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Blue Economy

An Ocean Science Perspective

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Foreword

Of the 17 Sustainable Development Goals (SDGs) of the United Nations' 2030 Agenda, SDG 14 specifically focuses on "life under water", a major portion of which is related to the ocean. But the ocean's importance in sustainable development is not limited to the SDG 14 and the ocean's contribution to other SDGs should not be overlooked. The ocean is also an important component in achieving the SDGs that are related to economic activities and community development, including, SDGs 1, 2, 3, 5, 7, 8, 9, 10, and 11.

Obviously, ocean-related economy plays a vital role for global sustainable development. It is particularly important for developing coastal states and small islands. In these countries, tourism and other important ocean-based sectors can account for much higher portion of national GDP, compared to those of Organisation for Economic Co-operation and Development (OECD) countries. Because of this greater reliance on ocean-based sectors, developing countries are prone to greater risks from climate and anthropogenic change. In this respect, the blue economy has gained a lot of attention recently. However, the term "blue economy" has been used without a clear definition, sometimes interchangeable with similar terms such as "ocean economy" or "marine economy". A practical, succinct definition of the blue economy would be a sustainable kind of ocean or marine economy. Examples are sustainable fisheries, sustainable tourism, renewable ocean energy, green shipping, ocean conservation, and reduction of ocean pollution, just to name a few. However, the sustainability of ecosystem management is a complicated issue as we try to establish optimal use across many sectors. Multiple stakeholders have different interests and, consequentially, conflicts or problems may be incurred. To make matters more complicated, solutions would be specific to each level of geopolitical organization and governance. Every nation may have different solutions. Even within each nation, provinces may have different agendas. To achieve a balance between risks and benefits across all ocean sectors under various geopolitical settings, scientific guidance is vital. Despite its importance, the science for the blue economy is still largely an uncharted sea. To this end, this volume provides a very timely discussion on the science and technology for the blue economy. It discusses a comprehensive set of topics related to the blue economy: biodiversity, blue carbon, tourism, living and nonliving resources,

various forms of threats, economics, observations, and capacity development. The science and technology for the blue economy has not been discussed in a rigorous, comprehensive manner and this book will open a new avenue for the forthcoming discussion.

Busan, Korea

Sinjae Yoo
President of SCOR

Preface

The ocean is now a major factor in the development of many coastal nations. For many developing countries resources and services from the ocean are a major source of income. To gain maximum benefits from the ocean, many of them have developed ocean-based national development plans. Very often economic gains remain at the core of these plans. Their implementation, however, occurs at a time when the ocean is already under threat from a variety of human activities, and now with the added stress from the impact of climate change. The combined effect of accelerating blue economic activities, and the impact of climate change threaten the sustainability of ocean use for human benefits. These challenges to blue economy are reflected in the World Bank definition of blue economy with its three pillars: environmental, economic, and social sustainability.

For blue economic development, the UN's Agenda 2030 and the SDGs provide a unique guiding platform, and its newly launched Decade of Ocean Science for Sustainable Development provides the necessary impetus to bring in the science for the sustainability of human interactions with the ocean. As a contribution to these efforts and with a view to creating awareness of the involved science and technology issues around blue economy among developing countries, the Science and Technology Centre of the Non-Aligned Movement and Other Developing Countries (NAM S&T Centre) initiated the preparation of this monograph and invited us to get involved as Editors.

The Monograph explores the challenges to blue economy from an environmental—ocean science—perspective. The premise is that scientific understanding of ocean processes and ecosystem functions is a prerequisite for functional and sustainable blue economy. The first set of chapters provide examples of ocean ecosystems and resources as well as the needed science to better understand and monitor their response to climate change and other human—blue economic—activities. Subsequent chapters describe the available ocean research and monitoring observation tools, the capacity development needs of developing countries for the practice of blue economy, and the opportunities available at national, regional, and global levels.

We are grateful to colleagues from around the world who were willing to share their time and efforts to contribute the chapters of the book. Their experience and

knowledge gained in South-South and North-South cooperation in ocean studies and through their participation in SCOR's (Scientific Committee for Ocean Research) Visiting Scholars Program have enriched the chapters with a wide variety of regional examples. The discussion at a joint NAM S&T Centre—SCOR Exposure Workshop on the topic with the participation of the authors has been helpful in fine-tuning the chapter contents. Primarily organized as a capacity-development exercise for participants from NAM S&T Centre and SCOR member countries, the Workshop also helped to gather input from the global community on the topics of the book chapters, and to demonstrate the work of the NAM S&T Centre and SCOR to a global audience.

Chapter authors were selected based on their work in developing countries, either living and working there, or serving as visiting scientists through the SCOR Visiting Scholars program and other activities. A major strength of the book is the wealth of case studies provided. We appreciate the efforts of the many chapter authors, without which the book would have lacked the richness of local examples and expert knowledge. We thank the chapter reviewers, who helped improve the quality of this book: Janice Cumberbatch, Sean Fennessy, Ken Furuya,Tim Jennerjahn, Joanna Waniek, Robert Weller, and several anonymous reviewers.

We thank the NAM S&T Centre for initiating and inviting us to be part of this endeavor and Springer Nature for their commitment to producing such a book. We hope that this book can serve as a resource for training in developing countries. The editors will devote any royalties from sales of this book to training programs for developing country scientists through the Scientific Committee on Oceanic Research of the International Science Council.

Newark, DE, USA Edward R. Urban Jr.
Bremen, Germany Venugopalan Ittekkot

Introduction

The oceans provide a major source of income for many coastal nations, particularly in the developing world. Economic benefits from the oceans depend on wise management of resources based on scientific understanding and appropriate application of technologies available. The intersection of science, technology, and economy is most obvious in nations' coastal zones.

Recognition of the significance of economic benefits from the oceans for national economies led to the development of the term "Blue Economy" at the UN Conference on Sustainable Development held in Rio de Janeiro, Brazil, in 2012. A useful definition of Blue Economy that is used by the World Bank for a Sustainable Ocean Economy is given as: *"the sustainable* use *of ocean resources for economic growth, improved livelihoods and jobs while preserving the health of ocean ecosystems."*

Advancement in science and technology through research and observations is needed to maximize blue economic benefits in a sustainable manner. Ignoring science can lead to resource extraction that is not sustainable, damaging the resources, the natural environment, and human society in ways that may significantly reduce the benefits available. In many developing countries, however, the currently available capacity to conduct ocean research and observations is still inadequate. Governments need to put in measures to enhance this capacity at the national level, particularly to promote ocean education and research. Given the excellent oceanographic capacities achieved by some among the NAM Member Countries, there is also huge potential for South—South Cooperation, as well as Triangular Cooperation, to augment national efforts.

This Monograph—*Blue Economy: An Ocean Science Perspective*—in its sixteen chapters describes how science and technology can be applied to improve the management of coastal resources for the best economic outcomes. It brings together scientific communities from both the developing and the developed world with comprehensive foundational understanding of the ocean science and technology available and related gaps to maximizing the safe use of the resources, mitigating the threats, and building overall blue economic capacity in a sustainable manner.

The chapters of the book have been categorized into dedicated sections on: (i) Resources, (ii) Threats, (iii) Observations, and (iv) Developing Capacity for Ocean Science and Technology that provide significant insights focused on coral reefs, seagrasses and mangroves, coastal fisheries, freshwater extraction, tourism, oil and gas, minerals, coastal pollution, harmful algae, ocean acidification, climate change and coastal ecosystems, blue economic prospects of small islands, observing systems, and building capacity for ocean science and technology.

The book altogether summarizes that only through appropriate scientific understanding and experience in the latest technological developments related to conserving and managing ocean resources, blue economies can be developed and sustained worldwide.

In this connection, I am proud to mention that in anticipation of publication of this Monograph, the NAM S&T Centre in collaboration with the Scientific Committee on Oceanic Research (SCOR), Newark, Delaware, United States, organized an International Workshop on Application of Ocean Science and Technology for the Practice of Sustainable "Blue Economy" in Developing Countries during 8–9 November 2021, during which the contributed chapters of this book were presented by the lead authors/co-authors.

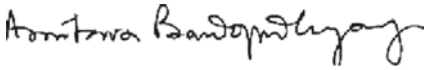
I am thankful to the editorial team of this book: Dr. Venugopalan Ittekkot, Former Director, Leibniz Center for Tropical Marine Research (ZMT), University of Bremen, Germany, and Dr. Edward R. Urban Jr., Former Executive Director, SCOR, for the scientific evaluation of the manuscripts and ensuring the best selection of the contents for wider dissemination of scientific knowledge on the chosen subject.

I express my sincere gratitude to Dr. Sinjae Yoo, President, Scientific Committee on Oceanic Research, USA, for kindly agreeing to write the "Foreword" of the Monograph.

I am thankful to Dr. Loyola D' Silva, Executive Editor, Springer Nature, Singapore, for considering this book for publication under the reputed banner of Springer Nature and Mr. Ramesh Kumaran, Project Coordinator, Springer Nature for monitoring and streamlining the publication process. I am confident that our association with "Springer" would lead to many more such valuable collaborative endeavors in future.

My sincere thanks are also due to the entire team of the NAM S&T Centre, especially to Mr. Madhusudan Bandyopadhyay (Senior Adviser) and Ms. Jasmeet Kaur Baweja (Programme Officer) for facilitating this book project. I am also thankful to Dr. Ranadhir Mukhopadhyay, Former Chief Scientist, CSIR-National Institute of Oceanography (NIO), Goa, for his inputs in bringing out this publication. I also record my appreciation for the invaluable assistance rendered by my colleagues Mr. Rahul Kumra and Mr. Pankaj Buttan towards bringing out this publication.

I am sure that this book would be a valuable reference material for scientists, researchers, government officials, policy makers, marine-sector professionals, managers, and representatives working in the areas of ocean sciences and sustainable coastal resource management.



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Contents

Acronyms

ADCIRC	Advanced Circulation Model
AGB	Above-Ground Biomass
AIS	Automatic Identification System
AMO	Atlantic Multidecadal Oscillation
ANIBOS	Animal Borne Ocean Sensors
ASAP	Automated Shipboard Aerological Program (GOOS)
ASIRI-OMM	Air-Sea Interaction Research Initiative–Ocean Mixing Monsoon
ASP	Amnesic Shellfish Poisoning
ASV	Autonomous Surface Vehicle
AUV	Autonomous Underwater Vehicle
AWI	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
AZP	Azaspiracid Shellfish Poisoning
BBMP	Blue Bay Marine Park (Mauritius)
BC	Blue Carbon
BCC	Benguela Current Commission
BCE	Blue Carbon Ecosystems
BCLME	Benguela Current Large Marine Ecosystem
BMP	Balaclava Marine Park (Mauritius)
BRD	Bycatch Reducing Device
Bsi	Biogenic Silica
Bq	Becquerel
C	Carbon
CAL-VAL	calibration and validation
CARICOM	Caribbean Community
CBD	Convention on Biological Diversity
CBEMR	Community Based Ecological Mangrove Restoration
CCCCC	Caribbean Community Climate Change Centre
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utlilization, And Storage

CD	Capacity Development
CEOS	Committee on Earth Observation Satellites
CFP	Common Fisheries Policy (EC)
CGTMT	Criteria and Guidelines on the Transfer of Marine Technology (IOC)
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COESSING	Coastal Ocean Environment Summer School in Ghana
COP	Conference of Parties
C_{org}	Organic Carbon
COSPPac	Climate and Oceans Support Program in the Pacific
CP	Ciguatera Poisoning
CPR	Continuous Plankton Recorder
CPUE	Catch Per Unit Effort
CREWS	Climate Risk and Early Warning System
DAC	Data Assembly Center
DBCP	Data Buoy Cooperation Panel
DDT	Dichlorodiphenyltrichloroethane
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DO	Dissolved Oxygen
DOOS	Deep Ocean Observing Strategy
Dsi	Dissolved Silicon
DSP	Diarrhetic Shellfish Poisoning
DSS	Decision Support System
EAMNET	Europe Africa Marine Network program
EBM	Ecosystem-Based Management
EBSA	Ecologically and Biologically Significant Area (CBD)
EBV	Essential Biodiversity Variable
EC	European Commission
ECAL	Environment and Climate Adaptation Levy
ECMWF	European Centre for Medium-Range Weather Forecast
ECOP	Early Career Ocean Professional
ECOWAS	Economic Community of West African States
ECV	Essential Climate Variable
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EJ	Exajoules
ENSO	El Niño-Southern Oscillation
EOR	Enhanced Oil Recovery
EOV	Essential Ocean Variable
EPL	Exclusive Prospecting License (Namibia)
ESP	Environmental Sample Processor
ESSO	Earth System Science Organization (India)
EU	European Union

EU ETS	European Union Emissions Trading Scheme
EWS	Early Warning System
FAD	Fish Aggregator Device
FAIR	Findable, Accessible, Interoperable, and Reusable Data
FAO	Food and Agriculture Organisation
FDI	Foreign Direct Investment
FOO	Framework for Ocean Observations
FPSO	Floating Production Storage and Offloading
FPV	Floating Solar Photovoltaic Energy
FSDG	Freshwater Component of SDG
FSM	Federated States of Micronesia
GDAC	Global Data Assembly Center
GDP	Gross Domestic Product
GEF	Global Environment Facility
GEO BON	Group on Earth Observations Biodiversity Observation Network
GHG	Greenhouse Gas
GIS	Geographic Information System
GLOSS	Global Sea Level Observing System
GMES and Africa	Global Monitoring for Environment and Security and Africa
GMSL	Global Mean Sea Level
GMSLR	Global Mean Sea Level Rise
GOA-ON	Global Ocean Acidification—Observation Network
GOOS	Global Ocean Observing System
GO-SHIP	Global Ocean Ship-based Hydrographic Investigations Program
GOSR	Global Ocean Science Report (IOC)
GRACE	Satellite
GRAs	GOOS Regional Alliances
Gt	Gigaton
GTS	Global Telecommunication System
GW	Gigawatt
HAB	Harmful Algal Bloom
HAEDAT	Harmful Algal Event Database
HBCU	Historically Black College and University (USA)
HCH	Hexachlorocyclohexane
HRE	Huanghe River Estuary
HSE	Health, Safety and Environmental
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IFCB	Imaging Flow Cytobot
IGY	International Geophysical Year
IMBeR	Integrated Marine Biosphere Research program
INCOIS	Indian National Centre for Ocean Information Services
IndOOS	Indian Ocean Observing System

IN-MHEWS	International Network for Multi-Hazard Early Warning System
IOC	Intergovernmental Oceanographic Commission
IOD	Indian Ocean Dipole
IODE	International Oceanographic Data and Information Exchange
IOGOOS	Indian Ocean Observing System
IORA	Indian Ocean Rim Association
IPCC	Intergovernmental Panel on Climate Change
IRF	IndOOS Resources Forum
IRS	Indoor Residual Spraying
ISC	International Science Council
IUU	Illegal, Unreported, and Unregulated (Fishing)
LC-MS/MS	Liquid Chromatography with Tandem Mass Spectrometry
LDC	Least-Developed Country
LECZ	Low Elevation Coastal Zone
LiDAR	Light Detection and Ranging
LIFDC	Low-Income Food-Deficit Country
LM	Light Microscopy
LME	Large Marine Ecosystem
LMS	Learning Management System
LNG	Liquified Natural Gas
LOCO	Long-Term Ocean Climate Observation project
MACBIO	Marine and Coastal Biodiversity Management in Pacific Island Countries
MBON	Marine Biodiversity Observation Network
MCA	Marine Conservation Agreement
MEFT	Ministry of Environment, Forestry and Tourism (Namibia)
MESA	Monitoring for Environment and Security in Africa
MFMR	Ministry of Fisheries and Marine Resources (Namibia)
MJO	Madden-Julian Oscillation
ML2030	Marine Life 2030
MME	Ministry of Mines and Energy (Namibia)
MOOC	Massive Open Online Course
MPA	Marine Protected Area
MPS	Massively Parallel Sequencing
MSME	Micro Small Medium-Sized Enterprise
MSY	Maximum Sustainable Yield
Mt	Megatons
MTPA	Million Ton Per Annum
MW	Megawatt
N	Nitrogen
NAM	Non-Aligned Movement
NANO	NF-POGO Alumni Network for Oceans
NAO	North Atlantic Oscillation
NCP	Nature's Contributions to People

NCS	Norway Continental Shelf
NERR	North Equatorial Recirculation Region
ng	Nanogram
NG	Natural Gas
NGO	Non-Governmental Organization
NIOT	National Institute of Ocean Technology (India)
NODC	National Oceanographic Data Center
NOK	Norwegian kroner
NOx	Compounds Containing Nitrogen and Oxygen
NPD	Norwegian Petroleum Directorate
NPP	Net Primary Production
NWP	Numerical Weather Prediction
O&G	Oil and Gas
OA	Ocean Acidification
OACPS	Organisation for Africa Caribbean and Pacific States
OA-ICC	Ocean Acidification International Coordination Centre (IAEA)
OASIS	Observing Air-Sea Interactions Strategy
OBIS	Ocean Biodiversity Information System
OBON	Ocean Biomolecular Observing Network
OBPS	Ocean Best Practices System
OCG	Observations Coordination Group (GOOS)
OCIMS	Oceans and Coastal Information Management System (South Africa)
OCP	Organochlorine Pesticide
OOFS	Operational Ocean Forecasting System (GOOS)
OPD	Optical Phytoplankton Discriminator
OpenMODs	Open Access Marine Observation Devices
OSSE	Observing System Simulation Experiment
OTEC	Ocean Thermal Energy Conversion
OTGA	OceanTeacher Global Academy (IODE)
P	Phosphorus
PAH	Polycyclic Aromatic Hydrocarbon
Pb	Lead
PCCOS	Pacific Community Centre for Ocean Sciences
PCD	Pollution Control Department (Thailand)
PDO	Pacific Decadal Oscillation
PETM	Paleocene–Eocene Thermal Maximum
PFZ	Potential Fishing Zone
PI	Principal Investigator
PICTs	Pacific Island Countries and Territories
PM	Participant Modeling
PNG	Papua-New Guinea
POGO	Partnership for Observation of the Global Ocean
POP	Platform of Opportunity

PPEF	Pristine Paradise Environmental Fee (Palau)
Ppmv	Parts Per Million Volume
PRD	Pearl River Delta
PSMA	Port State Measures Agreement
PSP	paralytic shellfish poisoning
PUI	Peaceful Uses Initiative (IAEA)
qPCR	Quantitative Polymerase Chain Reaction
R&D	Research and Development
Ra	Radium
RAMA	Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction
RCP	Representative Concentration Pathway (IPCC)
REE	Rare Earth Element
REM	Remote Electronic Monitoring
RFMO	Regional Fisheries Management Organization
RGGI	Regional Greenhouse Gas Initiative (U.S.)
RIMES	Regional Integrated Multi-Hazard Early-warning Systems
RMICS	Regional Marine Instrument Centres
ROV	Remotely Operated Vehicle
RSCAPs	Regional Seas Conventions and Action Plans (UNEP)
RSP	Regional Seas Program (UNEP)
S&T	Science and Technology
SAGITTA	Social AGITation for Temperature Analysis
SAM	Southern Annular Mode
SAMOA	SIDS Accelerated Modalities of Action
SAMREF	South African Marine and Exploration Forum
SCOR	Scientific Committee on Oceanic Research
SDG	Sustainable Development Goal
SEM	Scanning Electron Microscopy
SGD	Submarine Groundwater Discharge
SIDS	Small Island Developing States
SL	Sea Level
SMART	Strategic Marine Alliance for Research and Training
SMART cables	Science Monitoring And Reliable Telecommunications cables
SMSP	Seychelles Marine Spatial Plan
SOI	Sustainable Ocean Initiative (CBD)
SOLAS	Surface Ocean—Lower Atmosphere Study
SOOP	Ships of Opportunity Programme (SOOP)
SOT	Ship Observations Team (GOOS)
SOx	Compounds Containing Sulfur and Oxygen
SPC	South Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
SPTO	South Pacific Tourism Organisation
SROCC	Special Report on the Ocean and Cryosphere in a Changing Climate (IPCC)

SRP	Soluble Reactive Phosphorus
SSP	Shared Socio-Economic Pathways (IPCC)
SST	Sea Surface Temperature
ST	Sea Temperature
TCP	Technical Cooperation Programme (IAEA)
TEM	Transmission Electron Microscopy
Tg	Teragram
TGR	Three Gorges Reservoir
Th	Thorium
TOGA	Tropical Ocean Global Atmosphere program
TSG	Thermosalinograph
TWh	Terawatt Hour
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNFC	United Nations Framework Classification for Resources
UNISDR	United Nations Office for Disaster Risk Reduction
USD	U.S. dollars
UV	Ultraviolet
VMCA	Voluntary Marine Conservation Area
VMS	Vessel Monitoring System
VOS	Voluntary Observing Ship Scheme (GOOS)
WESTPAC	IOC Sub-Commission for the West Pacific
WIMS	Women in Marine Science Network (WIOMSA)
WIO-ECSN	Early Career Scientists Network (WIOMSA)
WIOMSA	Western Indian Ocean Marine Science Association
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WOI	World Ocean Initiative (*Economist* Group)
WSRS	Water Sediment Regulation Scheme (China)
μatm	Microatmosphere