institutions, in particular the Danish Fisheries Research Institute, and I wish to pay tribute to Dr Vagn H. Hansen. He provided much support to my association with the IOC, being one of the Danish Delegates, together with Dr Torben Wolff, who was also very supportive. A fine friendship developed between us all.

I have been very fortunate in having a very educational, encouraging and constructive association with ICES, including the Secretariat in Copenhagen, the elected leadership, several committees and many national delegates. For several years, I was a member of the Marine Environment Protection Committee of ICES, including a period as its chair; and at the statutory meeting in October 1982, I was elected to chair the consultative committee, which I served until becoming a staff member of the IOC in May 1985. The whole gave considerable work and responsibility but also much experience, many close contacts with fine people and leaders in their field, as well as friends. For all this I remain very grateful to ICES and the leaders at the time, perhaps in particular the General Secretary Mr Hans Tambs-Lyche, the Environmental Officer Dr Janet Pawlak, and the President and subsequently General Secretary, Dr Basil Parish.

It was through my work with ICES that I became involved with the marine pollution problem and related research. This led to my association with GESAMP, and a broader involvement with the problem. I learnt a lot from the related work, the cooperation with members of several working groups and GESAMP as a whole, including the representatives of the sponsoring UN Agencies. Many leading scientists were involved, including Prof. E. D. Goldberg from Scripps, Dr B. H. Ketchum from Woods Hole, Dr M. Waldichuck from Canada and Dr H. Cole from UK. I made many friends. The friendship and hospitality I received from Dr Ing. Francesco Valdez from Lima, Peru, during several visits to Lima was fantastic. During the work on the dumping problem, I recall in particular the contribution and support of Dr John Portmann from the UK, expert in marine chemistry with a broad experience and likewise mind. Together, we reviewed the draft report at his laboratory and he invited me to stay in his home. This was a very nice and encouraging, friendly attitude, from

John and his family. The whole process demonstrated scientific international cooperation involving several intergovernmental organizations addressing problems of socio-economic significance requiring science to find solutions.

At the GESAMP session in 1975 I was elected chair of the Group, for the period 1976–78. I was nominated and supported by UNESCO through the Division of Marine Sciences. In this connection, I met with the Director of the Division, Dr Dale Krauss. He was very supportive, provided good advice, and was very encouraging to me personally. When I later joined IOC-UNESCO, I came to work with him again and welcomed his cooperative attitude. During meetings at the FAO in Rome 1973–74, I also met Dr Mario Ruivo, then Director of Fisheries at the FAO Secretariat. He was a very broad-minded personality with many ideas. He later became the Secretary of the IOC at UNESCO. In that capacity, he was instrumental in my appointment at the IOC in 1985. Dr Ruivo remained in post until the end of 1988 and during these years I learnt much from him. We functioned very well together. In 1989, I had the honour to succeed him as Secretary of the IOC.

At the IOC, I was very fortunate to work under the direct leadership of Dr Ruivo. It was also a great experience to meet and gradually come to work under the leadership of the Director-General, Dr Federico Mayor. He was very stimulating and encouraging, giving much support, and had a wonderful sense of humour. We developed, for me at least, a very good relationship. It was, likewise, a great experience and honour to work with the presidents of the IOC during my period as Secretary – Prof. Ulf Lie, Dr Manuel Murillo and Dr Geoff Holland. We all developed an excellent working relationship and friendship. My initial responsibility at the IOC was the marine pollution programme, GIPME, Global Investigation of Pollution in the Marine Environment. This was under the leadership of the Chairman of the associated Working Committee, Dr Neil Andersen, from the National Science Foundation, USA. He had previously held the position I held at the IOC Secretariat. He was very dedicated and hardworking, with great experience. We developed a very fine working relationship, as well as friendship. There were several colleagues in the secretariat with whom a very good working relationship and friendship developed, and I wish in particular pay tribute to my deputy Dr Klaus Voigt, Dr Iouri Oulionine and Mrs Natalie Phillippon, and all of my secretaries who bore with me for several years, providing very good support and solidarity. I was also fortunate to work with several young colleagues who joined the secretariat for short or extended periods, a number of whom were supported by their national authorities. I am grateful to all of them for their dedication and good work. I wish to mention Mr Haiqing Li and Dr Jiang Jihang from China who worked with me for most of the period. Support

from National Delegations was given in most cases. In this context, I also wish to pay special tribute to Dr John Knauss from USA, Dr Sasha Metalnikov from the former Soviet Union, Mr Ge, Youxin from China, Dr Roy Green from Australia, with whom a very special friendship developed over the years. Cooperation with several organizations was also good and very constructive, in particular IMO, UNEP and the WMO, which is reflected in my interview with the *WMO Bulletin* (Vol. 48, No. 2, April 1999). Cooperation with UNEP was strongly supported and facilitated by Dr Stjepan Keckes, Director of the Regional Seas Programme, who was also a great friend. He was much appreciated and respected, and I am very grateful to him. We had worked together before I joined the IOC in the context of GESAMP, in particular regarding development of the first GESAMP *Review of the Health of the Ocean*, released in 1982 (GESAMP, 1982). When Dr Keckes left, the cooperation continued with the subsequent Directors, and in particular Ms Terttu Melvasalo.

Special attention should be given to the actions of the TEMA programme, in recognition of the importance this played with regard to the creation of the IOC and the UNESCO role for the development of education and training, and sharing of resources. During my period at the IOC, I had the opportunity to work with Dr Mahzar Haq, from India and Pakistan, when he served as head of the TEMA Programme, and I owe him a special tribute for his participation and support. Dr Haq contributed substantially to the development and implementation of the TEMA programme during his years as staff member of the IOC Secretariat and Head of the TEMA section, 1978–1990. He was very well served in this work by his previous educational and professional experience, including studies in India, England at the University of North Wales with a Ph.D. in 1960, followed by research at Woods Hole Oceanographic Institution and at the Marine Biological Association in Plymouth. He had served as founding Director of the Institute of Marine Biology at the University of Karachi in Pakistan, established on the basis of a discussion between the President of Pakistan and Dr Haq, and drafted the plan for the National Institute of Oceanography. He contributed as an invited expert to the development of the programme for the International Indian Ocean Experiment 1960–1965 and participated in several of the associated expeditions. He attended the negotiations for the Law of the Sea at Commission III as a member of the Pakistani Delegation. There, he elucidated the importance of marine scientific research for developing countries, the related requirement of the Consent Regime, the role of the International Seabed Authority, the concern for coastal seas pollution and development of integrated coastal area management. I had the honour to work with Dr Haq and learn from him, sharing some of his experiences. He demonstrated his knowledge and abilities, not only in the context of TEMA in marine research, but also in associated negotiations,

cooperation and diplomacy, with a deep sense of responsibility and pride as well as humility, solidarity and understanding.

The 50-year anniversary of the IOC was celebrated in St Petersburg in April 2010 by an overview of the development of education and training through the International Conference '50 Years of Education and Awareness Raising for Shaping the Future of Oceans and Coasts' (RSHU). The conference reviewed progress in education and training, the role of international organizations, technology, methods and funding of education and training processes, and awareness raising of the importance of marine research and protection of the marine environment on a scientific basis. Experiences and the need for renewal were highlighted, including with respect to cooperation between organizations, coordination and exchanges between regions. The conference reminded me of another, a quarter of a century earlier, in which I was directly involved before starting at the IOC. It likewise covered several science disciplines, education and training, with focus on an important socio-economic issue.

This was the meeting on scientific basis for the role of the ocean as a waste disposal option in Algarve, April 1985. It was the result of a wide-reaching cooperation under the leadership of the organizing committee, with members E. D. Goldberg, M. W. Holdgate, A. D. McIntyre, J. H. Steele, J. C. J. Nihoul and myself. The action was sponsored by the NATO Science Committee, Marine Science Panel, Advanced Science Institute Series on the basis of a proposal prepared by the committee, working by correspondence. A single planning meeting was held in Hamburg in 1983 to prepare the proposal and a preliminary programme. That meeting was supported by the Marine Sciences Panel of the NATO Science Committee. The panel approved the proposal and funded the symposium. This was also supported by the German Marshall Fund of the United States and the Alcoa Foundation and the National Institute for Fisheries Research, Lisbon which hosted the Symposium in Algarve. Dr Ing. M. de Barros served as the representative of the Institute on the organizing committee. The proceedings were published by D. Reidel in cooperation with the NATO Scientific Affairs Division (Kullenberg, 1986). During the whole process, I had the great pleasure to work closely with Dr John Steele, at the time Director of the Woods Hole Oceanographic Institution, and already a great friend. This became a memorable conclusion of many cooperative activities in ocean studies related to socio-economic issues, initiated by my involvement with ICES, in particular the Symposium in 1972. I remain deeply grateful to the General Secretary of ICES at the time, Mr Hans Tambs-Lyche, who involved me, trusted and advised me.

During my period as a seagoing oceanographer, I participated in many expeditions, from my student days in 1963 until 1985, when I started in the

IOC as an international civil servant. Several of these personal experiences are referred to in the boxes throughout the text. Most of these were in cooperation or partnership with other projects and groups of scientists onboard research vessels from different nations. Several of the expeditions were also part of large-scale regional or global ocean research programmes, organized through international bodies, including ICES, SCOR and IAPSO of ICSU, or IOC-UNESCO and other UN partners, and some of these were programmes of the International Decade of Ocean Exploration 1971–1980. I wish to pay tribute and express my appreciation and thanks to all these ships, their crews and officers and the institutions that managed them. My experiences were always very good, with excellent cooperation from all concerned. I am very grateful to all for the experiences and the extra colour they gave to my life. I remain very grateful to many special friends I made during the cruises.

After the cruise in Baja California in 1968, during which Prof. Jerlov had given my friend Mr Kjell Nygaard and I the responsibility of representing him and his institute, I remained in La Jolla, where my wife joined me for about a month while I worked as a research assistant at the IGPP. On the ship, I had made friends with the scientists and in particular with Dr Ray Smith, who was a scientist at Scripps. He very kindly invited us to stay with his family during our period in La Jolla. This really marked and developed our friendship. The arrangement also made it possible for us to see the area around San Diego-La Jolla, including the desert and its flowers, as well as visiting Tijuana in Mexico, just south of the border. We remain very grateful to Ray and his family for their kindness. We were very happy that they could visit us for a few days in a summer holiday at our cottage on the west coast of Sweden.

Following the period in La Jolla, we returned to the east coast. I had been given a fellowship to participate in an advanced course on geophysical fluid dynamics given at the Woods Hole Oceanographic Institution in cooperation with MIT, scheduled for the whole summer. It was thanks to the support of Prof. Pierre Welander that I was given this opportunity, and I am very grateful to him for that support. Both my wife and I visited him in Baltimore, where I was given the opportunity to visit Johns Hopkins University. After the training course, I had the opportunity to join a cruise to the Sargasso Sea on the Atlantis II as a student, under the leadership of Prof. Henry Stommel, gaining further experience from advanced ocean research at sea. I am very grateful for this opportunity.

Several other visits to Woods Hole and the USA demonstrate the extent of cooperation in ocean research which I was lucky to experience. I met with Dr Charlie Yentsch and his wife on the basis of similar research interests. They provided me with a great opportunity through a Fulbright scholarship at the

Bigelow Laboratory, where Charlie was the Director. With my family, I spent eight months in 1982 as a visitor to the laboratory. The hospitality of the Yentsch family and many others there was fantastic, as was the spirit. I met several friends from earlier expeditions, including Dr Lou Codispoti and Dr Ted Packard from the upwelling cruise in 1977 on the *Melville*. During the summer, I was also given the opportunity to participate in an expedition on the research vessel *Gyre* in the Gulf of Maine, including around the Georges Bank area. We were also able to visit Woods Hole again, this time with our two children. This was particularly memorable, since Dr John Steele was then the Director of the WHOI. We knew John and Evelyn from before, when they were still in Aberdeen. I got the chance to spend a few weeks there working on the plankton patchiness problem with John and his colleagues. We made friends and I experienced John and Evelyn's great hospitality. The whole experience was instrumental for the cooperation with John at sea during the Fladen Ground Experiment in 1976. The 1982 family visit to Woods Hole also provided the opportunity to meet with Terry Joyce, his wife and children. This was for me a great reunion from the 1976 expedition in the Drake Passage.

During the years at IOC-UNESCO, the activities, with many meetings, contacts with institutions at national level and other international organizations, led to an expanding network of colleagues, far beyond sea-faring oceanographers. The founder of the International Ocean Institute, Elisabeth Mann Borgese, had a fantastic reputation and was highly respected, known in most nations, through her own contributions as well as her famous father. She was a friend of the Director-General, Prof. Mayor and the IOC Secretary, Dr Ruivo. It was through him I met her and gradually got to know her. When I became Secretary, the cooperation between the IOI and IOC became my concern. She was the driving force behind the Mario Soares Commission, with which Dr Ruivo was also closely linked. The IOC provided some financial support to the commission, organized through the cooperation with the IOI. Gradually, she came to know me as well. When I announced my retirement from IOC-UNESCO, she invited me to apply for the position as Executive Director of the IOI, based at the headquarters in Malta, at the university. This was, of course, very stimulating and tempting, giving me a chance to work in an NGO, so I submitted my application. My wife and I visited Malta for an IOI meeting, and when I was given the position, we moved to Malta from Paris in June 1998 after my retirement from UNESCO. The IOI office was small, with just four employees, including the Executive Director. At the time, the IOI consisted of 12 operational centres based at universities, with considerable independence and with some limited financial support from the IOI. The number gradually grew to about 20. The idea was that the network, with the cooperation and interaction between the centres, institutions

and scientists involved, would pool resources, providing the basis for obtaining further financial and institutional support for joint activities. This worked pretty well. The activities included seminars, conferences, training courses, workshops and some individual research projects. The focus was on ocean governance, how to achieve it, and providing support for the implementation of UNCLOS. Through the workshops, regional seminars and training courses, a network was created involving officials with advanced national positions, all of whom were versatile, with a solid knowledge of UNCLOS and elements of ocean governance implementation. These officials normally represented their governments in related international meetings, including at the UN. It was very rewarding to be involved in the process of the IOI, including the fundraising. However, it did not last more than four years. In the winter of 2002, Elisabeth passed away. I was informed by a call from USA in the middle of the European night. This was very sad and a great loss for the ocean and its proper governance.

In the spring after she passed away, Elisabeth had been scheduled to participate as a keynote speaker in the conference on Sea and Human Security organized by UNITAR at its office in Hiroshima, in March 2002. The organizers wanted me to attend instead in my capacity as Executive Director of the IOI to deliver the keynote address in honour of Elisabeth. The conference and its proceedings are dedicated to 'Professor Elisabeth Mann Borgese in honour of her life and her tireless work for the oceans' (Azimi et al., 2002). This turned out to be a very interesting and stimulating occasion, despite the very sad reason for my attendance. It led to a good contact with Dr Nassrine Azimi, the director of the office. It also generated other contacts in Japan through the IOI Operational Centre in Japan, led by Ms Masako Otsuka Bennai. This then led to the IOI association with the Freshwater Conference in Kyoto in 2003, which in turn led to my invitation to spend some time with the Nippon Foundation in Tokyo. My tasks there were association with young researchers at the Foundation and preparing a report on elements of ocean governance and UNCLOS, much in line with the activities at the IOI. My contacts with the Hiroshima Office of UNITAR continued (see Box 8).

The whole sequence of events over the first decade of the Millennium demonstrated the role of the ocean in stimulating and generating a wide range of cooperation between countries, institutions and individuals in pursuance of ocean governance. For me, this also included becoming close to PEMSEA and Dr Chua Thia-Eng, as well as continuing my close association with a number of friends in China, with whom I had enjoyed an extended cooperation over many years. Dr Chua invited me to several very memorable activities in China and other countries in Asia. These were all cooperative efforts for the marine and

coastal environments. I am extremely grateful to all who made my continued involvement during the first decades of the Millennium possible.

During the period in Malta, I also met with Dr Vladimir Ryabinin, who was there as leader of an EU project on ocean modelling. He succeeded me as Executive Director of the IOI, but obtained a position at the WMO soon after. In turn, he was succeeded by my previous Deputy at the IOC, Dr Iouri Oliounine. The cooperative network continued and when Dr Ryabinin became Executive Secretary of the IOC, he asked me to do some work for the organization. This gradually led to my involvement in preparing a series of reports, including the drafting of the note for the new Ocean Decade. Thus, the loop was closed for me, through coincidence and opportunity emerging from a very extensive and sometimes intensive international cooperation in ocean science and related marine affairs.

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It is with much gratitude that I acknowledge the very substantial support and help for this work given to me by my friend Dr Salvatore Aricò. Without his support and encouragement, the project would not have been completed. Thank you very much Salvatore. Much support and help were also given by several of your assistants, and especially Ms Itahisa Déniz González, whose very professional assistance I wish to acknowledge with great appreciation. It is also with much appreciation that I thank Dr Vladimir Ryabinin, the Executive Secretary of the IOC, for his support, interest and help, and his willingness to publish the report through the IOC-UNESCO channel. A special 'thank you' goes to the UNESCO Publishing Board, which suggested some very good adjustments and additions, and to Patrice Boned for his help with the production process. I also wish to acknowledge several good suggestions and corrections from Jens Boel, former UNESCO's Chief Archivist. It is also with much pleasure and some pride that I thank the whole IOC Secretariat staff for their friendly and helpful approach to me over these years, since about 2014. I also wish to thank Dr Roy Green for his interest in the work, for reading the draft and help in drafting the Executive Messages, his encouragement and friendship. Finally, it is with a great feeling of gratitude that I thank my wife for her support, understanding and sustained encouragement, despite my prolonged absence from some other duties during the work, which absorbed much of my attention.

The vision of the UN Decade of Ocean Science for Sustainable Development 2021–2030 is the 'science we need for the ocean we want'. The Ocean Decade provides a convening framework for diverse stakeholders to co-design and co-deliver solution-oriented research for a well-functioning ocean. The Ocean Decade will facilitate the development of services and tools for decision- and policy-makers, innovators and managers at all scales to contribute to the achievement of the 2030 Agenda and complementary policy frameworks. The Ocean Decade will bring about a major step change in the knowledge and management of the ocean. Its design will address both deep disciplinary understanding of ocean processes and solution-oriented research. The Decade will start exactly 50 years after the start of the International Decade of Ocean Exploration (IDOE) that took place in 1971–1980 and which was responsible for some of the key 20th-century advances in ocean science.

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Since the mid-nineteenth century, ocean research, technological developments and social change have been inextricably linked. Ocean exploration and observation have been driven by revolutions and wars – especially the Second World War – and more recently by globalization, reflecting changes in the economy and society that have increased the need of governments, industries and the public for greater knowledge of the ocean and its resources. Such scientific knowledge encompasses the physical, chemical and biological functions of the ocean, its living and non-living resources, the impacts from human uses and abuses, and the natural and human-induced changes and environmental responses, which in turn have consequences for human security.

In the context of such an interconnected framework, international cooperation has proved fundamental to the advancement of ocean science. Firmly convinced that cooperation holds the key to navigating the complex dynamics of the ocean, Gunnar Kullenberg – oceanographer and former Executive Secretary of the Intergovernmental Oceanographic Commission of UNESCO – revisits more than two centuries of collaboration and partnerships in his book *Ocean Science and International Cooperation: Historical and Personal Recollections*. Both a history book and a personal memoir, this publication gives particular prominence to the creation of the Intergovernmental Oceanographic Commission of UNESCO, highlighting its role in promoting international cooperation, training and mutual assistance.

The publication of *Ocean Science and International Cooperation: Historical and Personal Recollections* is part of the commemoration of the 60th Anniversary of the Commission, which was celebrated on 14 December 2020.

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