Editorial Note

Title:
Sustainable development of the world's Large Marine Ecosystems

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Sustainable development of the world's Large Marine Ecosystems

1. Overview

The Large Marine Ecosystems (LMEs) of the world occupy coastal ocean space around the margins of the continents (**figure 1**). They produce 80% of the world's annual marine fish catch, are overfished, polluted, and subject to nutrient overenrichment, acidification, accelerated warming from climate change, loss of biodiversity and key habitats under stress (e.g. sea grasses, mangroves, coral reefs). These stressors are impacting the sustainable development of an estimated $12 trillion annually in coastal ocean goods and services, contributed by LMEs to the global economy. In recognition of the oceans' degraded condition, world political leaders at the 2012 United Nations Conference on Environment and Development in Rio de Janeiro committed themselves and their countries to. . . "protect and restore the health, productivity, and resilience of oceans and marine ecosystems, and to monitor their biodiversity enabling their conservation and sustainable use for present and future generations". . . and in doing so, to . . . "effectively apply an ecosystems approach and the precautionary approach to the management, in accordance with international law, of activities having an impact on the marine environment . . . ."

Some 28 years prior to Rio + 20, in 1984, natural scientists and social scientists were gathered together to address these very same coastal ocean issues at the annual meeting of the American Association for the Advancement of Science (AAAS). The results were published by the AAAS in the seminal LME volume entitled, "Variability and Management of Large Marine Ecosystems." Since 1986, over 450 natural and social scientists have published 6,000 pages of LME findings in 14 volumes published by the AAAS, Blackwell Science, and Elsevier Science (www.lme.edc.uri.edu).

In the intervening years since 1984, the LME approach to ecosystem based assessment and management has evolved into a global movement with participation of 110 developing countries in 22 LMEs around the globe, provided with $3.1 billion in financial support catalyzed by the Global Environment Facility (GEF) and the World Bank (WB).

In 2013, the 3rd in a series of Global LME Conferences was convened in Swakopmund, Namibia. The conference was hosted by the Benguela Current Commission and the Namibian government. Financial support was provided by the Norwegian and German governments through their developmental agencies, NORAD and GIZ respectively.

As guest editors of this thematic issue of Environmental Development, we are pleased to present the results of LME research, assessment and management from selected peer reviewed papers delivered to the Swakopmund Conference.

The boundaries of the world's 66 LMEs are based on ecological criteria including bathymetry, hydrography, productivity, and trophic linkages. It is within the spatial domains of LMEs that five modules of indicators of changing ecological states of LMEs

are applied to support ecosystem-based management (EBM) of LMEs: (i) productivity, (ii) fish and fisheries, (iii) pollution and ecosystem health, (iv) socioeconomics, and (v) governance. The first three modules listed are based on natural science metrics, and the last two address social science issues relative to human dimensions of LMEs.

The theme issue opens with overview remarks on the LME movement by Professor Dr. Gotthilf Hempel. Dr. Hempel is professor emeritus of Kiel University and former director of the Center for Tropical Marine Ecology, Bremen, Germany. Professor Hempel was a founding director of the Albert Wegener Institute for Polar and Marine Research. He served as president of the International Council for the Exploration of the Sea (ICES) and chaired various international advisory groups and national delegations to organizations such as the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

Professor Hempel provides an historical perspective. He considers global and regional estimates of marine fisheries productivity and the expansion of fisheries science to encompass other economic sectors important to sustainable development of multisectoral ocean resources from an ecosystems perspective. He examines the outcomes of the seminal LME symposia convened at annual meetings of the American Association for the Advancement of Science (AAAS), and the origins of the global LME movement advancing partnerships among natural sciences and social sciences into a network of United Nations (UN) agencies (e.g. UNDP, UNEP, UNIDO, IOC-UNESCO, FAO) and other international organizations including the International Council for the Exploration of the Sea (ICES) focused on introducing EBM practices for LME goods and services. As an example of the utility of the LME approach to the assessment and management of LMEs, Professor Hempel draws on his personal experiences in the linking of the contributions of Norway, Germany, and other countries in the fisheries investigations and training programs for Angola, Namibia, and South Africa and with the GEF supported Benguela Current Large Marine Ecosystem (BCLME) program.

The following two papers complete the overview of the LME approach to the assessment and management of coastal ocean goods and services. Dr. Benedict Satia of the University of Washington provides an overview of the application of the LME modular assessments to advance EBM in the LMEs of Africa, and Dr. Sherman traces the emergence of the global LME movement. He describes the application of the five-module LME approach to ecosystem based management by developing nations with the financial assistance of the GEF. The role of IOC-UNESCO in supporting the LME approach is reviewed, as are the challenges being met by a growing network of UN agencies and non-governmental organizations (NGOs) to advise developing countries toward ocean sustainability and development goals.

Papers are ordered as follows: case study assessments of LME Productivity and Climate Change, Fish and Fisheries, Pollution and Ecosystem Health, Socioeconomics, and Governance from regional and global perspectives. These studies are complimented by Communications from partnering institutions assisting developing countries in meeting the challenges of sustainable development of LMEs and by a

concluding Viewpoint paper on practical considerations of the LME approach to the assessment and management of the world's coastal ocean goods and services authored by 12 ministers from these countries participating in the Benguela Current Commission for sustaining the resources of the Benguela Current LME.

2. Productivity and climate change

The paper by Dr. Tony Koslow describes the application of ichthyoplankton surveys to important indicators of changes in productivity and biodiversity in the California Current LME during climate change. Dr. Koslow underscores the importance of including ichthyoplankton surveys in relation to ocean variability and biomass yields as important to coastal ocean productivity assessment methods. The following paper by academician Gennady Matishov and colleagues brings important information on the variability of temperature trends and ice cover in two subarctic LMEs—the Barents Sea and the Kara Sea.

In Dr. Vivekanandan et al., the authors conclude that the climate warming presently being experienced in the Bay of Bengal LME is likely to increase water column stratification and to lower levels of primary production. This could lead to declining trends in fish stock production and diminishing sustainable levels of fisheries biomass yields and increasing food security stress on the hundreds of millions of people inhabiting coastal communities dependent on marine biomass production as an important source of protein, and socioeconomic livelihood. The following contribution extends assessments to the Mediterranean Sea LME (MSLME) where Dr. Stergiou and coauthors examine multidecadal trends in biomass yields of the eastern, central, and western subareas of the MSLME in relation to climate change.

3. Productivity and biomass yields

The following six papers present the results of case studies of productivity and biomass yield assessments in LMEs of Africa, South America, and the subarctic North Pacific. The study by Dr. Verheye et al. assesses the effects of multi-decadal variation in the primary productivity and zooplankton of the northern and southern subareas of the Benguela Current LME. The authors make a strong case for continuation of multi-decadal monitoring and assessment of the BCLME plankton community using Continuous Plankton Recorder (CPR) and satellite remote sensing systems. Moving northward along the west coast of Africa, Dr. Wiafe et al. provide a comprehensive assessment of annual variability in the phytoplankton and zooplankton communities of the Guinea Current LME. The authors consider their results in relation to two thermal regimes—a warm phase in the early 1990s followed by a cooler phase later in the decade. Farther northward along the African west coast, Birane Sambe et al. examine the relationships between primary productivity and the biomass yields of small pelagic fish species and horse mackerel in the Canary Current LME where the upwelling primary productivity can support biomass yields of the fisheries that can exceed a

million metric tons per year under favorable environmental conditions. Annual biomass yields of all fisheries including tunas reached a total annual catch of 2.7 million tons in 2012. The paper by Dr. Vousden et al. is focused on the productivity and oceanography of the two east African LMEs, the Somali Coastal Current and the Agulhas Current. The former is described as being principally energized in primary productivity through upwelling generated by seasonal monsoons, whereas the Agulhas Current primary production is driven principally by a topographically generated series of eddies from the Mozambique channel southward along the coast to an area of confluence with the Benguela Current LME. The paper proceeds to describe the results of a Transboundary Diagnostic Analysis (TDA) completed by the countries participating in the GEF-supported combined Somali Coastal Current and Agulhas Current LMEs project. The section on productivity, fish and fisheries, and climate change closes with two case studies. The paper by Dr. Gutierrez et al. assesses the changing conditions in the productivity and biomass yields of the Humboldt Current LME that consistently yields high annual production levels of pelagic fish. The paper concluding the section is by Dr. Igor Belkin of the University of Rhode Island, who provides the results of a comparative study of the West Bering Sea and East Bering Sea LMEs.

4. Fish and fisheries

The papers that follow are contributions that are especially important to LMEs from a global perspective. The paper by Dr. Fogarty et al. titled, “Fishery Production Potential of Large Marine Ecosystems: A Prototype Analysis” applies an innovative trophodynamic model that includes micro plankton and global biome determinants for energy transfer coefficients at the LME scale. The authors estimate 180 million metric tons (mmt) of annual useable and sustainable finfish biomass yields and 50 mmt of benthic invertebrate sustainable yields for the world’s 66 LMEs. The 230 mmt total is nearly 3x the present 80 mmt annual average fisheries biomass yields reported by the Food and Agriculture Organization (FAO). The prototypic analysis as applied to each of the world’s LMEs indicates that sustainable fisheries biomass yields at levels above the present 80 mmt annual catch reported by FAO are possible.

The paper by Dr. Belhabib et al. of the University of British Columbia is focused on fisheries catch under-reporting in the Gambia, Liberia, and Namibia, and the three Large Marine Ecosystems which they represent. They conclude that world FAO fishery statistics as reported by national governments seriously underestimate annual fisheries yields, and need to be reconstructed. The method used in reconstruction is described. Based on their findings, the authors are continuing fisheries catch reconstruction for other LMEs around the globe.

The paper by Professor Qisheng Tang and coauthors is focused on changes in fisheries yields of the Yellow Sea LME. The authors discuss adaptive management actions underway to recover depleted capture fisheries and the expansion of pilot multi-trophic mariculture science and technology being applied to accelerate molluscan production as a growing source of protein for human consumption during the period of capture fisheries recovery resulting from a 30% reduction in fishing effort.

In the next paper Dr. Bianchi et al. provide a perspective of the FAO as a UN partner agency in the global LME movement toward sustainable development of coastal ocean goods and services. They describe the importance of the fish and fisheries sector to overall planning and implementation of ecosystems based management, using as an example FAO's contributions to the Canary Current and Bay of Bengal LME projects. In the paper by Johannes Kathena et al., innovative approaches to the assessment of two hake stocks (*Merluccius capensis* and *M. paradoxus*) of the Benguela Current LME are examined. In the concluding paper in the section, Dr. Bradford Brown examines the role of regional fisheries management organization in the assessment and management of LMEs.

5. Pollution and ecosystem health

In the Pollution and Ecosystem Health section of the issue are two important contributions. Nutrient overenrichment is a serious problem in the world's LMEs leading to oxygen depletion and biomass mortality events. In the lead paper, Dr. Seitzinger et al. provide results of a global estimated dissolved inorganic nitrogen loading to LMEs using a spatially explicit river export model (Global NEWS 2) for the year 2000 for forecasting the outcome of a trend analysis for the year 2050. Among the data inputs are natural biological fixation, agricultural biological fixation, fertilizer, manure, atmospheric deposition and sewage. The authors conclude that dissolved inorganic nitrogen (DIN) export to LMEs by 2050 relative to 2000, is predicted to increase by 40-45%. This important finding should serve to elevate the priority for mitigating the inputs of DIN to the world's LMEs. The other paper in the Pollution and Ecosystem Health section, by Dr. Van der Lingen et al., is focused on the Benguela Current LME and the effects of harmful algal blooms (HABs) on the health and mortality of small pelagic fish species important to the socioeconomics of the coastal communities along the southern coast of the BCLME. The authors consider the zooplankton and hydrographic influences on the distribution and abundance of HABs in relation to water column oxygen levels and physical impairment from entrapment of dinoflagellates on sardine gill rakers.

6. Socioeconomics and governance

The single paper on socioeconomics is by Professor Dr. Rashid Sumaila of the University of British Columbia, who provides an initial estimate of the value of goods and services of the Benguela Current LME to the economies of Angola, Namibia, and South Africa. The paper includes a prototype framework for LME benefits and costs at the global scale and for fisheries and marine recreational activities for the three countries bordering the BCLME. The calculated annual estimates for fisheries are quite high for the target year of 2006, including $2.1 billion in total economic input supporting 560,000 jobs with a wage budget of $400 million.

During the 3rd Global Conference, we were fortunate in the large number of papers delivered on examples of governance applications. The GEF perspective on LME governance is provided by a former senior member of the GEF Secretariat, Dr. Alfred Duda. Dr. Duda describes the GEF Operational Strategy and its adoption in 1995 to begin addressing transboundary (among nations) concerns of LMEs and their coasts, and application of the five-module LME approach to the assessment and management of coastal ocean goods and services in economically developing countries around the globe. The governance approach advocated by the GEF is based on a bottom up process of Transboundary Diagnostic Analysis conducted by countries engaged in GEF supported LME projects. Following their prioritization of issues to be addressed, the countries proceed to develop 5-year Strategic Action Program (SAP) for countries to begin working together on their shared transboundary priority issues within the general framework of the five module LME approach to ecosystem based management. In this piece, Dr. Duda describes how the GEF operational strategy supports countries participating in GEF-LME projects to incorporate integrated coastal management (ICM), marine spatial planning (MSP), and marine protected areas (MPAs) into supporting governance activities within the spatial domain of LMEs. The important best governance practice finding of Dr. Duda is that different LMEs demand different governance mechanisms consistent with the cultures of the countries participating in the GEF-supported LME program. Within this framework, eight good practices for GEF portfolio wide actions in support of EBM in LMEs related to institutional governance structures are recommended.

An island perspective to LME governance is described for the numerous small island states of the Caribbean Sea LME by Drs. Chen and Ganapin. They apply a polycentric governance approach based on the results of the work of Nobel laureate, E. Ostrom. The authors describe Professor Ostrom's body of work as emphasizing that governments managing common pool resources are only part of the players in the governance of LMEs. They argue that the more important players in the governance of common pool resources (CPR) are polycentric, including citizens, resource users, and global communities encompassing multiple decision makers operating at different geographic scales with different structures, functions, norms, values, and interests who are ready to cooperate and coordinate activities to achieve common goals. The authors argue that polycentric institutional arrangements provide a useful framework for LME governance in that issues to be addressed are complicated, multifaceted, and multijurisdictional. They use the Caribbean LME case study as an example of place-based governance efforts wherein full-scale GEF best practices for governance practices work better if supplemented with the GEF's small grants program (SGP) to address and integrate community-based actions within the governance mechanisms addressing broader scale international transboundary issues within the spatial extent of LMEs.

The polycentric governance approach of Ostrom is applied by Dr. David Vousden to the east African Somali Coastal Current and Agulhas Current LMEs. Professor Vousden argues that polycentric governance offers increased opportunity for more effective participation between developmentally equal entities and institutions, applying vertical

top-down and bottom-up levels of governance. In the piece, Professor Vousden describes challenges found and overcome in the transformation of country-focused sector-by-sector assessment and management practices to a multisectoral EBM practice across existing governance institutions among the countries of East Africa participating in the GEF supported Agulhas Current and Somali Coastal Current combined LME Strategic Action Programme. In another case study of the west side of Africa, Dr. Jacques Abe et al. address the temporal dimension of polycentric governance regime building. The 16 countries participating in the GEF supported Guinea Current LME project exemplify the importance of building trust across diverse groups of project participants. The process of trust building required more than a decade of GEF support and country-driven commitment to support TDA derived priority actions for implementing EBM practices in an agreed upon Strategic Action Plan. Active involvement of the program's Regional Coordination Unit and key ministers from participating countries was critical to achieve consensus for establishment of an Interim Guinea Current Commission responsible for carrying forward ecosystem based management practices from local to regional polycentric levels of governance among the 16 participating countries.

The next case study in LME governance is focused on the fish and fisheries of the Barents Sea LME. The paper by Lidvard Grønnevet traces a 40-year agreement on joint Norwegian-Russian management of principal fish stocks of the BSLME of cod, haddock, and saithe where the outcome has proven quite successful. The author provides a dramatic figure depicting increasing levels of spawning biomass of Atlantic cod, haddock, and saithe (pollock) rising from an estimated nine hundred thousand metric tons (mt) in 1985 to just over 3 million mt in 2012. The paper describes how Norway and Russia jointly conducted the science-based stock assessments from an ecosystem perspective leading to agreements of annually determined total allowable catch levels (TACs) that produced sustainable fisheries yields for these major demersal fish stocks of the BSLME. Given present political tensions between both countries from the Crimean and Ukrainian situation, Grønnevet underscores the ongoing effort to continue the joint governance for the BSLME fisheries based on results of ongoing joint Norwegian and Russian natural science and social science assessments to ensure sustainable biomass yields from the world's largest cod stock.

The concluding paper in the Governance section, by Dr. Hamukuaya et al., is on the Benguela Current LME project. The project stands as the best practice in the application of the governance module in harmony with the other four multisectoral modules for carrying forward ecosystem based management practice. Three participating countries—Angola, Namibia, and South Africa—have developed, over a multi-decadal period, a firmly established EBM approach to the assessment and management of the BCLME. The three countries have established a Commission and a legally frame-worked Convention that is the first in the world to be based on the LME approach to ocean governance. The paper describes the actions executed by the three governments, as they progress in their joint effort towards sustainable development of shared LME goods and services.

7. Communications

The penultimate section of the theme issue is a series of communication papers contributed by experts from the United Nations and donor country institutions supporting the global LME movement towards sustainable development. Included in the Communications section are statements from Professor G. Hempel and colleagues on LME training and development, a United Nations Development Programme (UNDP) communication by Dr. A. Hudson, a perspective on LMEs by Yvonne Walther of International Council for the Exploration of the Sea (ICES), by Christian Susan of United Nations Industrial Development Organization (UNIDO), by Julian Barbière and Dr. Sherry Heileman of IOC-UNESCO, and by Dr. Valeria Bers et al. of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The Communications section concludes with a paper by Dr. Bianchi et al., on the contributions of the *RV Nansen* as a training and survey vessel supporting the assessments of changing ecological conditions in several of the LMEs of Africa and Asia.

8. Viewpoint

We are especially privileged to have the opportunity to bring readers a viewpoint on the LME approach on LME sustainability as expressed by 12 ministers from Angola, Namibia, and South Africa, representing four sectors in each of the three countries participating in the BCLME project. Their commitment to closing the gap between science and policy to reduce environmental stress and promote the sustainable development of the Benguela Current LME is presented in their own words. Their message closes the LME thematic issue with a positive and optimistic message for the future.

10. World summits and LMEs

The global LME movement towards EBM and sustainable development of the coastal oceans around the globe is dependent on economically developing nations and advanced Organization for Economic Co-operation and Development (OECD) nations committed to achieving their national sustainable development goals. Since 1992, the nations of the world have convened three global environmental summits, the first in Rio de Janeiro as the United Nations Conference on Environment and Development in 1992 followed at 10-year intervals by a second World Summit on Sustainable Development (WSSD) in Johannesburg in 2002, and a third Summit on Sustainable Development convened in 2012 in Rio (Rio+20). The Summits have made a difference. Following the 1992 UNCED, the GEF was established as a financial mechanism for supporting developing countries in improving global environmental conditions. In 1995, the GEF included support for the LME approach to the assessment and management of coastal ocean goods and services. Subsequent replenishments of GEF funds in 2010 and 2014 following the WSSD and Rio+20 summits have provided an unprecedented opportunity by catalyzing $6 billion in financial assistance to developing nations for accepting the

challenges of sustainable development and moving ahead in ecosystem based management practices for sustaining natural recovery and sustainability of oceans and fisheries, restoring degraded habitats, curbing pollution and nutrient overenrichment, conserving biodiversity, and mitigating effects of acidification and climate change within the spatial domains of LMEs along the coasts of economically developing nations around the globe.

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The editors are indebted to the willingness of the contributors to take the time from their normal schedules to prepare the expert syntheses and reviews that serve to move us forward towards ecosystem based assessment and management of the world's Large Marine Ecosystems. We are pleased to acknowledge the interest and financial support of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, the Norwegian Agency for Development Cooperation (NORAD), and the Benguela Current Commission (BCC). This LME theme issue would not have been possible without the capable cooperation of many people who gave unselfishly of their time and effort. We are especially indebted to Dr. Sally Adams, Technical Editor for NOAA's LME Program, for her extraordinary dedication, care, and editorial expertise in overseeing the peer reviews and organization of the contributions to the theme issue. The professional contributions of Nadine Everi Moroff-Kohlstädt of AddWise Consulting (Namibia) and of Dr. Betsy Peterson of Integrated Statistics (US) in completing the editing and production process for the volume are greatly appreciated.

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Caption Page

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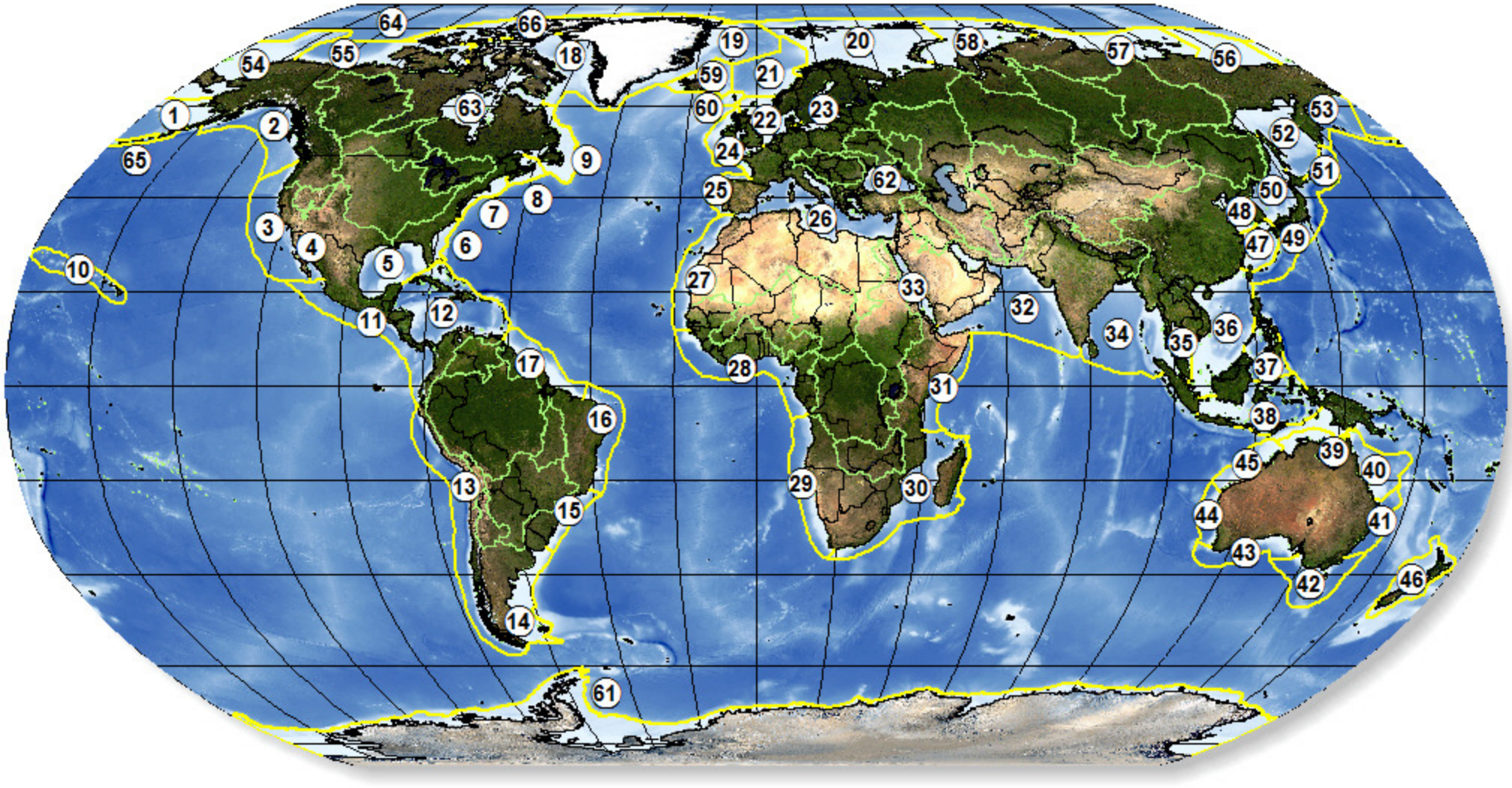
Fig. 1 The 66 large marine ecosystems of the world.

Large Marine Ecosystems of the World and Linked Watersheds



1. East Bering Sea
2. Gulf of Alaska
3. California Current
4. Gulf of California
5. Gulf of Mexico
6. Southeast U.S. Continental Shelf
7. Northeast U.S. Continental Shelf
8. Scotian Shelf
9. Newfoundland-Labrador Shelf
10. Insular Pacific-Hawaiian
11. Pacific Central-American
12. Caribbean Sea
13. Humboldt Current
14. Patagonian Shelf
15. South Brazil Shelf
16. East Brazil Shelf
17. North Brazil Shelf
18. Canadian Eastern Arctic - West Greenland
19. Greenland Sea
20. Barents Sea
21. Norwegian Sea
22. North Sea
23. Baltic Sea
24. Celtic-Biscay Shelf
25. Iberian Coastal
26. Mediterranean
27. Canary Current
28. Guinea Current
29. Benguela Current
30. Agulhas Current
31. Somali Coastal Current
32. Arabian Sea
33. Red Sea
34. Bay of Bengal
35. Gulf of Thailand
36. South China Sea
37. Sulu-Celebes Sea
38. Indonesian Sea
39. North Australian Shelf
40. Northeast Australian Shelf
41. East-Central Australian Shelf
42. Southeast Australian Shelf
43. Southwest Australian Shelf
44. West-Central Australian Shelf
45. Northwest Australian Shelf
46. New Zealand Shelf
47. East China Sea
48. Yellow Sea
49. Kuroshio Current
50. Sea of Japan/East Sea
51. Oyashio Current
52. Sea of Okhotsk
53. West Bering Sea
54. Northern Bering-Chukchi Seas
55. Beaufort Sea
56. East Siberian Sea
57. Laptev Sea
58. Kara Sea
59. Iceland Shelf and Sea
60. Faroe Plateau
61. Antarctic
62. Black Sea
63. Hudson Bay Complex
64. Central Arctic Ocean
65. Aleutian Islands
66. Canadian High Arctic-North Greenland