THE UNEP LARGE MARINE ECOSYSTEMS REPORT

A PERSPECTIVE ON CHANGING CONDITIONS IN LMES OF THE WORLD'S REGIONAL SEAS

UNEP

This report may be cited as:

Sherman, K. and Hempel, G. (Editors) 2008. The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas. UNEP Regional Seas Report and Studies No. 182. United Nations Environment Programme. Nairobi, Kenya.

Bound and printed in the United States

DEP/089I/HA

ISBN 978-92080702773-9

A Message from the Executive Director of UNEP

The world's 64 Large Marine Ecosystems are as much economic as they are environmental assets contributing around 12 trillion dollars annually to the global economy.

Increasingly the management of these assets is beginning to reflect that importance. Combined efforts among coastal countries in Africa, Asia, Latin America, and eastern Europe are now contributing to assessment and management actions aimed at tackling coastal pollution, restoration of degraded habitats, and recovery of depleted fish stocks.

They have been joined by United Nations agencies, the Global Environment Facility, and a growing number of northern hemisphere countries and principle stakeholders in fish and fisheries, coastal transportation, tourism, gas and oil production, and diamond and mineral extraction operations.

The effort to reverse the degraded status of LMEs will take time, well-focused and creative policies and funding. However it is clear that with the financial assistance of the GEF and in partnership with the UN the effort has begun, especially among the economically developing nations.

The work reflects the targets put forward at the World Summit on Sustainable Development in Johannesburg in 2002 to achieve substantial reductions in land-based sources of pollution; introduce an ecosystems approach to marine resource assessment and management by 2010; designate a network of marine protected areas by 2012 and restore and maintain fish stocks to maximum sustainable yield levels by 2015. UNEP is among several agencies and donors assisting developing countries to achieve these targets.

Climate change adds new urgency to this effort. Indeed the original findings in this report have been up-dated to reflect new findings showing that in many of the LMEs warming is proceeding at two to three times the global rate. Some of this most rapid warming is being witnessed in northeastern North Atlantic and around Europe and in the East Asian seas.

Pollution, such as high levels of nutrients coming from the land and the air, may be aggravating the effect. So we must not only secure a deep and decisive climate regime post 2012 but also tackle the wider sustainability issues to ensure the abundant productivity of not only LMEs but the Regional Seas and oceans in general for this and future generations.

Achim Steiner,UN Under-Secretary General and UNEP Executive Director

A Message from the Chief Executive Officer, GEF

We live on the land yet we often forget the sea. We forget that 70% of our planet is made up of coastal and marine ecosystems and that our coastal economies depend on these ecosystems to generate sustainable communities.

Many do not know that more than half of the carbon sequestered on the planet is attributed to marine ecosystems; our planet's temperature is regulated by the oceans. We take them for granted as we do the fact that international trade in coastal and marine fisheries is a $70 billion a year business that drives coastal economies.

While we tend to focus on a plethora of terrestrial environmental problems over the last 35 years, we have neglected coastal and marine water pollution. The Large Marine Ecosystems (LMEs) of our planet that span the continental shelves and enclosed marine waters are warming, over-fished, and becoming ever more degraded with nitrogen.

This book represents the first attempt at establishing the baseline environmental conditions of the world's LMEs and comes from a partnership among the United Nations Environment Programme, the U.S. National Oceanic and Atmospheric Administration, the Intergovernmental Oceanographic Commission of UNESCO, and the Global Environment Facility. Eighty percent of marine capture fisheries are taken in these LMEs where billions of people reside in coastal areas.

The satellite-based time series of warming of LMEs presented in this baseline assessment presents a stark picture. The trend of over-fishing of valuable and less desirable species of fish based on many decades of data from the Food and Agriculture Organization and the University of British Columbia's Sea Around Us Project shows vast depletion of species in many LMEs to the point of overexploitation and collapse. The authors also found there is an increased trend expected for nitrogen pollution from land-based sources—this promises to create more dead zones of oxygen depletion and hazardous algal blooms that threaten human, ecosystem, and economic health.

We at the Global Environment Facility hope that the release of this global assessment will call attention to the degraded state of many coasts and marine waters as well as the high risk that human behavior is placing on loss of perhaps trillions of dollars of annual goods and services. We need to stop taking these precious resources for granted.

Monique Barbut, CEO Global Environment Facility

The UNEP Large Marine Ecosystems Report

A Perspective on Changing Conditions in LMEs of the World's Regional Seas

Edited by

Kenneth Sherman
Director, Narragansett Laboratory and Office of Marine Ecosystem Studies, NOAA-NMFS, Northeast Fisheries Science Center
Narragansett, Rhode Island, USA
Adjunct Professor of Oceanography, Graduate School of Oceanography
University of Rhode Island, Narragansett, RI, USA
Adjunct Professor, School of Marine Science and Technology, University of Massachusetts, Dartmouth.

Gotthilf Hempel
Science Advisor, Senate of Bremen, Germany
Professor emeritus, Bremen and Kiel Universities
Director, Alfred-Wegener Institute for Polar and Marine Research, Bremerhaven until 1992
Director, Center for Tropical Marine Ecology, Bremen until 2000
Director, Institute for Baltic Research, Rostock until 1997

Preface

The world's coastal ocean waters continue to be degraded by unsustainable fishing practices, habitat degradation, eutrophication, toxic pollution, aerosol contamination, and emerging diseases. Against this background is a growing recognition among world leaders that positive actions are required on the part of governments and civil society to redress global environmental and resource degradation with actions to recover depleted fish populations, restore degraded habitats and reduce coastal pollution. No single international organization has been empowered to monitor and assess the changing states of coastal ecosystems on a global scale, and to reconcile the needs of individual nations to those of the community of nations for taking appropriate mitigation and management actions. However, the World Summit on Sustainable Development convened in Johannesburg in 2002 recognized the importance for coastal nations to move more expeditiously toward sustainable development and use of ocean resources. Participating world leaders agreed to pursue 4 marine targets: (i) to achieve substantial reductions in land-based sources of pollution by 2006; (ii) to introduce an ecosystems approach to marine resource assessment and management by 2010; (iii) to designate a network of marine protected areas by 2012; and (iv) to maintain and restore fish stocks to maximum sustainable yield levels by 2015. At present, 110 developing countries are moving toward these targets in joint international projects supported, in part, by financial grants by the Global Environment Facility (GEF) in partnership with scientific and technical assistance from UN partner agencies, donor countries and institutions, and non-governmental organizations including the World Conservation Union (IUCN). Many of these projects are linked to ecosystem-based initiatives underway in Europe and North America.

This report is a result of a collaborative effort to promote a global view of conditions within LMEs across the North-South divide. It was generously coordinated by UNEP Regional Seas Programme, and the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA Coordination Office) in The Hague, Netherlands. In summer 2005 it was agreed that UNEP, in partnership with the GEF-supported Global International Waters Assessment (GIWA) project, and NOAA's Large Marine Ecosystem Program, would provide synopses of ecological conditions for each of the worlds' Large Marine Ecosystems (LMEs). In accordance with the outcome of a series of consultations among the three parties, it was concluded that the five-module LME assessment framework of productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance, would provide a useful basis for describing ecological conditions within the world's LMEs.

The synopses are relatively brief for the LMEs adjacent to the more economically developed countries where ecological conditions are fairly well documented by periodically released reports, published in print or electronically, on various sectoral interests including: fisheries, pollution, habitats, tourism, shipping, oil and gas production and mineral extraction. Sources for this summary information are provided for the reader. Whereas, for the LMEs bordering countries less economically developed in Africa, Asia, and Latin America, the synopses are longer. They are based on information collected through GIWA and the GEF-LME project planning and implementation process using information that would otherwise not be readily available in the published marine assessment and management literature. The synopses were prepared by two principal authors, Dr. Sherry Heileman and Dr. Marie Christine Aquarone. For several LME synopses, where one or more of the peer reviewers added substantially to the description of ecological conditions, they are listed as co-authors of the synthesis. Each of the 64 synopses of ecological conditions includes standardized information on productivity ($gCm^{-2}y^{-1}$), ocean fronts, multi-decadal time series of trends in annual fishery yields, and changes in mean annual trophic levels of fish catch, as well as data on the physical extent (km^2) of LMEs, the presence of sea mounts, coral reefs and linked rivers, watersheds and estuaries.

Chapters I, through XVIII describe conditions of LMEs within the Regional Seas areas, followed by chapter XIX on the LMEs bordering Regional Seas areas. Three generic issues recur in the synopses: (1) the issue of encroachment of industrial fisheries into near coastal community based fisheries in Africa, Asia, and Latin America, and the need for application of the precautionary principle to protect the food security and livelihood of coastal communities; (2) the need for improved forecasting of climate driven events affecting LME resources, especially during present extensive global climate change, and (3) the global scale increasing frequency and extent of eutrophication stress on ecosystem integrity and health. Examples of these issues are included in the introductory chapter.

The substantial contribution in start-up funding by the GEF to 110 developing countries is enabling a global effort to go forward in initiating movement in Asia, Africa, and Latin America towards the WSSD marine targets. Although the way ahead is costly, a concerted and focused effort has been initiated. Within the context of the baseline initiated in this report, UNEP in partnership with other actors in the conservation and management of the marine and coastal environment will aim at measuring progress regularly through further editions of this report or through contributing to other reports such as the Global Marine Assessment (GMA).

The Editors

Acknowledgments

Preparation of this initial report on the ecological conditions of the LMEs in the Regional Seas has been a collaborative effort. We are greatly indebted to the GEF-LME Programme Managers for their pioneering contributions to the LME assessment and management process and their willingness to take the time from busy schedules to provide reviews of the LME descriptions in this report. Special appreciation is extended to: Andrew Cooke (Canary Current LME), Gerardo Gold-Bouchot (Gulf of Mexico LME), Chidi Ibe (Guinea Current LME), Yihang Jiang, Qisheng Tang and Hyung Tack Huh (Yellow Sea LME), Robin Mahon (Caribbean Sea LME), Jan Thulin (Baltic Sea LME), and Michael O'Toole (Benguela Current LME).

The GEF had tasked the Global International Waters Assessment (GIWA) to identify the ecological conditions of the GEF-eligible LMEs, thereby allowing, on the basis of these assessments, the GEF to prioritize the activities or areas needing more financial, scientific and technical support. The reports on the ecological condition for 34 LMEs, for which bordering countries are eligible for GEF financial support, were prepared by Dr. Sherry Heileman, marine and fisheries biologist, Paris, France. We are indebted to Dr. Heileman for her carefully prepared reports. We are indebted to Dr. Marie Christine Aquarone for her expert synthesis of ecological conditions in the 30 LMEs bordering the more economically advanced countries. We are indebted as well to Dr. Sara Adams, Technical Editor, for recent updates to LME descriptions and for extraordinary care and expertise in producing this volume for publication.

The following experts gave much of their time, effort, and considerable expertise to review the LME reports in Africa, Asia, Latin America and eastern Europe: Dr. Johann Augustyn (South Africa), Dr. Andrew Bakun (USA), Dr. Ratana Chuenpagdee (Nova Scotia), Dr. Andrew Cooke (Senegal), Brian Crawford (South Africa), Dr. Werner Ekau (Germany), Dr. Li Haiqing (China), Dr. Kwame Koranteng (Kenya), Dr. Daniel Lluch Belda (Mexico), Johann Lutjeharms (South Africa), Dr. Robin Mahon (Barbados), Dr. Gennady G. Matishov (Russia), Dr. Laurence Mee (United Kingdom), Dr. Sunilkumar Kolliyil Mohamed (India), Dr. Dirar Nasr (Saudi Arabia), Dr. Michael O'Toole (Namibia), Dr. Nancy Rabalais (USA), Dr. Claude Roy (France), Rodolfo Serra (Chile), Jerker Tamelander (Sri Lanka), Dr. Jan Thulin (Sweden), Professor Dr. Matthias Wolff (Germany), Jiang Yihang (Korea) and Dr. Sinjae Yoo (Korea).

The LME descriptions for North America, Europe and East Asia were originally made possible by LME experts who prepared syntheses of ecosystem productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance that have been published in the 14 LME volumes. These experts include P. Cury, S. J. Heymans, P. Hoagland, S. Levin, P.A. Livingston, J.M. McGlade, J.E. Overland, J. Rice, V. Shannon, H. R. Skjoldal, Q. Tang, and K.C.T. Zwanenburg.

We thank Dr. Daniel Pauly and other members of the Sea Around Us Project (Fisheries Centre, University of British Columbia, Vancouver, Canada, for contributing graphs of fisheries catch time series and related statistics for each of the LMEs covered here, and embedding these graphs and their explanatory text into the LME descriptions.

Finally, we acknowledge with gratitude the support and encouragement of Dr. Veerle Vandeweerd, former coordinator of UNEP/GPA and Head of the Regional Seas Program in the Hague, and Anjan Datta, Officer in Charge of the UNEP/GPA Coordination Office, Nairobi, Kenya, and Annie Muchai of UNEP, Nairobi, Kenya

The Editors

Expert Reviewers

I West and Central Africa
Michael J. O'Toole (Namibia and Ireland); Johann Augustyn (SouthAfrica);
Johann R.E. Lutjeharms (South Africa); Kim Prochazka (South Africa);
Chidi Ibe (Nigeria); Julius Wellens-Mensah (Ghana); Jean Folack (Cameroon); Bradford Brown (USA); Andrew Cooke (Senegal); Claude Roy (France); Merete Tandstad (Italy);
Tayaa Mhammed (Morocco)

II Eastern Africa
Lucy E.P. Scott (South Africa); Johann R.E. Lutjeharms (South Africa); Chris Magadza (Zimbabwe); Renison K. Ruwa (Kenya)

III Red Sea and Gulf of Aden
Khulood Tubaishat (Saudi Arabia); Dirar Nasr (Saudi Arabia); David Aubrey (USA)

IV Mediterranean
Paul Mifsud (Athens)

V Black Sea
Yegor Volovik (Turkey); William Parr (Turkey); Felix Stolberg (Ukraine)

VI ROPME Sea Area
Peyman Eghtesadi-Araghi (Iran); Najah T. Mistafa (Sweden)

VII South Asian Seas
Simon Funge-Smith (Rome); Gabriella Bianchi (Rome)

VIII East Asian Seas
Ratana Chuenpagdee (Canada); Clive Wilkinson (Australia)); Miles Furnas, (Australia);
David Souter (Australia); John Keesing (Australia); Tennille Irvine (Australia);
Nick D'Adamo, (Australia)

IX South Pacific
Iain Suthers (Australia); M.E. Baird (Australia); Janet Bradford-Grieve (New Zealand);
Jon Brodie (Australia); Stewart Frusher (Australia)

X North West Pacific
Qisheng Tang (P.R. China); Jing Zhang (P.R. China); Igor Belkin (U.S.A);
Arkady V. Alekseev (Russia); Yihang Jiang (Republic of Korea);
Teng Seng-Keh (P.R. China)

XI Arctic
Gennady Matashov (Russia); Igor Belkin (USA); NMFS, Alaska Fisheries Science Center (AFSC), U.S.A.; Alla Tsyban (Russia); Natalia Golubeva (Russia);
Mogens Dyhr-Nielsen (Russia)

XII Baltic Sea
Jan Thulin (Denmark); Ain Lääne (Estonia)

XIII North East Atlantic
Hein Rune Skjoldal (Norway); Natalia Golubeva (Russia); Luis Valdés (Spain); Michael J. O'Toole (Ireland); Eilif Gaard (Faroe Islands); Ditte Mickelsson (Greenland); Thomas Juul Pedersen (Greenland); Ólafur S. Ástþórsson (Iceland)

XIV North East Pacific
NMFS, Northwest Fisheries Science Center (USA); Igor Belkin (USA); NMFS, Alaska Fisheries Science Center (AFSC; Daniel Lluch Belda (Mexico); Edgar Arias Patron (Mexico)

XV Wider Caribbean
Robin Mahon (Barbados); NMFS, Southeast Fisheries Science Center (SEFC) (USA); Nancy Rabelais (USA)

XVI South West Atlantic
Igor Belkin (USA); Marcia Marques (Brazil); Maria Gasalla (Brazil); Ana Mugetti (Argentina)

XVII South East Pacific LME
Renato Guevara (Perú); Francisco Chavez (USA); Arnau Bertrand (France); Adm. Hector Soldi (Perú); Ulises Munaylla Alarcón (Ecuador)

XVIII Antarctic
NMFS Southwest Fisheries Center (USA)

XIX LMEs Outside Regional Sea Areas
Ditte Mickelsson (Greenland); Thomas Juul Pedersen (Greenland); Igor Belkin (USA); Kees C.T. Zwanenburg (Canada); Robert Siron (Canada); NMFS Pacific Island Fishery Center (USA); John Keesing (Australia); Tennille Irvine (Australia); Nick D'Adamo (Australia)

Contents

BACKGROUND REPORTS

Perspectives on Regional Seas and the Large Marine Ecosystem Approach

K. Sherman and G. Hempel

UNEP REGIONAL SEAS PROGRAMME LINKS WITH LARGE MARINE ECOSYSTEMS ASSESSMENT AND MANAGEMENT

A new partnership has been developed that links the coastal and marine activities of the global Regional Seas Programme (RSP), coordinated by the United Nations Environment Programme (UNEP), with the Large Marine Ecosystem (LME) approach to the assessment and management of living marine resources and environments. The joint initiative assists developing countries in using LMEs as operational units for translating the Regional Seas Programme into concrete actions. With substantial support in over one billion dollars in financial grants from the Global Environment Facility (GEF) and investment funds from the World Bank in partnership with other UN agencies and government and industrial donors, countries in Africa, Asia, the Pacific, Latin America and the Caribbean, and Eastern Europe are presently engaged in LME assessment and management projects that implement actions to restore and sustain living marine resources in coastal waters.

THE LARGE MARINE ECOSYSTEM APPROACH

The LME approach to the assessment and management of marine resources and their environments was first introduced at an international symposium convened at the annual meeting of the American Association for the Advancement of Science, in 1984. At the outset, it was understood that the LME approach would provide a framework for utilizing ecologically defined Large Marine Ecosystems as place-based areas around the globe, to focus the methods of marine science, policy, law, economics and governance on a common strategy for assessing, managing, recovering, and sustaining marine resources and their environments (Sherman and Alexander 1986).

There are two important features in the LME approach. ***First and foremost, the physical extent of the LME and its boundaries are based on 4 linked ecological rather than political or economic criteria. These are: (i) bathymetry, (ii) hydrography, (iii) productivity, and (iv) trophic relationships.*** It is the bathymetry or bottom topography that greatly influences water column structure and flow. Within the water column, the nutrient flux, vertical circulation and advective processes determine to a large extent the levels of primary productivity of the phytoplankton of the LME—productivity that is a determinant of zooplankton biomass and species composition (biodiversity), and subsequent energy-flow (trophodynamics), from plankton to fish and shellfish to marine birds and marine mammals, through the food web of the LME. Based on the 4 ecological criteria, 64 distinct LMEs have been delineated around the coastal margins of the Atlantic, Pacific, and Indian Oceans (Figures 1a and 1b).

Frontal maps and quantitative assessments of the sea surface temperature (SST) and temperature anomalies for each of these LMEs are provided by Dr. Igor Belkin. SST was selected as the only thermal parameter routinely measured worldwide that can be used to characterize thermal conditions in each and every LME. Subsurface hydrographic data, albeit important, lack spatial and temporal density required for reliable assessment of thermal conditions at the LME scale worldwide.

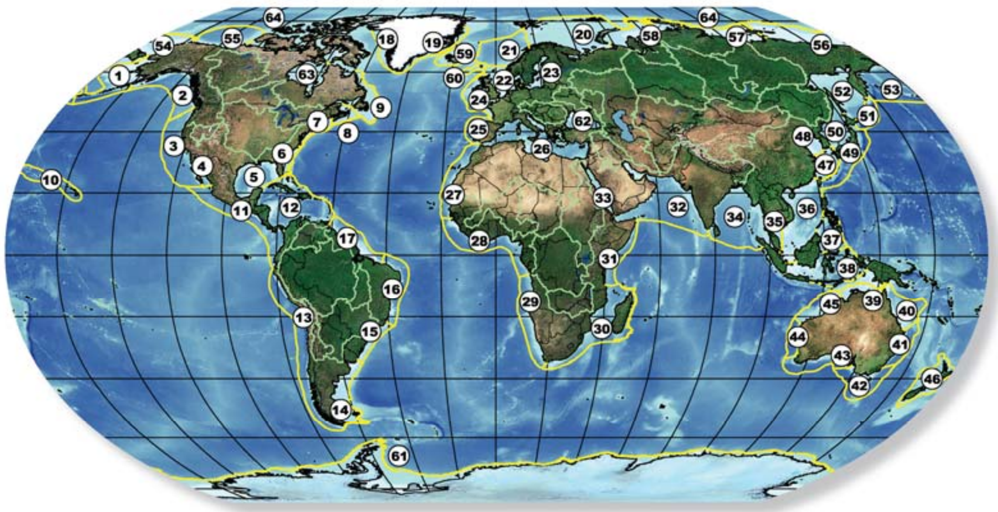

Figure 1a. Map showing 64 Large Marine Ecosystems of the world. LMEs in this map are numbered as they are on the LME website, www.lme.noaa.gov.

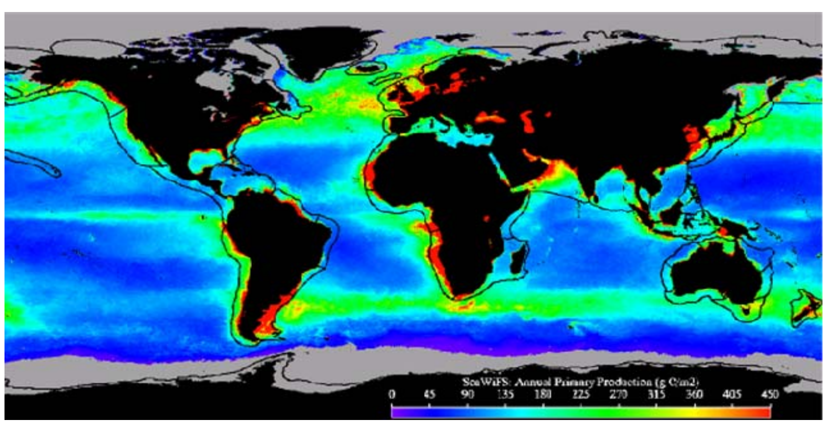

Figure 1b. Global map of average primary productivity and the boundaries of the 64 Large Marine Ecosystems (LMEs) of the world, available at www.lme.noaa.gov. The annual productivity estimates are based on Sea WiFS satellite data collected between September 1998 and August 1999, and the model developed by M. Behrenfeld and P.G. Falkowski (Limnol. Oceangr. 42(1): 1997, 1-20). The color-enhanced image provided by Rutgers University depicts a shaded gradient of primary productivity from a high of 450 $gCm^{-2}yr^{-1}$ to a low of $10gCm^{-2}y^{-1}$.

All LMEs are relatively large areas of ocean space, of approximately 200,000 km^2 or greater, adjacent to the continents in coastal waters where primary productivity is generally higher than in open ocean areas**.** It is within the boundaries of the LMEs that 80% of the world's annual marine fish catch is produced, degraded habitats are most prevalent and the frequency and effects of pollution and eutrophication of ocean waters are most severe. The LMEs are also centers of marine gas and oil production; mining for sand, gravel, diamonds and other extractive minerals; coastal shipping; and tourism.

A second important feature of the LME approach is the use of a 5-module strategy for measuring the changing states of the ecosystem and for taking remedial actions toward recovery and sustainability of degraded resources and environments. From a management perspective it is essential to establish a baseline condition against which to measure the success or failure of management actions directed toward recovery of degraded conditions within the LMEs. The 5 modules are focused on the application of suites of indicators measuring LME (1) productivity, (2) fish and fisheries, (3) pollution and ecosystem health, (4) socio-economics, and (5) governance.

LMES AND THE UNEP REGIONAL SEAS PROGRAMME

Since 1984, the LME approach has matured into the planning and implementation activities of 16 projects in 110 countries bordering on LMEs in Africa, Asia, Latin America and countries in economic transition in eastern Europe (Sherman et al. 2007). The projects are country driven, wherein the direction and priorities of assessment and management actions are "driven" by nations sharing the transboundary goods and services of the LMEs.

There is a growing body of peer-reviewed published reports on the application of the LME approach to the assessment and management of marine resources. As of 2006, the American Association for the Advancement of Science, Westview Press, Blackwell Science, and Elsevier Science have published a total of fourteen peer-reviewed volumes with contributions by 445 authors (www.noaa.lme.gov).

The LME approach is a way forward for advancing ecosystem-based management of coastal and marine resources within a framework of sustainable development. Country-driven GEF-LME assessment and management projects are linked to the WSSD Plan of Implementation and to the global Regional Seas Programme, coordinated by UNEP. The descriptions in this report of the general ecological conditions of the LMEs, with regard to their productivity, fish and fisheries, pollution and ecosystem health, socioeconomics and governance, are arranged in accordance with the Regional Seas designations (Figure 2**)**.

Regional Seas, LMEs and the 2002 World Summit on Sustainable Development

In December 2004, at the 6th Global Meeting of the Regional Seas Conventions and Action Plans, new strategic directions were adopted, in order to strengthen the Regional Seas Programme at the global level and address evolving challenges and priorities, while continuing to implement the individual work programmes of the Conventions and Action Plan secretariats. One of the directions calls to ***"Develop and promote a common vision and integrated management, based on ecosystem approaches, of priorities and concerns related to the coastal and marine environment and its resources in Regional Seas Conventions and Action Plans, introducing amongst others proactive, creative and innovative partnerships and networks and effective communication strategies."*** In 1982, UNEP began to address issues related to impacts on the marine environment from land-based activities. Some 80% of the pollution load in the oceans originates from land-based activities (municipal, industrial and agricultural wastes, run-off, and atmospheric deposition). These contaminants affect the most productive areas of the marine environment, including estuaries and near-shore coastal waters.

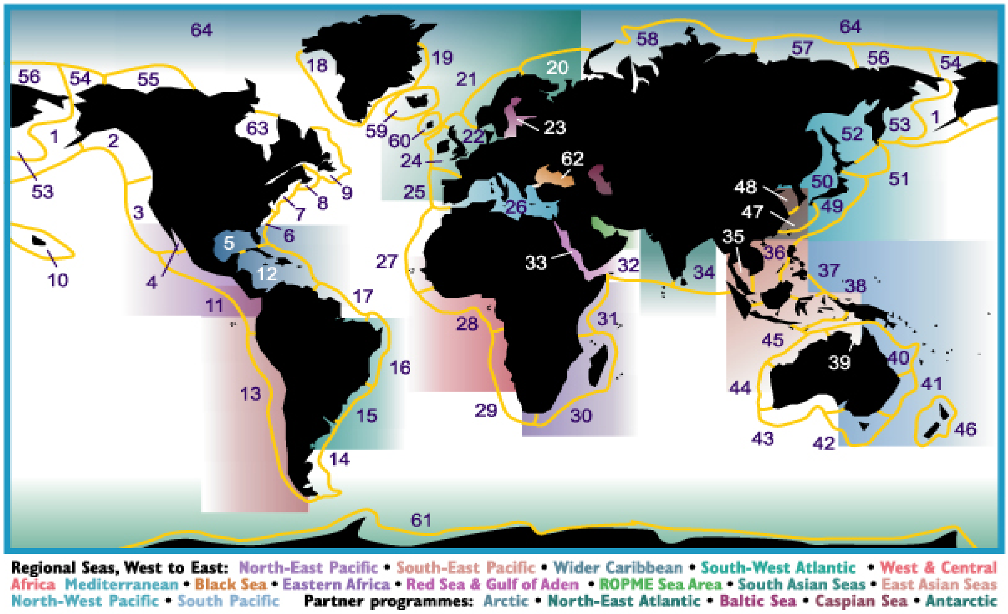

Figure 2. Regional Seas map with boundaries (in yellow) of the 64 Large Marine Ecosystems. Numbers correspond to the LME map numbers for the 64 LMEs.

The health and, in some cases, the very survival of coastal populations depend upon the health and well being of coastal systems such as estuaries and wetlands. In response to intense pressures put on coastal systems, 108 governments and the European Commission adopted the 1995 Washington Declaration, to establish a Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA). To support the GPA activity, a UNEP/GPA office was established in The Hague, Netherlands.

During the World Summit on Sustainable Development (WSSD), held in Johannesburg in 2002, participating world leaders agreed to pursue 4 marine targets: (i) to achieve substantial reductions in land-based sources of pollution by 2006; (ii) to introduce an ecosystems approach to marine resource assessment and management by 2010; (iii) to designate a network of marine protected areas by 2012; and (iv) to maintain and restore fish stocks to maximum sustainable yield levels by 2015. In an effort to encourage the global movement toward the 4 WSSD targets, UNEP along with other partnering UN and non-governmental organizations (NGOs), and the GEF and its partners, is assisting developing countries in operationalizing LME projects to serve as operational and management units for translating the legal frameworks and objectives of the Regional Seas Programmes into concrete actions to restore, sustain, protect and manage coastal environments and linked watersheds. Assessments of the state of most LMEs in GEF eligible regions were carried out by the Global International Waters Assessment (GIWA) between 2000 and 2005. The GIWA Regional Reports can be downloaded from their website www.giwa.net/publications/.

TRANSBOUNDARY DIAGNOSTIC ANALYSIS AND STRATEGIC ACTION PROGRAM

The GEF Operational Strategy recommends that nations sharing an LME begin to address coastal and marine issues by jointly undertaking strategic processes for analyzing science-based information on transboundary concerns, their root causes, and by setting priorities for action on transboundary concerns. This process is referred to as a Transboundary Diagnostic Analysis (TDA) and it provides a useful mechanism to foster participation of policy makers, scientists, management experts, stakeholders, and civil society at local, regional, national and international levels of interest. Countries then determine the national and regional policy, legal, and institutional reforms and investments needed to address the priorities, and based on the strategies prepare and initiate an LME wide Strategic Action Program (SAP). This allows sound science to assist policy making within a specific geographic location for an ecosystem-based approach to management that can be used to engage stakeholders (Figure 3).

GEF-LME Projects	TDA/SAP	Regional Seas
Benguela Current (3 countries)	**TDA and SAP**	**West and Central Africa**
Red Sea (7 countries)	**TDA and SAP**	**Red Sea and Gulf of Aden**
Mediterranean Sea (19 countries)	**TDA and SAP**	**Mediterranean Sea**
Gulf of Guinea (6 countries)	**TDA and SAP**	**West and Central Africa**
Black Sea (6 countries)	**TDA and SAP**	**Black Sea**
South China Sea (7 countries)	**TDA and SAP**	**East Asian Seas**
Yellow Sea (2 countries)	**TDA and SAP**	**North-West Pacific**
Baltic Sea (9 countries)	**TDA and SAP**	**Baltic Sea**
Bay of Bengal (8 countries)	**TDA and preliminary SAP**	**South Asian Seas**
Canary Current (7 countries)	**TDA in preparation**	**West and Central Africa**
Humboldt Current (2 countries)	**TDA in preparation**	**South-East Pacific**
Guinea Current (16 countries)	**Expanding the SAP and TDA**	**West and Central Africa**
Gulf of Mexico (3 countries)	**TDA in preparation**	**Wider Caribbean**
Caribbean Sea (23 countries)	**TDA in preparation**	**Wider Caribbean**

Figure 3. Summary of Transboundary Diagnostic Analyses (TDA) and Strategic Action Plans (SAP) for GEF sponsored LME projects planned and underway. An additional 2 projects outside the Regional Seas areas have completed TDAs.

In the GEF-LME projects either approved or in the preparation stage, 110 countries are moving to meet WSSD ecosystem-related targets and to address overfishing, fishing down food webs, destruction of habitat and accelerated nitrogen export. Countries engaged in the TDA process have already begun to scientifically characterize the LME, to identify the root causes of trends in LME biomass yields and the most pressing transboundary characteristics of coastal pollution, damaged habitats and depleted fish stocks, in order to prioritize these issues. Seven country-driven GEF-LME Projects are advancing to the drafting of the SAP, in which the countries commit to making institutional arrangements and taking policy actions, based on sound science, to address the issues identified in the TDA. The SAP addresses actions to correct institutional fragmentation, ecosystem assessment gaps, lack of cooperation and weak coastal policies and is signed by high-level government authorities of each participating country. The strategic framework for developing TDAs and SAPs is guided by the geographic area of LMEs and the application of the 5-module approach to LME assessment and management. Examples of TDA and SAP documents for the Benguela Current LME Project are available at www.bclme.org.

These processes are critical for integrating science into management in a practical way and for establishing appropriate governance regimes. The five modules consist of 3 that are science-based indicators focused on: productivity, fish/fisheries, pollution/ecosystem health; the other two, socio-economics and governance, are focused on economic benefits to be derived from a more sustainable resource base and implementing governance mechanisms for providing stakeholders and stewardship interests with legal and administrative support for ecosystem-based management practices (Figure 4). The first four modules support the TDA process while the governance module is associated with periodic updating of the Strategic Action Program or SAP (Duda and Sherman, 2002; Wang 2004). Adaptive management regimes are encouraged through periodic assessment processes (TDA updates) and updating of SAPs as gaps are filled.

CHANGING STATES OF THE LMES: INDICATOR MODULES

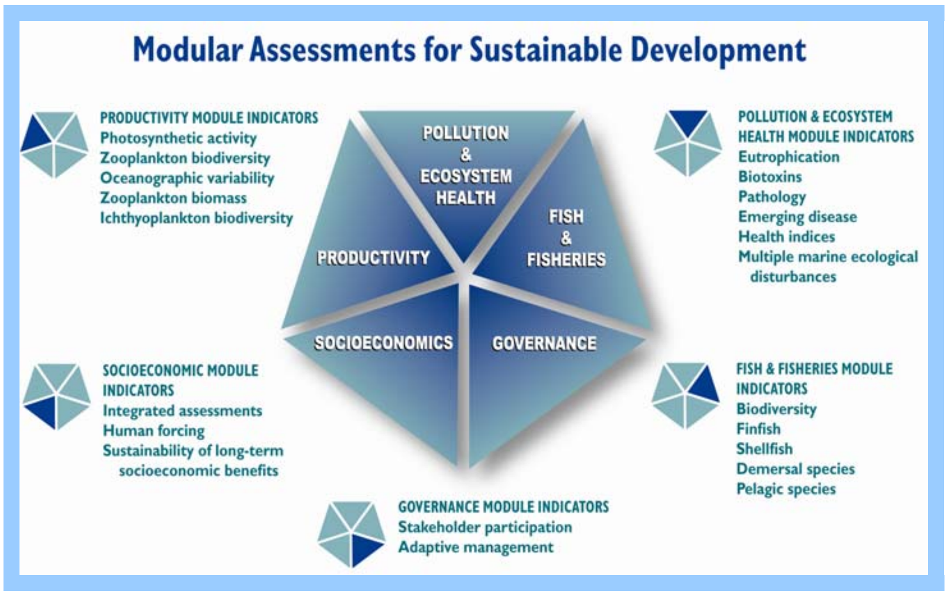

Figure 4. The Large Marine Ecosystem (LME) approach to sustainable development includes 5 modules with indicators.

The five-module indicator approach to the assessment and management of LMEs has proven useful in ecosystem-based projects. The modules are customized to fit the situation within the context of the TDA process and SAP development process for the groups of nations or states sharing an LME.

Productivity module indicators

Primary productivity can be related to the carrying capacity of an ecosystem for supporting fish resources (Pauly & Christensen 1995). Measurements of ecosystem productivity can be useful indicators of the growing problem of coastal eutrophication. In several LMEs, excessive nutrient loadings to coastal waters have been related to algal blooms implicated in mass mortalities of living resources, emergence of pathogens (e.g., cholera, vibrios, red tides, and paralytic shellfish toxins), and explosive growth of non-indigenous species (Epstein 1993, Sherman 2000). The ecosystem parameters measured and used as indicators of changing conditions in the productivity module are zooplankton biodiversity and species composition, zooplankton biomass, water-column structure, photosynthetically active radiation, transparency, chlorophyll-*a*, nitrite, nitrate, and primary production, (Aiken 1999, Berman & Sherman 2001, Melrose *et al*. 2006), (Figure 5).

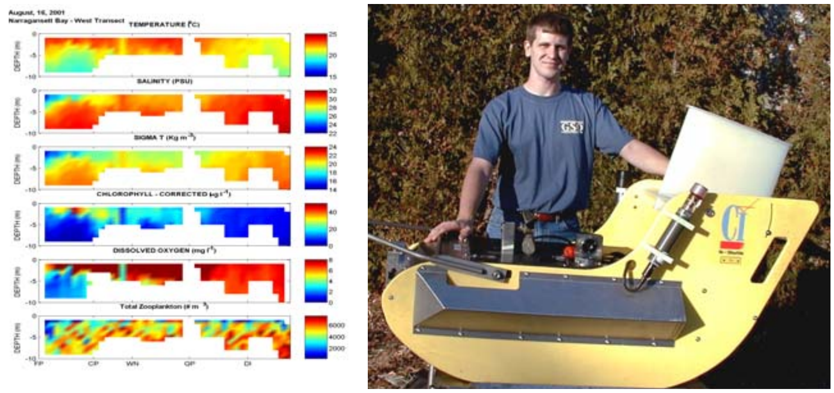

Figure 5. A Mariner Shuttle, towed behind a ship is used to collect measurements for assessing changing conditions of temperature, salinity, density, chlorophyll and primary productivity, oxygen and zooplankton within LMEs.

Fish and Fisheries module indicators

Changes in biodiversity and species dominance within fish communities of LMEs have resulted from excessive and selective exploitation, environmental shifts due to climate change and coastal pollution. Changes in biodiversity and species dominance in a fish community can cascade up the food web to apex predators and down the food web to plankton and benthos components of the ecosystem.

The Fish and Fisheries Module includes both fisheries-independent bottom-trawl surveys and pelagic-species acoustic surveys to obtain time-series information on changes in fish biodiversity and abundance levels (Figure 6). Standardized sampling procedures, when employed from small, calibrated trawlers, can provide important information on changes in fish species (Sherman 1993). The fish catches on the surveys provide biological samples for stock identification, stomach content analyses, age-growth relationships, fecundity, and for coastal pollution monitoring, based on pathological examinations.

Figure 6. The Norwegian Research Vessel *Dr. Fridtjof Nansen* readies to depart from Accra, Ghana on the Third Guinea current LME Survey (June 4 – July 15, 2005) of the fish and fisheries of the Guinea Current LME Project (GCLME). Scientists and technicians from all of the GCLME countries participated in this survey. The countries represented were Angola, Benin, Cameroon, Congo, Democratic Republic of Congo, Côte d'Ivoire, Ghana, Equatorial Guinea, Guinea, Liberia, Nigeria, Sierra Leone and Togo.

Fish stock demographic data are used for preparing stock assessments (NAFO 2005) and for clarifying and quantifying multispecies trophic relationships (NAFO 2005). NOAA Fisheries information is available at http://nft.nefsc.noaa.gov (username: nft; password: nifty) for development of a standard suite of methods for standardizing assessment tasks. The survey vessels can also be used as platforms for obtaining water, sediment, and benthic samples for monitoring harmful algal blooms, diseases, anoxia, and structure of benthic communities.

Pollution and Ecosystem Health module indicators

In semi-enclosed LMEs, pollution and eutrophication can be important driving forces of change in biomass yields. Assessing the changing status of pollution and health of an entire LME is scientifically challenging. Ecosystem health is a concept of wide interest for which a single precise scientific definition is difficult. The health paradigm is based on multiple-state comparisons of ecosystem resilience and stability, and is an evolving concept that has been the subject of a number of meetings (Sherman 1993). To be healthy and sustainable, an ecosystem must maintain its metabolic activity level and its internal structure and organization, and must resist external stress over time and space scales relevant to the ecosystem (Costanza 1992). The modules are all used to a greater or lesser extent in the US, in ICES, and are now being introduced in the GEF-LME Projects.

The Pollution and Ecosystem Health Module measures pollution effects on the ecosystem through the pathobiological examination of fish, and through the estuarine and nearshore monitoring of contaminant effects in the water column, the substrate, and selected groups of organisms. Where possible, bioaccumulation and trophic transfer of contaminants are assessed, and critical life history stages and selected food web organisms are examined for indicators of exposure to, and effects from, contaminants. Effects of impaired reproductive capacity, organ disease, and impaired growth from contaminants are measured. Assessments are made of contaminant impacts at both species and population levels. Implementation of protocols to assess the frequency and effect of harmful algal blooms, emergent diseases, and multiple marine ecological disturbances (Sherman 2000) are included in the pollution and ecosystem health module. In the United States, the Environmental Protection Agency (EPA) has developed a suite of 5 coastal condition indicators: water quality index, sediment quality index, benthic index, coastal habitat index, and fish tissue contaminants index (Figure 7) as part of an ongoing collaborative effort with the National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service (FWS), the U.S. Geological Survey (USGS), and other agencies representing states and tribes.

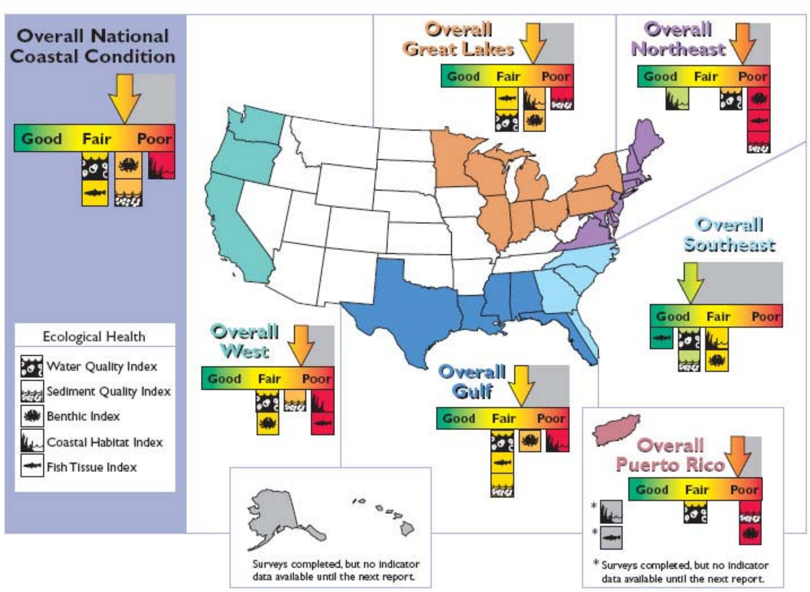

Figure 7. The U.S. Environmental Protection Agency (EPA) 2004 indicators of coastal condition A stoplight approach is used to indicate relative conditions: poor (red), moderate (orange) or good (green). (National Coastal Condition Report II. 2004).

The 2004 report, "National Coastal Condition Report II," includes results from EPA's analyses of coastal condition indicators and NOAA's fish stock assessments by LMEs aligned with EPA's National Coastal Assessment (NCA) regions (USEPA 2004). Several GEF supported LME projects are adapting EPA's 5 coastal condition indicators for assessing the health of near coastal areas of LMEs (Figure 7).

Socioeconomic module indicators

This module emphasizes the practical application of scientific findings to the management of LMEs and the explicit integration of social and economic indicators and analyses with all other scientific assessments to assure that prospective management measures are cost-effective. Economists and policy analysts work closely with ecologists and other scientists to identify and evaluate management options that are both scientifically credible and economically practical with regard to the use of ecosystem goods and services.

In order to respond adaptively to enhanced scientific information, socioeconomic considerations must be closely integrated with science findings. Both the socioeconomic and governance indicators are used in the planning and implementation actions as summarized in Figure 8.

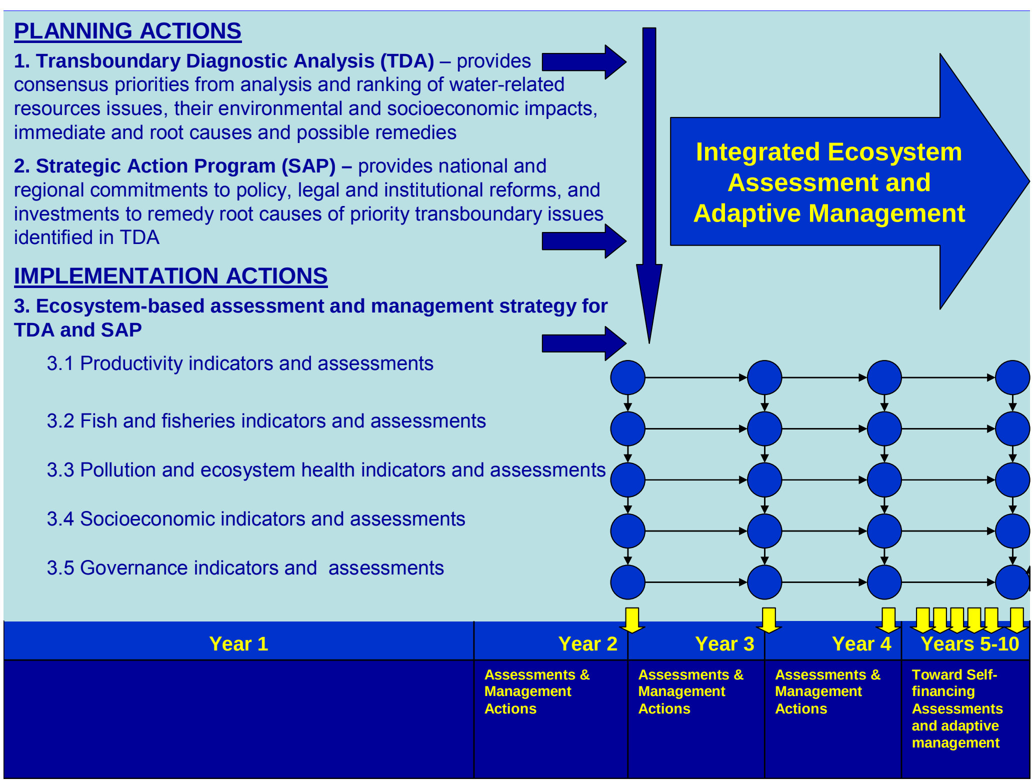

Figure 8. Integrated Ecosystem-based assessment and adaptive management planning actions over 10 years.

The new ecosystem accounting paradigm requires that resource managers of the different sectors of stakeholder interests incorporate the cumulative assessments of changing ecosystem productivity, fish and fisheries, pollution and ecosystem health and their effects on socioeconomic conditions and governance jurisdictions, as both additive and integrative effects on ecosystem conditions. These latter components of the LME approach to marine resources management have recently been described as the human dimensions of LMEs (Hennessey & Sutinen 2005). A framework has been developed by the Department of Natural Resource Economics at the University of Rhode Island for monitoring and assessment of the human dimensions of LMEs and for incorporating socioeconomic considerations into an adaptive management approach for LMEs (Sutinen et al. 2000; Juda et al. 2006, Olsen et al. 2006). One of the more critical considerations, a method for economic valuations of LME goods and services, has been developed using framework matrices for indexing economic activity (Sherman et al. 2005, Hoagland & Jin 2006).

Governance module indicators

The Governance Module is evolving, based on demonstration projects now underway in several ecosystems, that are being managed from an ecosystem perspective. In LME assessment and management projects supported by the Global Environment Facility for the Yellow Sea, the Guinea Current, and the Benguela Current LMEs, agreements have been reached among the several ministries in each country bordering the LMEs (ministries responsible for ocean resources for the environment, fisheries, energy, tourism, finance and foreign affairs, for example), to enter into joint resource assessment and management activities as the framework for ecosystem-based management practices. Elsewhere, the Great Barrier Reef LME and the Antarctic LME are also being managed from an ecosystem perspective, the latter under the Commission for the Conservation of Antarctic Marine Living Resources. Governance profiles of LMEs are being explored to determine their utility in promoting long-term sustainability of ecosystem resources (Juda and Hennessey 2001). In each of the LMEs, governance jurisdiction can be scaled to ensure conformance with existing legislated mandates and authorities. An example of multiple governance-related jurisdictions that includes areas designated for fisheries management, pollution control and marine protected areas, is described in Sherman *et a*l. (2004).

Within the context of ecosystem-based management the integration of data and information for decision making is additive and vertically integrated for the five modules, and adaptive contingent on annual assessment findings horizontally across years. From Year 1, the GEF supported projects move toward the goal of self-financing of the ecosystem assessment and management process by year 10 (Figure 8).

GEF-SUPPORTED LME PROJECTS

An increasing number of countries and organizations are engaged in LME projects aimed at moving toward the WSSD marine targets. The LME approach to the assessment and management of marine resources and their environments is being applied with financial assistance from GEF to developing countries who are planning and implementing LME projects focused on introducing an ecosystem-based approach to the (1) recovery of depleted fish stocks; (2) restoration of degraded habitats; and (3) reduction of coastal pollution and eutrophication. GEF-LME projects are presently located in 16 LMEs that provide goods and services in bordering countries containing over half the world’s population. These LMEs produce 46% of the world’s annual marine fish catch while also being subjected to significant eutrophication in near coastal waters. These stressors have been identified during the TDA and SAP process. Taken together, the 16 projects represent a significant movement toward the WSSD targets, and will be the subject of future UNEP and partners’ ecological condition reports.

The new generation
The LME projects themselves as well as their academic, administrative and political environment have to be scientifically and technically strong. The complexity of the modern ecosystem oriented approach of fisheries and other marine activities calls for a new generation of professionals addressing the sustainability issue in a much broader sense than before. Not only do the preservation of the fish stocks and the other goods and services of the ecosystem including the protection of marine biodiversity have to be taken care of, but also the socio-economic development of the region. Management goals have to be defined and defended under the pressure of conflicting ecological interests and societal and political constraints.

On the one hand, in order to address all five modules of the LME concept, specialists are needed like ichthyologists and oceanographers and plankton experts, fish stock assessment biologists, sociologists, economists and experts in international law. There is an increasing demand for reliable data sets of adequate length and resolution in space and time to feed modern data-driven models on the medium- and long-term consequences of various management strategies. On the other hand experienced generalists and modelers are required to put the facts and findings together and to create such management scenarios. Those generalists are rather rare and not easy to recruit. Therefore, capacity development has to be continued in all parts of the world, not only in developing countries. Much of it can now be done in the regions themselves through mutual assistance.

To a certain extent a fair division of research work between the rich and the poorer countries might be envisaged. Rich countries have the capacity and hence the responsibility of advancing science in the broadest possible way in natural and social sciences per se but also in theory and analysis of the interactions in the sustainability triangle of environment, economy and society. Those interactions differ in structure from region to region. Working in collaboration with colleagues and institutions in poorer parts of the world, including developing countries with their rich and diverse perspectives, is a win-win situation.

In a nutshell
The LME approach is the pathway towards sustainable use of marine ecosystems provided the interaction between the various players becomes much stronger amongst the various science sectors and between scientists and stakeholders, the general public and the national and international administration. Partnership and communication are required on all levels and on all geographical scales. What is lacking is not so much the money but rather the political will and the vision of enthusiastic and competent experts on the way to apply the LME concept for the sustainable development of the use and conservation of the marine environment in many parts of the World Ocean.

TECHNICAL DESCRIPTION OF THE DATA SETS CONTAINED IN THIS REPORT

ECOLOGICAL INDICATORS OF LME CONDITION AND METHODOLOGY

Ocean front maps

Igor Belkin of the University of Rhode Island provided descriptions and maps of LME oceanographic fronts for each of the 64 LMEs (Belkin *et al*. 2008, Belkin & Cornillon 2003). An oceanographic front is a relatively narrow zone of enhanced horizontal gradients of physical, chemical and biological properties (e.g. temperature, salinity, nutrients). Fronts occur on a variety of scales, from several hundred meters up to many thousand kilometers. Some of them are short-lived, but most are quasi stationary and seasonally persistent: they emerge and disappear at the same locations during the same season, year after year. The temperature and salinity ranges across the strongest fronts can be as high as 10-15 degrees C and 2 to 3 parts per thousand (ppt) salinity, although somewhat smaller numbers, such as 5 degrees C and 1 ppt, are far more common. The width of fronts varies widely: from less than 100 m to 200 km. Vertically, many fronts extend several hundred meters in depth. Major fronts can extend as deep as 2,000 m. Fronts are crucial in various processes that evolve in the ocean and at the ocean interfaces with the atmosphere, sea ice and sea bottom. Fronts are important for climate change monitoring and prediction, the fishing industry, pollution control, waste disposal and hazards mitigation, marine transportation, marine mining, including the oil and gas industry, submarine navigation and integrated coastal management.

- Fronts are associated with current jets, so that any frontal pattern represents a circulation pattern;
- The along-frontal current jets are accountable for the bulk of water/heat/salt transport;
- Fronts separate different water masses and spawn rings responsible for the bulk of cross-frontal and meridional transport of water, heat and salt;
- Fronts usually coincide with major biogeographical boundaries associated with zones of enhanced bio-productivity, including fisheries grounds;
- The surface heat fluxes, wind stress and other meteorological parameters may differ drastically between the warm and cold sides of a front. Fronts strongly interact with the marine atmospheric boundary layer and separate regions with different response to atmospheric forcing, so they are crucial for weather forecasting and climate monitoring;
- Some high-latitude fronts are directly related to sea ice conditions, so the front locations are determined by the maximum extent of the sea ice cover;
- Fronts profoundly influence acoustic environment so that solving any sound propagation problem requires knowledge of the fronts' locations and characteristics;
- Ocean sedimentation regimes are largely determined by the circulation (hence frontal) pattern, therefore the interpretation of paleo-oceanographic and paleoclimatic information recorded in marine sediments requires *a priori* knowledge of the modern frontal situation;
- Because fronts are associated with convergent currents, oceanic and riverine pollutants can be concentrated thousands of times on fronts, thus endangering the fish, sea birds and marine mammals that inhabit the frontal zones.

The descriptions and maps provide both textual and visual summaries of dominant frontal patterns and principal individual fronts. The frontal schematics are annual long-term means, based largely on a 12-year data set of frontal maps assembled at the University of Rhode Island. They are the result of a comprehensive global analysis, based on Pathfinder Sea Surface Temperatures. The maps show the most robust and well-defined fronts, regardless of the seasons during which they develop and peak.

Sea Surface Temperature

The U.K. Meteorological Office Hadley Center SST climatology data was selected for its superior resolution (1 degree latitude by 1 degree longitude globally); for the historic reach of the data; and for its high quality. A highly detailed, research-level description of this data set has been published by Rayner *et al.* (2003). The Hadley data set consists of monthly SSTs calculated for each 1° x 1° rectangular cell (spherical trapezoid, to be exact) between 90°N-90°S, 180°W-180°E. To calculate and visualize annual SSTs for each LME, the annual SST for each 1° x 1° cell was calculated and the area-averaged annual 1° x 1° SSTs within each LME. Since the square area of each trapezoidal cell is proportional to the cosine of the middle latitude of the given cell, all SSTs were weighted by the cosine of the cell's middle latitude. After integration over the LME area, the resulting sum of weighted SSTs was normalized by the sum of the weights, that is, by the sum of the cosines. Annual anomalies of annual LME-averaged SSTs were calculated by computing the long-term LME-averaged SST for each LME by a simple long-term averaging of the annual area-weighted LME-averaged SSTs. Then, annual SST anomalies were calculated by subtracting the long-term mean SST from the annual SST. Both SST and SST anomalies were visualized using adjustable temperature scales for each LME in order to bring out details of temporal variability that otherwise would be hardly noticeable if a unified temperature scale were used. The resulting plots of SST and SST anomalies are for 63 LMEs. Ice cover precludes a meaningful assessment of the LME-averaged SST for the Arctic Ocean. John O'Reilly (NOAA) kindly provided a data set of the LME coordinates for these processes.

Primary productivity data

The LME descriptions include primary productivity estimates derived from satellite borne data of NOAA's Northeast Fisheries Science Center, Narragansett Laboratory. These estimates originate from SeaWiFS (satellite-derived chlorophyll estimates from the Sea-viewing Wide Field-of-view Sensor), Coastal Zone Color Scanner (CZCS), a large archive of *in situ* near-surface chlorophyll data, and satellite sea surface temperature (SST) measurements to quantify spatial and seasonal variability of near-surface chlorophyll and SST in the LMEs of the world. Daily binned global SeaWiFS chlorophyll *a* (CHL, mg m^{-3}), normalized water leaving radiances, and photosynthetically available radiation (PAR, Einsteins m^{-2} d^{-1}) scenes at 9 km resolution for the period January 1998 through December 2006) are obtained from NASA's Ocean Biology Processing Group. Daily global SST (^{o}C) measurements at 4 km resolution are derived from nighttime scenes composited from the AVHRR sensor on NOAA's polar-orbiting satellites and from NASA's MODIS TERRA and MODIS AQUA sensors. Daily estimates of global primary productivity (PP, gC m^{-2} d^{-1}) are calculated using the Ocean Productivity from Absorption and Light (OPAL) model (Marra, personal communication), a derivative of the model first formulated in Marra et al. (2003). The OPAL model generates profiles of chlorophyll estimated from the SeaWiFS chlorophyll using the algorithm from Wozniak et al. (2003) and uses the absorption properties in the water column to vertically resolve estimates of light attenuation in approximately 100 strata within the euphotic zone. Absorption by pure water is assumed to be a constant value over PAR wavelengths; chlorophyll-specific phytoplankton absorption is parameterized empirically (Bricaud et al., 1998); absorption by photosynthetic pigments is distinguished from total absorption; and absorption by colored dissolved organic matter (CDOM) is calculated according to Kahru and Mitchell (2001). The chlorophyll-specific phytoplankton absorption is used to calculate productivity, while absorption by photosynthetic pigments, water, and CDOM are used to vertically resolve light attenuation. SST, which is used as a proxy for seasonal changes in the phytoplankton community, is related to the chlorophyll-specific absorption coefficient. The quantum efficiency is obtained from a hyperbolic tangent and a constant φmax. Productivity is calculated for the 100 layers in the euphotic zone and summed to compute the integral daily productivity (gC m^{-2} d^{-1}).

Monthly and annual means of PP were extracted for each LME and a simple linear regression of the annual PP was used to determine the rate of change over time. The significance (alpha = 0.01 and 0.05) of the regression coefficient was calculated using a t-test according to Sokal and Rohfl (1995)(Table 1). The data allowed for classifying the LMEs into 3 categories: **Class I**, high productivity (>300 gCm^{-2} year^{-1}), **Class II**, moderate productivity (150-300 gCm^{-2}year^{-1}), and **Class III,** low (<150 gCm^{-2} year^{-1}) productivity.

LME	Chl	PP
Barents Sea	+ **	
Bay of Bengal		- *
California Current	+ *	
East Greenland Shelf	+ *	
East Siberian Sea	- *	
Hudson Bay	+ **	+ *
Humboldt current		+ *
Indonesian Sea	+ *	
New Zealand Shelf	+ *	
North Australian Shelf	+ *	
Red Sea	+ **	+ *
Sea of Okhosk	+ *	

Table 1. Significance of T test on chlorophyll (Chl) and primary productivity (PPD) regression coefficients for SeaWiFS time series data on chlorophyll and primary productivity (1998-2006). Only cases where p<.05 are listed. All other comparisons were nonsignificant. Plus and minus signs are used to designate the direction of the slope of the trend line. * Indicates P<.05 ** Indicates P<.01

Fisheries catch and values trends, and ecosystem state indicators

Trends in fisheries biomass yields and catch value, provided by the Sea Around Us Project, Fisheries Centre, University of British Columbia (see www.seaaroundus.org), are also included in the LME descriptions. The datasets and methods used for deriving the catch trends and the concepts behind the indicators are described in Pauly *et al.* (this volume).

THE GLOBAL INTERNATIONAL WATERS ASSESSMENT

The assessments presented in this volume on state and trends in LMEs in GEF eligible regions are based mainly on the data collections and regional reports compiled by the Global International Waters Assessment (GIWA), supplemented by information from other sources (see Appendix 2). GIWA was designed as a globally comparable assessment of the present state and future trends of transboundary aquatic resources in the world‘s shared waters. On a regional basis, a bottom-up and multidisciplinary approach was adopted that involved nearly 1,500 natural and social scientists from around the world, particularly in developing regions (Hempel & Daler 2004, UNEP 2006).

The GIWA project divided the world into transboundary water regions, each comprising one or more major drainage basin(s) with adjacent LMEs. Regional teams conducted the assessment based on existing regional data and information, and adapted the methodology to the local conditions. In many GIWA regions, the assessment process has strengthened communication between social and natural scientists, as well as managers. It has also fostered new partnerships within the regions and between neighbouring regions. The GIWA project was initiated and largely funded by GEF and led by UNEP. The key products of GIWA are 35 regional reports, most of them published in print and/or electronically. The GIWA Final Report (UNEP 2006) summarises the findings of the regional reports in a global perspective and provides information on GIWA’s methodology and theoretical background.

Globally comparable results were achieved by a common and consistent methodology applied by all of the regional teams. The GIWA methodology provides criteria for assessing water-related environmental concerns, and for identifying their immediate and root causes and potential policy options. Regional experts assessed and compared the severity of impacts from a regional perspective (Belausteguigoitia 2004).

The numerous and complex transboundary water-related environmental problems were grouped into five major concerns:

1) Freshwater shortage
2) Pollution
3) Overfishing and other threats to aquatic living resources
4) Habitat and community modification
5) Global change

The GIWA methodology is comprised of four major steps:

1) Scaling defines the geographic boundaries of the GIWA region, boundaries generally demarcated by a large drainage basin and its adjacent marine areas. The boundaries of the marine parts of the GIWA regions often correspond with those of LMEs.
2) Scoping assesses and scores the severity of present and predicted environmental and socioeconomic impacts caused by each of the GIWA concerns.
3) Causal chain analysis traces the cause and effect pathways from the socio-economic and environmental impacts back to their root causes.
4) Wherever possible, the causal chain analysis was followed by policy option analysis which outlined potential courses of action that aim to mitigate or resolve environmental and socioeconomic problems in the region.

The GIWA provided baseline information at the regional level for the preparation of TDAs and SAPs initiated by GEF. At the same time, many GIWA regional assessments have benefited from completed TDAs. GIWA has been the largest global assessment of ecosystem-wide water issues from a transboundary perspective, linking international river basins to their adjacent LMEs. It was designed to provide policy makers and managers with the information they need to improve transboundary resources management.

RECENT TRENDS IN LMES WITHIN REGIONAL SEAS, IDENTIFIED THROUGH THE 5-MODULE ASSESSMENTS

During the review of the LME condition descriptions, three major challenges emerged: (1) the need to apply the precautionary approach, especially in LMEs with limited access to science-based stock assessments, to control the industrial fishing effort that threatens the community-based artisanal fisheries, (2) The need to improve forecasts of climate effects on abundances of key species, and (3) the need to reduce nutrient inputs into estuaries to levels that protect coastal waters from eutrophication.

Need for Precautionary Approach:
One example illustrating the need for a precautionary approach is the encroachment of industrial globalized fisheries on artisanal fisheries in the Guinea Current LME. Findings from a time series analysis of Catch-Per-Unit-Effort for both small-sized inshore artisanal-type vessels and industrialized fishing fleets from the European Union showed that the large industrialized trawlers are fishing species in near-shore areas previously not fished by the industrial fishmeal extraction enterprises that provide product to industrialized farms in the developed world as animal feed or fertilizer (Figure 9). The analysis found a consistent rise in industrial trawling coinciding with a downward trend during the late

1980s in inshore seasonal artisanal fishing, which raises concerns for the community-based fish harvest, available to meet the growing nutritional needs of the 300 million people living along the Guinea Current coast (Korentang 2002, Figure 9).

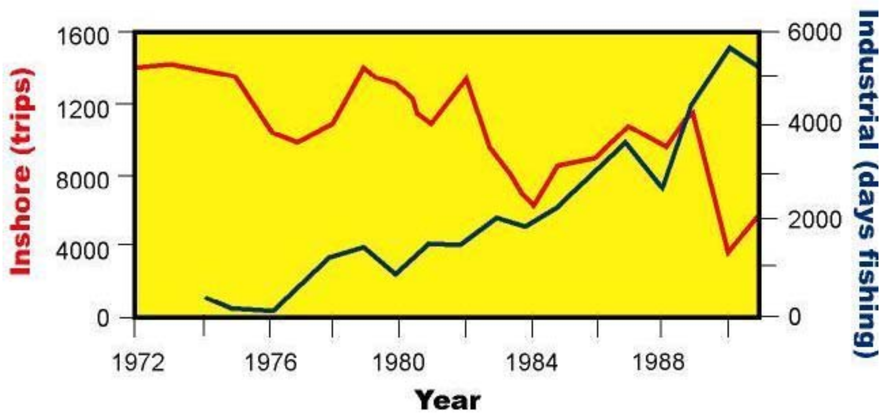

Figure 9. Negative influence of industrial fisheries (days fished) on catch based in shore fishing fishing trips along the coast of Ghana in the Guinea Current LME (from Koranteng, 2002)

Need for improved forecasts of fishery fluctuations during climate change:

The variability in mean-annual fisheries catch of Humboldt Current LME provides one illustration of the need for improved forecasts of fishery fluctuations in order to move toward long-term sustainability of pelagic and demersal fish stocks. The Humboldt Current LME contains the world's largest upwelling system and is the world's most productive marine ecosystem, providing between 15% and 20% of the world's annual marine catch. Anchovy, sardine and horse mackerel are used for fish meal and for human consumption. Fishing sustains thousands of fishermen and their families. The sharp decline in landings in the early 1970s and increases in the late 1980s and 1990s are related to El Niño climate effects (see Humboldt Current description, this volume).

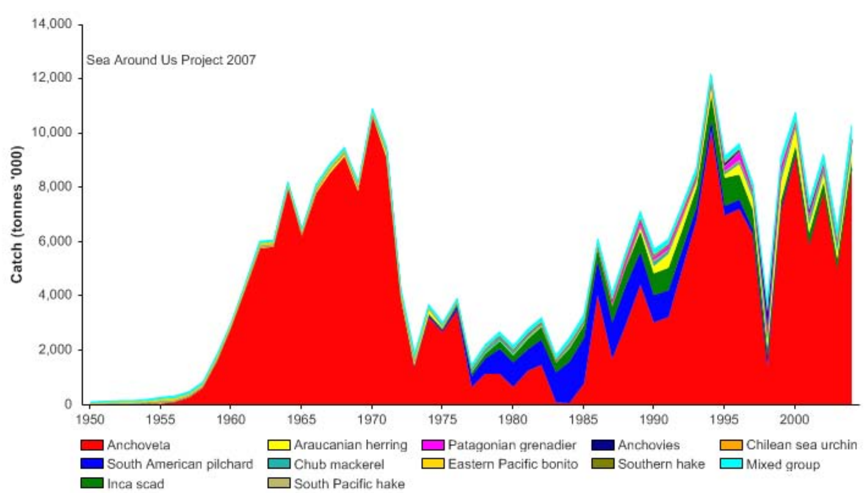

Figure 10.--Humboldt Current LME multi-decadal fish catch (1950-2004). Source: Sea Around Us Project 2007.

While the high productivity of the Humboldt Current LME is the result of upwelling processes governed by strong trade winds, the upwelling is subjected to considerable annual climatic variability, which causes variations in marine populations and catch (Figure 10). The normal seasonal upwelling can be interrupted by the El Niño-Southern Oscillation (ENSO), which results in intrusions of warm water. For the long-term sustainability of the pelagic and demersal fish stocks of this LME, improved forecasts of climate-driven fishery fluctuations are required. Polar region LMEs are now also changing from extensive global climate warming and ice melt (see East Bering Sea and Gulf of Alaska descriptions, this volume).

Need to curb excessive nitrogen loading:
Models of nitrogen affecting LMEs predict significant increases. Excessive levels of nitrogen contribution to coastal eutrophication constitute a growing global environmental problem that is cross-sectoral in nature. Excessive nitrogen loadings have been identified as problems *inter alia* in the Baltic Sea, Black Sea, Adriatic portion of the Mediterranean, Yellow Sea, South China Sea, Bay of Bengal, Gulf of Mexico, and Patagonian Shelf LMEs.

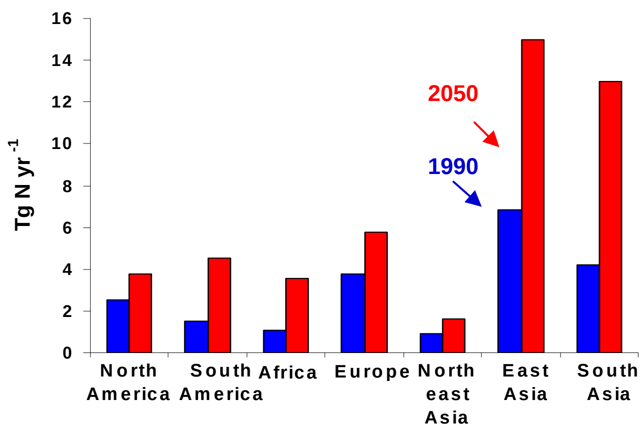

Figure 11. Model-predicted nitrogen (dissolved inorganic N) export by rivers to coastal systems in 1990 and in 2050—based on a business-as-usual (BAU) scenario. Figure modified from Kroeze and Seitzinger (1998).

Model-predicted global estimates of dissolved inorganic nitrogen (DIN) export from freshwater basins to coastal waters in 1990 and 2050 have been developed by Kroeze and Seitzinger (1998). These estimates, based on a business-as-usual (BAU) scenario, are cause for concern for the future condition of LME coastal waters with expected nitrogen exports doubling between 1990 and 2050 (Figure 11). Given the expected future increases in human population size and in fertilizer use, without significant nitrogen mitigation efforts, LMEs will be subjected to a future of increasing harmful algal bloom events, reduced fisheries, and hypoxia that will further degrade marine biomass and biological diversity.

REFERENCES

Aiken, J., Pollard, R., Williams, R., Griffiths, G., Bellan, I. (1999). Measurements of the upper ocean structure using towed profiling systems. In: Sherman, K. and Q. Tang, eds. *Large Marine Ecosystems of the Pacific Rim: Assessment, Sustainability, and Management*. Malden: Blackwell Science, Inc. 346-362.

Behrenfeld, M. and Falkowski, P.G. (1997). *Limnol. Oceangr*. 42(1):1-20.

Belausteguigoitia, J.C. (2004). Causal chain analysis and root causes: the GIWA approach. *Ambio* 33:7-12.

Belkin, I.M. (2008) Rapid warming in Large Marine Ecosystems. *Progress in Oceanography*, in press.

Belkin, I.M., and Cornillon, P.C. (2005). Bering Sea thermal fronts from Pathfinder data: Seasonal and interannual variability, *Pacific Oceanography* 3(1): 6-20.

Berman, M.S. and Sherman, K.. 2001. A towed body sampler for monitoring marine ecosystems. *Sea Technology* 42(9):48-52.

Bouvet M., Hoepffner, N. and Dowell, M.D. (2002). Parameterization of a spectral solar irradiance model for the global ocean using multiple satellite sensors. Journal of Geophysical Research, 107(C12), 3215, doi:10.1029/2001JC001126.

Bricaud, A., A. Morel, M. Babin, K. Allali, and H. Claustre. 1998. Variations of light absorption by suspended particles with chlorophyll *a* concentration in oceanic (case 1) waters: Analysis and implications for bio-optical models. *Journal of Geophysical Research* 103(C13):31033-31044.

CBD (2004). Annex I, Decision VII/30, p 351 in: The 2020 Biodiversity Target: a Framework for Implementation. Decisions from the Seventh Meeting of the Conference of the Parties of the Convention on Biological Diversity, Kuala Lumpur, 9-10 and 27 February 2004. Secretariat of the CBD, Montreal.

Costanza, R. (1992). Toward an operational definition of ecosystem health. In: Costanza R, B.G. Norton, B.D. Haskell, eds. *Ecosystem Health*: New Goals for Environmental Management. Island Press, Washington DC. 239-256.

Duda, A. and Sherman, K. (2002). A new imperative for improving management of large marine ecosystems. *Ocean & Coastal Management* 45:797-833.

Epstein, P.R. (1993). Algal blooms and public health. *World Resource Review* 5(2):190-206.

FAO'S Fisheries Agreement Register (FARISIS). 1998. Committee on Fisheries. Twenty-third Session Rome, Italy, 15-19 February 1999 www.fao.org/docrep/meeting/w9885e.htm

GEF. 2007. Operational Programs , available online at http://gefweb.org/Operational_Policies/Operational_Programs/OP_8_English.pdf.

Hempel, G. and Daler, D.. (2004). Why a Global International Waters Assessment (GIWA)? *Ambio* 33:2-6.

Hennessey, T. and Sutinen, J., eds. (2005). *Sustaining Large Marine Ecosystems: The Human Dimension.* Elsevier. Amsterdam. 368p.

Hoagland, P. and Jin, D. (2006). Accounting for Marine Economic Activities in Large Marine Ecosystems and the Regional Seas. Final Report to the United Nations Environment Programme, Regional Seas Programme (UNEP/RSP) Project No. CP/6000-04-71-2108.

Hoepffner N., Finenko, Z., Sturm, B. and Larkin, D. (1999). Depth-integrated primary production in the eastern tropical and sub-tropical North Atlantic basin from ocean colour imagery. International Journal of Remote Sensing, 20: 1435-1456.

Juda, L. and Hennessey, T. (2001). Governance profiles and the management of the uses of large marine ecosystems. *Ocean Development and International Law* 32:41-67

Kahru, M., and B.G. Mitchell. 2001. Seasonal and nonseasonal variability of satellite-derived chlorophyll and colored dissolved organic matter concentration in the California Current. *Journal of Geophysical Research* 106(C2):2517-2529.

Koranteng, K.A. (2002). Status of demersal fishery resources on the inner continental shelf off Ghana. 261-274 in: McGlade, J., Cury, P. and Koranteng, K.. *The Gulf of Guinea Large Marine Ecosystem: Environmental Forcing and Sustainable Development of Marine Resources*. Elsevier Science. Netherlands. 392p.

Kroeze, C. and Seitzinger, S. (1998). Nitrogen inputs to rivers, estuaries and continental shelves and related nitrous oxide emissions in 1990 and 2050: A global model. *Nutrient Cycling in Agroecosystems* 52:195-212.

Marra, J., C. Ho, and Trees. C. 2003. *An alternative algorithm for the calculation of primary productivity from remote sensing data*. LDEO. Technical Report # LDEO-2003-1

Melrose, D.C., Oviatt, C.A. O'Reilly, J.E., Berman, M.S. (2006). Comparisons of fast repetition rate fluorescence estimated primary production and 14 C uptake by phytoplankton. *Mar Ecol Prog Ser* 311:37-46.

Northwest Atlantic Fisheries Organization (NAFO). (2005). NAFO SCS Doc. 06/10, Serial No. N5235. U. S. Research Report for 2005. by K.A. Sosebee.

Olsen, S.B., Sutinen, J.G., Juda, L., Hennessey, T.M., Grigalunas, T.A.. (2006). A Handbook on Governance and Socioeconomics of Large Marine Ecosystems. University of Rhode Island. 94p

Pauly D. and V. Christensen. 1995. Primary production required to sustain global fisheries. Nature 374:255-257.

Pauly, D., Alder, J., Booth, S., Cheung, W.W.L., Close, C., Sumaila, U.R., Swartz, W., Tavakolie, A., Watson, R., Wood, L., and Zeller, D. (2008). Fisheries in Large Marine Ecosystems: Descriptions and Diagnoses. 21-38, this volume.

Platt T. ,and Sathyendranath, S. (1988). Oceanic primary Production: estimation by remote sensing at local and regional scales. Science, 241: 1613-1620.

Rayner, N.A., D.E. Parker, E.B. Horton, C.K. Folland, L.V. Alexander, D.P. Rowell, E.C. Kent and A. Kaplan, (2003) Global analyses of SST, sea ice and night marine air temperature since the late nineteenth century, *J. Geophys. Res*, 108, doi:10.1029/2002JD002670, 2003

Sea Around US (2007). A Global Database on Marine Fisheries and Ecosystems. Fisheries Centre, University British Columbia, Vancouver, Canada. www.seaaroundus.org/ --click on Large Marine Ecosystems.

Seitzinger, S.P. and Kroeze. C. (1998). Global distribution of nitrous oxide production and N inputs in freshwater and coastal marine ecosystems. Global Biogeochemical Cycles 12(1): 93-113.

Sherman, B. (2000). Marine ecosystem health as an expression of morbidity, mortality, and disease events. *Marine Pollution Bulletin* 41(1-6): 232-254.

Sherman, K. ed. (1993). Emerging theoretical basis for monitoring the changing states (Health) of large marine ecosystems. Summary report of two workshops: 23 April 1992, National Marine Fisheries Service, Narragansett, Rhode Island, and 11-12 July 1992, Cornell University, Ithaca, New York. NOAA Technical Memorandum NMFS-F/NEC-100.

Sherman, K. (2003). Physical, biological and human forcing of biomass yields in large marine ecosystems. ICES CM 2003/P12

Sherman, K. and Alexander, L.M. (1986). *Variability and Management of Large Marine Ecosystems.* AAAS Selected Symposium 99. Westview Press. Boulder, Colorado. 319p.

Sherman, K. P. Celone and S. Adams. 2004. NOAA Fisheries Service's Large Marine Ecosystems Program: Status Report. NOAA Technical Memorandum NMFS-NE-183. U.S. DOC, NOAA, NMFS, Northeast Fisheries Science Center. Woods Hole, MA.

Sherman, Hoagland and Jin, D. (2005). Driving forces affecting resource sustainability in large marine ecosystems . ICES 2005/M:07. Presented at the ICES Annual Science meeting in Aberdeen Scotland, 2005.

Sokal, R.R., and F.J. Rohlf. 1995. *Biometry: The Principals and Practical Statistics in Biological Research*. W.H. Freeman and Company, New York.

Sutinen, J., editor. (2000). A framework for monitoring and assessing socioeconomics and governance of large marine ecosystems. NOAA Techical Memorandum. NMFS-NE-158. 32p

Wozniak, B., J. Dera, D. Ficek, and R. Majchrowski. 2003. Modeling light and photosynthesis in the marine environment. *Oceanologia* 45(2):171-245.

USEPA. (2004). National Coastal Condition Report II. EPA-620/R-03/002. Washington, DC. 285p.