Sustaining the World's Large Marine Ecosystems

Edited by

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Preface

This volume, *Sustaining the World's Large Marine Ecosystems*, is a collaborative effort of NOAA's Large Marine Ecosystem (LME) Program, and the International Union for the Conservation of Nature (IUCN). The IUCN is the world's largest global environmental network. Its members include governments, non-governmental organizations and 10,000 volunteer scientists in 160 countries. The IUCN Global Marine Programme has eight focus areas related to the conservation and sustainable use of oceans: climate change mitigation and adaptation, coastal livelihoods, the conservation of threatened species, energy and industry, fisheries and aquaculture, the management of marine invasive species, marine protected areas, and ocean governance. The IUCN promotes large marine ecosystem monitoring, assessment, management and biodiversity conservation through its support of capacity building and socioeconomic studies that further the understanding of ecological processes that drive the coastal economies of developing countries.

Large Marine Ecosystems (LMEs) are regions of ocean space of 200,000 km^2 or greater, that encompass coastal areas from river basins and estuaries to the outer margins of a continental shelf or the seaward extent of a predominant coastal current. LMEs are defined by ecological criteria, including bathymetry, hydrography, productivity, and trophically linked populations. The LME concept for ecosystem-based management with its 5-module approach focused on productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance, was selected as a notable scientific breakthrough and commemorated in 2007 during the celebration of 200 years of ocean science by the US National Oceanic and Atmospheric Administration (NOAA) and its predecessor agencies (http://celebrating200years.noaa.gov/).

LME Projects

One hundred and ten developing countries are presently engaged in 16 joint international projects in Africa, Asia, Latin America and eastern Europe, that are based on the LME approach and use the LME as a management unit. The projects are funded by the Global Environment Facility (GEF), the World Bank, participating countries, and other donors at a level of $1.8 billion. The GEF LME projects apply an ecosystem based management (EBM) strategy to (i) recover depleted marine fish and fisheries, (ii) reduce and control coastal pollution and nutrient over-enrichment, (iii) restore degraded habitats, (iv) establish marine protected areas and (v) sustain ecosystem goods and services.

LME Project Partners

NOAA and IUCN are providing technical and scientific support to the projects through close partnerships with the United Nations Development Program (UNDP), the United Nations Environment Program (UNEP), the United Nations Industrial Development Organization (UNIDO), the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), the Food and Agriculture Organization (FAO), and multisectoral ministries supporting the hands-on participation of 2,500 experts. Globally, the UNDP, UNEP, UNIDO and FAO serve as UN executing and implementing agencies, assisting developing countries to operationalize GEF-LME projects.

Supplemental financing of LME projects with World Bank Investment Funds is likely to increase support of LME projects to a level of $3 billion by 2012. This unprecedented level of funding provides developing countries with the means to apply the 5-module LME assessment and management approach for obtaining time series data on LME productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and implement ecosystem-based governance practices.

The TDA and SAP Process

With IUCN assistance, coastal communities are benefiting in the application of marine ecosystem based management from the growing number of lessons learned from the GEF supported LME projects. LME activities supported by the GEF and World Bank are endorsed at the national level by the ministers of the environment, fisheries, energy and mining, tourism, and finance in each of the participating countries. The countries' activities are organized and conducted through an agreed upon Transboundary Diagnostic Analysis (TDA) and Strategic Action Programme (SAP). The SAP is a regional policy framework that strengthens the participating countries' individual and collective ability to contribute directly to actions that are consistent with the World Summit on Sustainable Development (WSSD) marine program of implementation, endorsed by world leaders in Johannesburg in 2002.

IUCN Congress

The IUCN partners with the LME Program of NOAA in assisting developing countries to maintain community-based artisanal fisheries and better manage transboundary marine goods and services. The IUCN contributes to the LME movement in working with West African and Asian nations to set standards for negotiation of fisheries agreements, improve the management of marine protected areas, and help raise awareness and build capacity in developing countries through a range of training courses and publications on climate change, the economic valuation of LMEs, and coral reef management.

At the 2008 IUCN Congress in Barcelona, the presenters at a Large Marine Ecosystem (LME) session on indicators of changing LME conditions provided case study examples of the application of indicator suites for all five modules, along with summaries of lessons learned, with special reference to the Benguela Current, Baltic Sea and Yellow Sea LME projects. This publication is based on invited papers from contributors made at the LME session during the Congress and other related LME studies. It is an outreach and educational publication produced by IUCN for marine scientists, marine resource policy and management professionals, colleges, universities and schools, and the public, describing practical applications of the LME approach to recover and sustain depleted and degraded marine goods and services.

Global LME Movement

Sustaining the World's Large Marine Ecosystems, provides examples of advances made in the operationalization of the five-module approach to ecosystem based management (EBM) for sustaining the goods and services of the world's LMEs. The opening contribution by A. Duda is focused on the global movement underway by the LME partners (GEF, UNEP, UNDP, UNIDO, IOC-UNESCO,FAO, NOAA, IUCN and WWF) to assist over 100 developing countries in operationalizing the LME approach to the assessment and management of coastal ocean goods and services. The following chapter, by Sherman et al., describes the suites of indicators used to monitor and assess changing states of LMEs in support of ecosystem-based adaptive management practices. The subsequent contributions are focused on the results of initial phases of fully operationalized LME projects. In the case of the Benguela Current LME, M. O'Toole describes the emergence of the world's first LME governance Commission. In his chapter, he summarizes the present institutional structures, future plans, and lessons learned from ten years of engagement by Angola, Namibia, and South Africa in operationalizing the LME approach to address specific transboundary priorities of the Benguela Current LME project based on the countries' agreed upon Transboundary Diagnostic Analysis (TDA) and Strategic Action Program (SAP).

LME Project Applications

In the Baltic Sea LME (BSLME) project chapter, J. Thulin describes the application of the 5-module LME approach for controlling nutrient over-enrichment from improved agricultural practices in partnership with the WWF and the Helsinki Commission (HELCOM). With regard to fisheries sustainability, he explains how the BSLME project enhanced the application of the ecosystem-based approach to initiate recovery of depleted fish stocks of the BSLME through activities of working groups of the International Council for the Exploration of the Sea (ICES) and supported by GEF funds to allow for greater participation in the project by emerging democratic countries of the eastern Baltic.

Q. Tang, addresses the application of time-series metrics for investigating multi-decadal changing states of the Yellow Sea LME (YSLME). Results of the analyses of ecosystem productivity and ecosystem health are described in relation to environmental and anthropogenic ecosystem driving forces of change. He concludes the chapter with a description of an adaptive management approach to both recover depleted fisheries and improve the water quality of the YSLME. A major effort to reduce fishing effort is selected as the strategy to recover depleted capture fishery stocks, while a parallel marine mariculture effort is to be ramped up to replace the estimated loss of capture fisheries biomass yields with intensive expansion of marine polyculture.

M. Walton and Y. Jiang detail the emergence of the adaptive ecosystem-based management strategy applications adopted by China and the Republic of Korea based on operationalization of the agreed-upon YSLME project TDA and SAP ecosystem recovery and sustainability targets. They describe actions underway by both countries to reduce fishing effort by 33% for restoring seriously depleted capture fisheries. Using carrying capacity models based on primary productivity values (gCm^2), they argue that the estimated annual one million metric tons of lost fisheries catches from reduced fishing effort will be replaced annually by one to two million metric tons of polyculture production of fish, bivalve mollusks and shrimp, while the capture fishery stocks are recovering. An important by-product of the massive coastal polyculture (China) and coastal fish ranching (R. Korea) is the expected improvement in coastal water quality from advancements in mariculture technology.

LMEs and MPAs

The chapter by J. Oliver et al. addresses IUCN's global efforts to expand the number of marine protected areas (MPAs) in LMEs. To aid the marine resources science and management communities, they provide a world map of the areas within LMEs that have been designated as MPAs. Activities of IUCN's World Commission on MPAs are highlighted, and MPAs of the Canary Current LME, Guinea Current LME, South China Sea LME, Mediterranean Sea LME, Agulhas Current LME and Somal;i Current LME are described

Training and Outreach

At present, 2,500 scientists, technicians and resource managers are involved in GEF supported LME project activities. By 2015 it is estimated that the LME movement for marine resources assessment and management will require up to 10,000 trained and educated LME project practitioners. Future LME education and training needs are addressed by Professor Gotthilf Hempel in his contribution to the volume. As a former President of ICES and Professor and Director of marine institutes in Kiel, Bremerhaven, and Bremen, Professor Hempel stresses the need for increased interaction between pragmatic LME science and more basic marine science underway in academia to initiate a new generation of marine ecosystem experts in specialty areas of ichthyology, planktology, sociology, economics and international law, and more general ecological subjects focused on application of science to management. The volume concludes with a chapter by M.C. Aquarone describing efforts underway to reach beyond the marine community with LME volumes, reports, and multimedia DVDs, websites and portals. A listing of the authors and titles of LME publications of 14 peer-reviewed published volumes is given in the Annex.

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The Editors

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GEF Support for the Global Movement toward the Improved Assessment and Management of Large Marine Ecosystems

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While our planet's coastal and marine assets have been in trouble for a while, recent information has documented beyond a doubt the scale and severity of risks to humanity associated with depletion and degradation of near coastal oceans and their contributing watersheds. Lack of attention to policy and legal and institutional reforms has resulted in coastal freshwater depletion, pollution from sewage and industrial wastes, human health risks, coastal groundwater supply contamination, overexploitation of fisheries, the destruction of economically important coastal habitats like coral reefs, diseases and alien species propagated by maritime transport. All these trends lead to socioeconomic losses.

The Global Environment Facility (GEF) has recognized these concerns since the early 1990s, and has responded with an ecosystem-based approach to the assessment and management of Large Marine Ecosystems (LMEs) across the world in order to stem the tide of depletion and degradation, and lead the transition to ocean security. This paper describes the approach adopted by the GEF in the last dozen years to create a movement in support of intergovernmental instruments to reverse the downward spiral of coastal and marine resources. One hundred and thirty two nations are working together in GEF International Waters projects to support this movement with improved human capacity, governance reforms, and critical investments.

The GEF approach at different scales is described, along with some early results of the type of decadal long effort needed to make real changes in human behavior. As GEF enters a phase that will invest in the LME movement, its future focus depends on the amount of GEF replenishment funding provided by industrialized countries to catalyze actions, and on the commitments coming from developing countries to adopt collective reforms and utilize available financing for investments. When industrialized countries are lukewarm in support of GEF efforts to assist developing nations in sustaining ocean goods and services, the world community should expect little action in return.

The collective actions of many countries are needed to cope with shifts in climate and the impacts of globalization, with its financial pressures that further stress declining coastal ecosystems. The scale of economic loss facing coastal countries is at the level of trillions of dollars of ecosystem goods and services at risk through failures in governance. Governments failing to make progress in attaining Millennium Development Goals (MDGs) face internal social and political unrest, the loss of natural resources along with economic benefits, and human communities that cannot sustain themselves.

Why Large Marine Ecosystems?

The depletion of fisheries resources in coastal oceans is but one symptom of mismanagement, along with land practices, the pollution of freshwater systems, and wasteful energy use that loads our atmosphere with climate changing carbon. The lack of attention to policy, legal, and institutional reform, low priority given to public investments, and lack of enforcement of many regulations now place at risk not only coastal and marine ecosystems but also human communities that depend on them for economic security and social stability.

Traditional sector-by-sector approaches to economic development have created this global crisis. Calls to establish environment programs focused solely on single marine sectors (e.g. fisheries, pollution, habitat, biodiversity) are doomed to fail if they do not incorporate the policies and programs of economic and other sectors. Rather, an ecosystem-based approach to coastal and marine systems that can operate at multiple scales and harness stakeholder support for integrated management in synchrony with the improved management of other sectors is needed in both Northern and the Southern countries.

Marine ecosystems and their contributing freshwater basins are transboundary in nature by virtue of interconnected currents, pollution, and movement and migration of living resources. Eighty percent of the global marine fisheries catch comes from 64 Large Marine Ecosystems (LMEs) delineated along the continental shelves and coastal currents, that represent multi-country, ecosystem-based management units for reversing fisheries depletion (Duda and Sherman, 2002; Sherman et al. 2009, this volume). LMEs are natural regions of ocean space encompassing coastal waters from river basins and estuaries to the seaward boundary of continental shelves and the outer margins of coastal currents. They are relatively large regions of 200,000 km^2 or greater, the natural boundaries of which are based on four ecological criteria: bathymetry, hydrography, productivity, and trophically related populations (Sherman 1994).

The Role of the GEF

The GEF was established in 1991 as a pilot multilateral financial mechanism to test new approaches and innovative ways to respond to global environment challenges, in its four focal areas of climate change, biodiversity conservation, ozone depletion, and international waters. Following 18 months of negotiations, agreement was reached in 1994 to transform the GEF from its pilot phase into a permanent financial mechanism. The restructured facility, with its multi-billion dollar trust fund, is open to universal participation, with 176 countries currently serving as members. It builds upon partnerships with the United Nations Development Program (UNDP), the United Nations Environment Program (UNEP), the World Bank, and seven other agencies with expanded opportunities such as the four regional development banks, FAO, and UNIDO. These agencies can access funding on behalf of developing countries and those in economic transition for activities consistent with the GEF Operational Strategy.

The only new funding source to emerge from the 1992 Earth Summit, the GEF has allocated $US 7.6 billion in grants supplemented by more than $US 31 billion in additional financing, for 2000 projects in 165 developing countries and countries in economic transition. For the International Waters focal area, 132 transboundary water projects, at a level approaching $6 billion in total cost and $1.2 billion in GEF grants, have been funded with 147 different GEF-recipient countries.

Late in 1995, the GEF Council issued its Operational Strategy on the use of GEF funding (GEF 1995). Chapters 17 and 18 of Agenda 21 provided a guide for Council discussions in the International Waters (IW) focal area, which addresses transboundary concerns of shared river basins, groundwater systems, coasts, and oceans. The Operational Strategy recognized that special international collaboration was needed among sovereign states to reverse the decline of large multi-country water systems and help resolve conflicting uses leading to resource depletion, degradation, conflicts, and loss of socioeconomic benefits. For coasts and oceans, the Strategy uses LMEs as the unit of assessment and management (Duda 2005).

The Serious Nature of Coastal Depletion and Degradation

Fishing down food webs, destructive fishing gear, habitat conversion to aquaculture, and the associated pollution loading have all been shown to contribute to the decline of marine ecosystems across the globe (Pauly et al. 1998). The depletion of ocean fisheries` and the destruction of coastal habitats through damage caused by aquaculture constitute globally significant environmental problems. Recent estimates suggest that 90% of the large fish have been removed from the oceans (Myers and Worm 2003), and that three quarters of fish stocks are fished at their maximum yield level, overfished, or depleted (FAO 2007). Jackson et al. (2001) noted that ecological extinction caused by historical over-fishing is the most important cause of marine biomass and biodiversity depletion around the world, with existing populations being only a fraction of historical levels. Habitat loss from destructive trawling and “slash and burn" coastal aquaculture have made matters much worse, with wild fisheries losing habitats for spawning and nursery grounds.

Recently, Worm et al. (2006) have concluded that cumulative catches within the world's LMEs have declined by 13% (10.6 million metric tons) since passing a cumulative maximum in 1994. They argue that species average catches in non-collapsed fisheries were higher in species rich systems, and that species robustness to overexploitation was enhanced in LMEs with high fish species diversity. They further argue that sustainable fisheries management, pollution control, the maintenance of essential habitats, and the creation of marine reserves will prove to be good investments in the productivity and value of the goods and services that the ocean provides to humanity. The oceans have been depleted of their largest fish. And species loss, declines through by-catch, and fishing down food webs threaten the food security of hundreds of millions of poor people globally.

Overfishing and lack of regulation are also costing governments valuable foreign exchange revenues. A World Bank analysis released in 2008 revealed that poor management, inefficiencies, pirate fisheries, and overfishing cost governments a conservative $US 50 billion in lost revenues annually (World Bank, 2008). The cumulative loss in the last 3 decades has been over $US 2 trillion. If a loss of 1 percent of this was associated with a terrorist attack, the world would be outraged. With global trade in fisheries at $70 billion, and all coastal and marine ecosystem goods and services valued at US$ 12.6 trillion annually (Costanza et al. 1997), it is time to act to reverse this depletion.

The GEF Support for Country-driven Action at Different Scales

The GEF-supported LME projects are piloting and testing ways to implement integrated management of oceans, coasts, estuaries, and freshwater basins through an ecosystem-based approach. Since 1995, the Global Environment Facility has provided substantial funding to support country-driven projects for introducing multi-sector, ecosystem-based assessment and management practices for LMEs located around the margins of the oceans. At present, 110 developing countries and 16 industrialized countries are partnering in GEF Council approved LME projects. **Figure 1** identifies 16 LME projects and one LME-equivalent (the Warm-water Pool of the Western and Southern Pacific), where countries have requested and received funding for GEF-LME projects.

A five-module indicator approach to the assessment and management of LMEs has proven useful in ecosystem-based projects in the United States and elsewhere (Duda and Sherman 2002). The modules are adapted to LME conditions through a Transboundary Diagnostic Analysis (TDA) process to identify key issues, and a Strategic Action Program (SAP) development process for the groups of nations or states sharing an LME to remediate the issues.

These processes are critical for integrating science into management in a practical way, and for establishing appropriate governance regimes to change human behavior in different sectors.

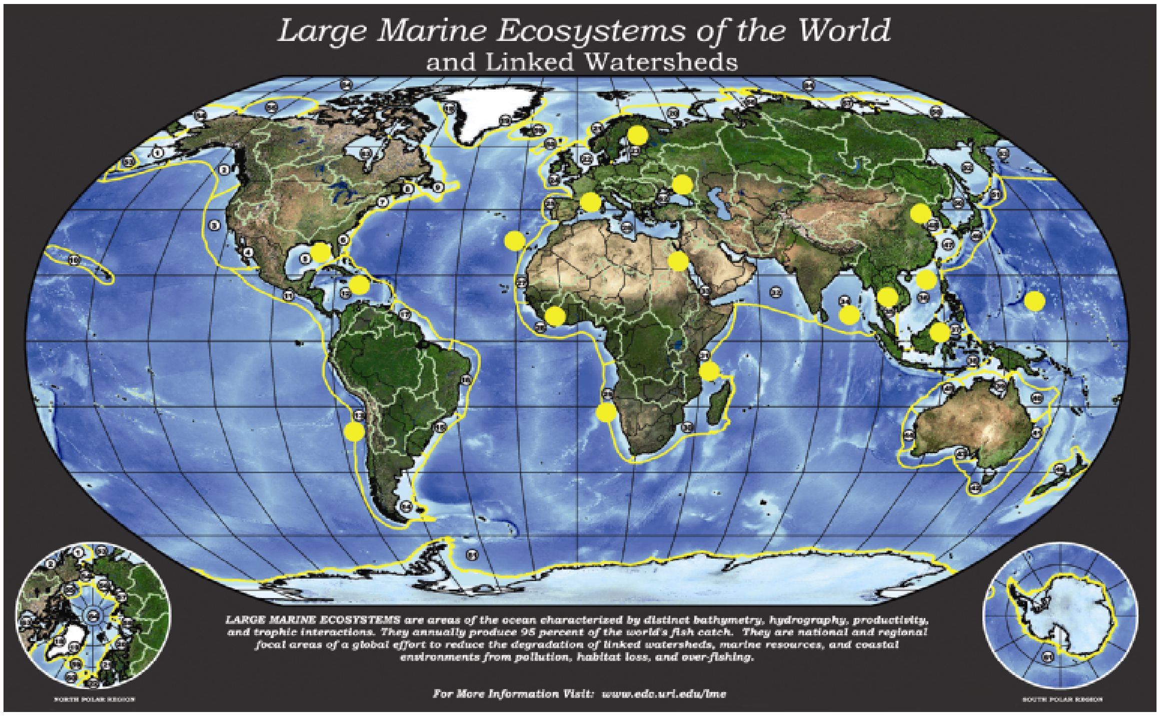

Figure 1. Global Distribution of Large Marine Ecosystem Projects Funded by the GEF. The yellow dots on the map represent the location of the 16 operational LME projects approved by the GEF Council and with GEF International Waters funding. These are (from left to right and top to bottom): the Caribbean, Gulf of Mexico, Humboldt Current, Baltic Sea, Black Sea, Mediterranean Sea, Canary Current, Guinea Current, Benguela Current, Agulhas and Somali Current, Red Sea, Bay of Bengal, Gulf of Thailand, Yellow Sea, South China Sea, and Sulu Celebes LMEs. Also represented with a yellow dot is a 17th project in the Pacific Ocean, the Pacific Warm-Water Pool LME Equivalent.

The SAP translates the shared commitment and vision into action, a process that has proven essential in GEF projects for developing and sustaining partnerships. Countries cooperate in establishing adaptive management structures for monitoring and evaluation and for establishing indicators. This has led countries to adopt their own LME-specific ecosystem targets in response to the 2002 Johannesburg World Summit on Sustainable Development (WSSD), and to establish partnerships with bilateral, multilateral, and UN agencies for better coherence by the development assistance community.

The GEF in support of LMEs also works at other scales, to catalyze integrated coastal management (ICM) at the scale of municipalities, coastal provinces, contributing river basins, and at the community level to promote sustainable resource use and habitat protection. One example of the provincial and municipal scale of action is the successful GEF-funded and UNDP-supported Partnerships in Environmental Management for the Seas of East Asia (*PEMSEA*) program with its focus on integrated coastal management (ICM). Tools similar to those used in LME projects are utilized at a smaller scale to foster the integration, participation, and reforms needed for implementing ICM. ICM programs can have a cascading effect in transforming governance, improving people's awareness of important ecosystem assets and social values, and spurring additional private sector involvement.

GEF also works at the scale of river basins draining to coasts in order to improve water flow regimes and reduce pollution loading. Consistent with the targets of the UNEP Global Programme of Action (GPA) for the protection of the marine environment from land based activities, and with paragraph 33 of the WSSD Program of Implementation, over US$1 billion has been allocated by GEF to focus on projects related to the GPA and land-based activities. The GEF-supported Hai Basin initiative led by China with World Bank assistance is an example. Another is the large scale GEF-supported Danube and Black Sea Basin Strategic Partnership with UNDP and the World Bank that aligns the World Bank policy with the 15 countries of the Black Sea basin to include pollution reduction reforms, habitat restoration, and pollution reduction investments. The two basin projects create a bridge between land and sea, with GEF combining projects to link the improved management of freshwater basins with coastal zones and large marine ecosystems.

GEF also utilizes support at other appropriate geographic scales for securing valuable habitats for livelihood of communities and food security. Community level work has led to the establishment of fish refugia. First developed in the GEF/UNEP South China Sea and Gulf of Thailand LME projects, the concept for securing habitats builds on community knowledge of fish reproduction and co-management and limits gear and fishing at critical periods of lifecycles to sustain fisheries (Paterson and Pernetta, 2008).

The Benguela Current LME Project

In the mid 1990s, the governments of South Africa, Namibia and Angola requested GEF's assistance for a project focusing on the sustainable management and utilization of the Benguela Current LME with a focus on living marine resources, the reduction of mining impacts, predicting environmental variability and improving ecosystem forecasting, managing land-based pollution, protecting biological diversity, and strengthening capacity to adapt to fluctuating climatic conditions that threaten fisheries. During a 12-month project development period, the three countries reached consensus on a strategic approach for the project, based on GEF procedures for developing a TDA and SAP, which was signed in 2000 by three ministers from each nation. As the first GEF project to successfully complete this initial work, the Benguela Current

(BCLME) project serves as a successful model for other LME projects. Especially significant were the national dialogues fostered in inter-ministerial committees. They proved to be an important factor in aligning different ministries related to land and water activities to work in an integrated, ecosystem-based fashion.

This early success led to the establishment of the new, ecosystem-based, Benguela Current Commission (BCC). The Commission was an illustration of how the political commitment of 3 countries can secure ecosystem sustainability. As a result, a second and final GEF LME project was funded to operationalize the BCC and support negotiations for a legal agreement among the 3 countries to sustain its work (Duda 2008). The BCC marries the advice of science-based groups with the advice of management institutions to improve decision-making in fisheries, coastal management, mining and energy. With an ever warming and fluctuating marine environment in which the fish stocks move, the science-based advice and forecasting tools are used by GEF supported LME projects to provide sound recommendations to the joint management institutions so that stakeholders at all levels can adapt to fluctuating and changing climate.

The Danube/Black Sea Basin under the GPA

Seventeen countries rely on the Danube River Basin including its tributaries and the Black Sea LME project, for economic, social, and environmental services. These important waters have been degraded by pollution and other human influences, and have been over-fertilized by nitrogen and phosphorus from agricultural, municipal, and industrial sources.

Since 1992, the GEF has supported an array of projects aimed at improving ecosystem quality in the region, designed to bring Danube basin and Black Sea coastal states together in the TDA and SAP process and in national inter-ministry committees. In order to fund the *Strategic Partnership for Nutrient Reduction in the Danube River and Black Sea*, the World Bank, UNDP, and UNEP mobilized more than $US 450 million in co-financing that supplemented the $US 100 million from GEF to make policy, legal, and institutional reforms, invest in the agriculture, municipal, and industrial sectors, and restore wetlands to reduce nitrogen pollution in the Black Sea watershed.

The Strategic Partnership of the 17 watershed states, the GEF, the UN agencies, and donors now brings coordinated support and benefits to the Black Sea Basin under the Bucharest and Istanbul Conventions and is taking an adaptive management approach. The GEF International Waters partnership has served as a test of whether a greater and more comprehensive participation of the GEF and a streamlined process for sub-project approvals can leverage significant environmental improvements in a large, damaged, transboundary Large Marine Ecosystem (**Table 1**). The approach has proven successful and is now being replicated to support several emerging partnerships of significant importance to the coastal and marine environment.

Table 1. List of nutrient reduction investment projects supported by the GEF. The mid-term report on the Danube River and Black Sea partnership shows progress and recovery in the Black Sea environment (GEF 2005).

Country and Sector Operation	Status	$ Mil
Romania: Agricultural Pollution Control	**Completed**	**5.15**
Bulgaria : Wetland Restoration and Pollution Reduction	**Approved**	**7.5**
Moldova: Agricultural Pollution Control	**Approved**	**4.95**
Turkey: Anatolia Watershed Rehabilitation	**Approved**	**7**
Serbia and Montenegro: Reduction of Enterprise Nutrient Discharges	**Approved**	**9.02**
Bosnia-Herzegovina : Water Quality Protection	**Approved**	**4.25**
Hungary: Reduction of Nutrient Discharges	**Approved**	**12.5**
Moldova: Wastewater, Environmental Infrastructure	**Approved**	**4.56**
Romania: Integrated Agriculture Nutrient Pollution Control	**Approved**	**5**
Croatia: Agricultural Pollution Control	**Approved**	**4.81**
Ukraine: Odessa Wastewater Treatment (est. Jan 2009)	**Pending**	**5**

GEF Support for the LME Movement

The GEF supported, ecosystem-based approach is centered on LMEs and participative processes that build political and stakeholder commitment and action. The inter-ministerial buy-in sets the stage for the world community to invest in capacity building and technology. This collective response to global conventions and other instruments can be achieved in a practical manner. The iterative framework for adaptive management can address new issues or unexpected ecological developments.

Ultimately, each nation must find a way to balance capture fisheries, fishmeal fisheries, aquaculture, and biodiversity conservation, with food security support for the poor, and public, regulatory, and program reforms. Removing subsidies, improving global trade policies, establishing safety nets for poor coastal communities, undertaking management reforms, securing property rights, and conserving marine biodiversity through protected areas and limited use zones are all part of the reform picture to reverse the decline of marine fisheries. GEF LME projects show that a place-based approach helps focus the attention of competing nations and competing ministries on the multiple benefits to be derived from global instruments. Instead of establishing competing programs and duplicating efforts, LME projects address priority transboundary issues in an integrated manner—in accordance with UNCLOS, Chapter 17 of Agenda 21, the Jakarta Mandate of the Convention on Biodiversity (CBD), the Global Programme of Action (GPA) of UNEP and under the Climate Change Treaty.

Whether undertaken in LMEs or at an equivalent LME level as in the GEF/UNDP/IMO PEMSEA project, the place-based participatory process generates political solutions and commitments to reverse marine degradation and resource depletion. Sound science informs policy-making when an ecosystem-based approach to management can be developed and stakeholders can be engaged. The place-based participatory process engages governments and stakeholders to understand what is needed for implementing integrated management and capacity building. Marine science has all too often remained confined to the science community and has not embraced policy-making.

The shared commitment and vision embodied in the SAP has proven essential in GEF-LME projects for developing partnerships that can sustain commitment to action. Participating countries cooperate in establishing adaptive management structures and indicators. The countries in adopting their own LME-specific ecosystem targets collectively track their progress on-the-ground and enact conventions or protocols to existing treaties to express their joint commitment. Establishing partnerships with bilateral, multilateral, and UN agencies is resulting in a realignment of priorities toward WSSD targets, as these agencies assist countries in making policy, legal, and institutional reforms in different economic sectors.

For 2006-2010, GEF will likely commit over US $230 million in grants to LME-related projects, which will likely leverage over US $1 billion in co-financing. As of October 2008, GEF funding support has achieved 75% of that expectation, with funding expected in 9 LME projects. The investment will ramp up further support. **Figure 2** illustrates the time-trend of GEF support in the International Waters focal area. Co-financing barely kept up with GEF funding in the early years; more recently, countries in entering the investment phase of the 10-year project span have received co-financing that greatly exceeds the GEF allocations. This shows the commitment of countries and the leverage that these GEF-LME projects can produce when governments realize the critical actions that need to be undertaken.

GEF intends to deepen its support for LME projects and focus more attention on management and learning in support of the LME network. The UNDP, UNEP, NOAA, UNESCO-IOC and GEF have worked together in the past to enhance capacity building, learning, cooperation, and the sharing of experiences among the GEF LME projects through the GEF IW:LEARN Program.

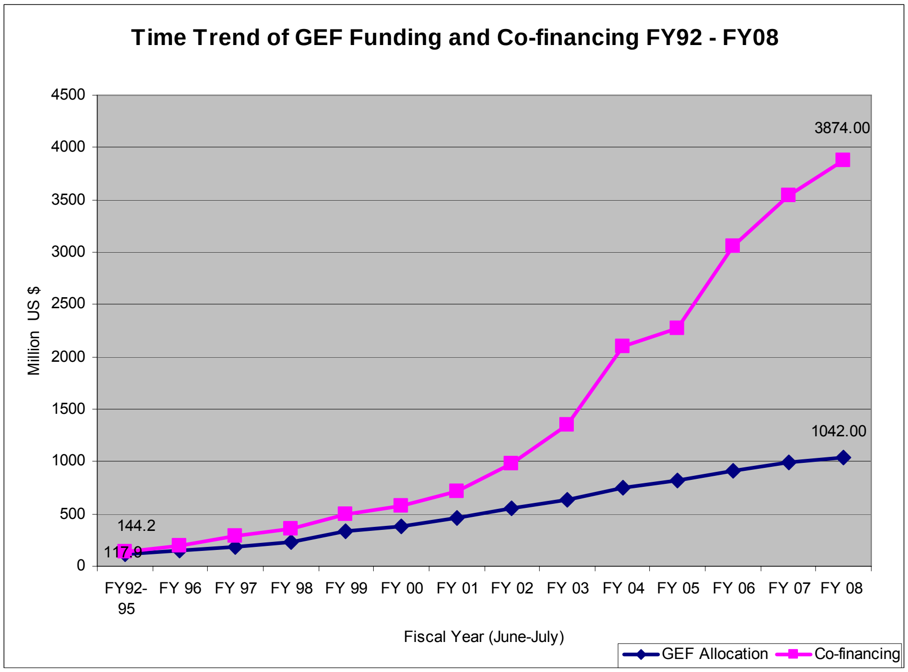

Figure 2. Time trend of GEF funding and co-financing for International Waters Focal Area Projects in FY92-FY08.

Institutes and governments with marine-related programs in the North and South need to be linked together if real progress is to be made in reversing coastal and marine degradation. There is an important future place for GEF assistance in linking these leading institutions together, given the multiple causes of degradation in coastal and marine ecosystems and the progress that can be made with minimal, cost-effective improvements.

The LME Movement: the Imperative for Securing Livelihoods

The multi-country, participatory process developed by the GEF and utilized by 110 sovereign nations in 16 LMEs over the last decade has built trust and confidence to work jointly on shared areas of sea space, coasts and adjacent freshwater basins to reverse natural resource depletion and degradation. The activities generated are being balanced among multiple nations, sectors, and communities. This is just a start.

The warming planet and warming oceans, changes in currents and salinity decreases are placing coastal economies and communities at great risk. Ocean security is at stake. With more than 200 million people around the world depending on fisheries for food security, with international trade of marine fisheries valued at $70 billion annually, and $50 billion lost every year in rents to governments, it is easy to see why ocean security must be placed higher on the political agenda if poverty reduction goals, security and stability are to be achieved. GEF embraced this challenge in the early 1990s by being the first agency operating in the developing world to use ecosystem-based approaches for managing LMEs. The pragmatic, science-based, joint management approach piloted by the GEF funded Benguela Current LME project and other GEF LME projects must succeed—nothing less than the future of our coastal oceans and coastal communities is at stake.

Planning is underway for a GEF-LME Community of Practice among LME projects and related GEF coastal and marine initiatives in the GEF portfolio, to focus cost-effective support on learning and experience-sharing. Networking, learning, capacity building, personnel exchange and dialogue are needed to accelerate global progress so that the livelihood of coastal communities, food sources, and drinking water supplies can be secured as communities make the transition to sustainability. Responsibility for action still rests with governments from the South and the North in removing trade barriers, providing assistance, fully funding the GEF so it may play its role, carrying out needed reforms to sustain coastal and marine systems, and reducing vulnerability to a changing climate. Annual goods and services from coasts and oceans are valued at $12.6 trillion. The international trade in fisheries products is valued at $70 billion annually, and $50 billion is lost annually through corruption and lack of enforcement. These figures alone are enough to push us forward.

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Indicators of Changing States of Large Marine Ecosystems

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Di Jin****, Marie-Christine Aquarone*, and Sally Adams*

The Large Marine Ecosystem Approach

A global movement that applies an ecosystem based management (EBM) approach to recover marine goods and services is presently being practiced in a growing number of developing countries. It is known as the Large Marine Ecosystem (LME) approach, and it is being endorsed and supported by governments world-wide, as well as by financial institutions including the Global Environment Facility, the World Bank and by a broad constituency in the scientific community.

While we concur with the movement toward an ecosystem-based approach to the management of marine fisheries (Pikitch et al. 2004), it is important to recognize that a broader, place-based approach to marine ecosystem assessment and management, focused on clearly delineated ecosystem units, is needed. In 2005, Large Marine Ecosystems were recognized in a scientific consensus statement by over 200 marine scientists, academics and policy experts as important global areas for practicing ecosystem-based research, assessment and management of ocean goods and services (McLeod et al. 2005). A movement is presently under way to assess and manage a growing number of the world's LMEs, with the support of financial grants, and donor and UN partnerships, in nations of Africa, Asia, Latin America and eastern Europe. It is within the boundaries of 64 LMEs **(Figure 1),** that 80% of mean annual marine fisheries yields is produced, overfishing is most severe, marine pollution is concentrated, and eutrophication and anoxia are increasing.

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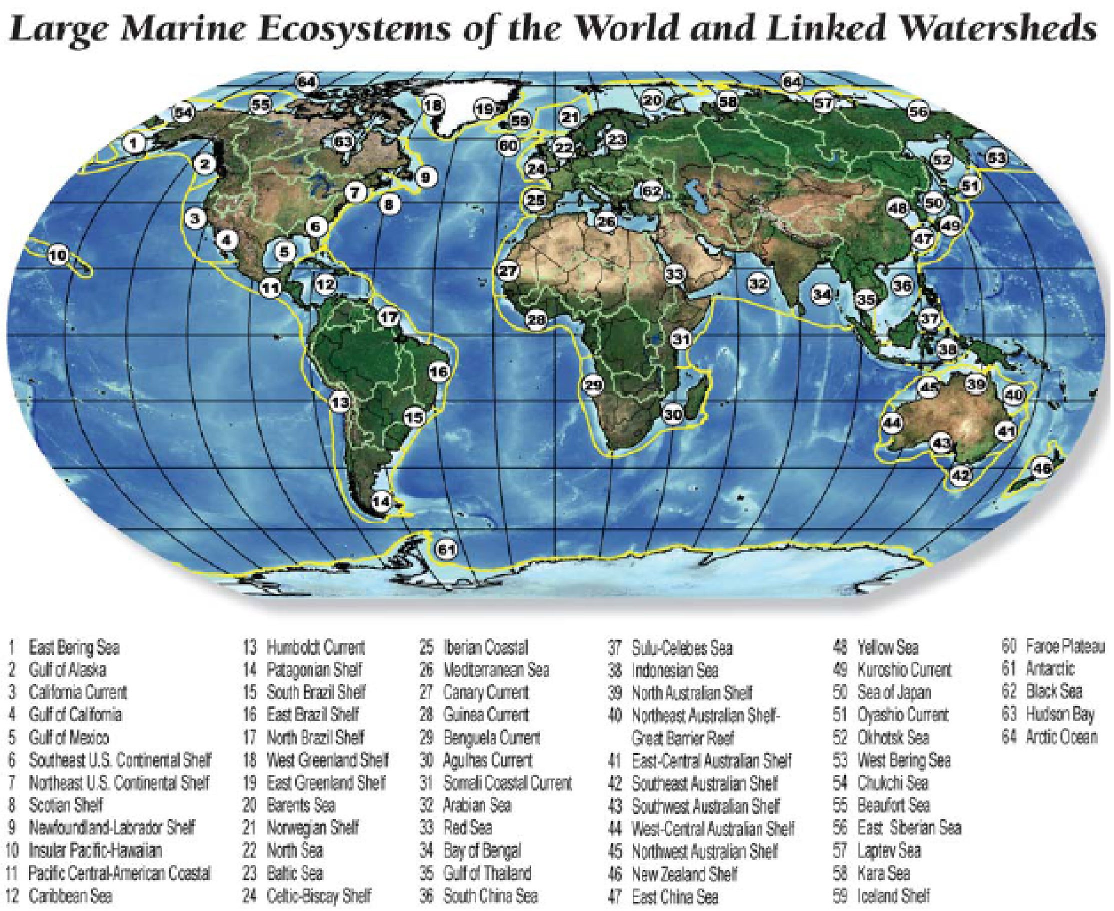

Figure 1. Map of the 64 Large Marine Ecosystems of the world and their linked watersheds (Sherman et al. 2004). The LMEs for which ecosystem based assessment and management practices are being introduced include: the Agulhas Current and Somali Current, the Baltic Sea, the Bay of Bengal, the Benguela Current, the Black Sea, the Canary Current, the Caribbean Sea, the Guinea Current, the Gulf of Mexico, the Gulf of Thailand, the Indonesian Sea, the Humboldt Current, the Mediterranean Sea, the South China Sea, the Sulu-Celebes Sea, and the Yellow Sea LMEs.

The LMEs are natural regions of coastal ocean space encompassing waters from river basins and estuaries to the seaward boundaries of continental shelves and seaward margins of coastal currents and water masses. They are relatively large regions characterized by distinct bathymetry, hydrography, productivity, and trophically dependent populations (Duda and Sherman 2002)

Since 1995, the Global Environment Facility (GEF) has provided substantial funding to support country-driven projects for introducing multisectoral ecosystem-based assessment and management practices for recovery and sustainability of LME goods and services located around the margins of the oceans. Primary productivity supporting marine populations in LMEs is higher than in the open ocean (**Figure 2**). At present, 110 developing countries are engaged in the preparation and implementation of 16 GEF-LME projects totaling $1.8 billion in start-up funding (Sherman et al. 2007).

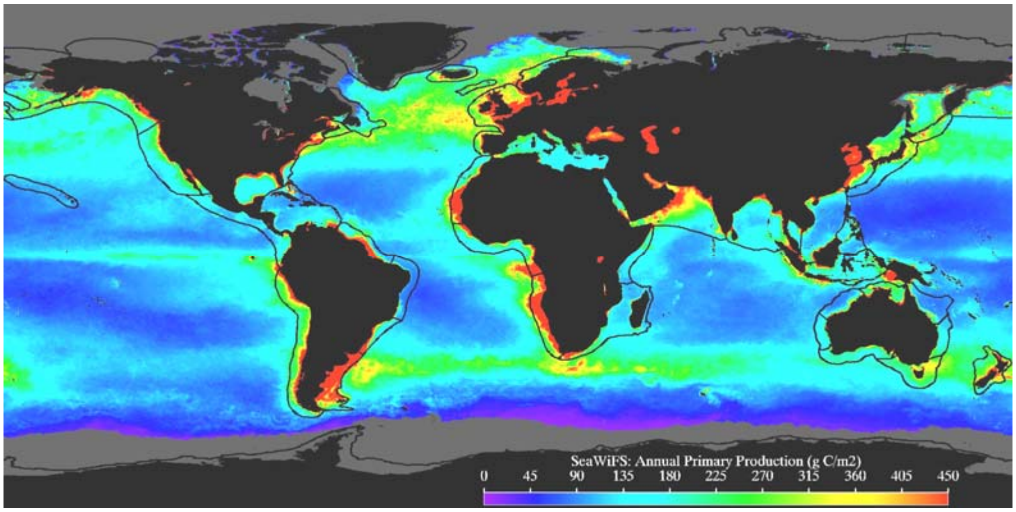

Figure 2. Global map of average primary productivity and the boundaries of the 64 Large Marine Ecosystems (LMEs) of the world, available at www.lme.noaa.gov. The annual productivity estimates are based on SeaWiFS satellite data collected between September 1998 and August 1999, and the model developed by M. Behrenfeld and P.G. Falkowski (1997). The color-enhanced image provided by Rutgers University depicts primary productivity from a high of 450 gCm^2yr^{-1} in red to less than 45 gCm^2yr^{-1} in purple.

The 5 Modules—Suites of time series, LME condition indicators

A five-module indicator approach to assessment and management of LMEs has proven useful in ecosystem-based projects in the USA and elsewhere, using suites of indicators of LME productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance. The suites of LME indicators are used to measure the changing states of LMEs in relation to a driver-pressure-state-impact-response (DPSIR) system in support of adaptive management actions (**Figure 3**). The effort to better understand climate variability, to improve the long-term sustainability of marine goods and services, and to move in the direction of ecosystem-based ocean management applies to all 64 LMEs and linked watersheds. For example, climate warming of 1° in the North Sea LME can result in a reduction in primary productivity leading to a decline in fisheries biomass yield (**Figure 3**).

The methodology used for input to the DPSIR is based on the application of the five-modular LME approach. Since 1984, NOAA's Large Marine Ecosystems (LME) Program has been engaged in the development of an ecosystem-based approach to support the assessment and management of marine resources and their environments. The approach uses indicators of ecosystem (i) productivity, (ii) fish and fisheries, (iii) pollution and ecosystem health, (iv) socioeconomics, and (v) governance (**Figure 4**). Taken together, the modules provide indicators and metrics used to determine the changing states of LMEs and support actions for the recovery, sustainability, and management of marine resources and their habitats.

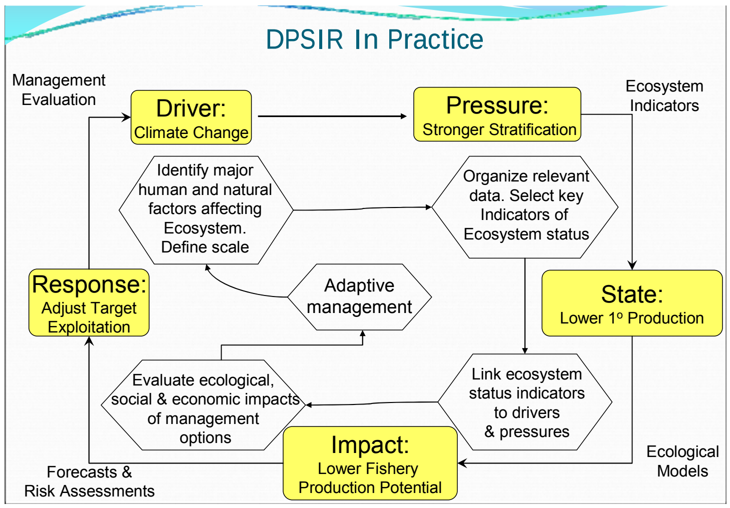

Figure 3. The Driver-Pressure-State-Impact-Response (DPSIR) model of indicators in relation to climate warming of the North Sea LME. Courtesy of Michael Fogarty, NMFS.

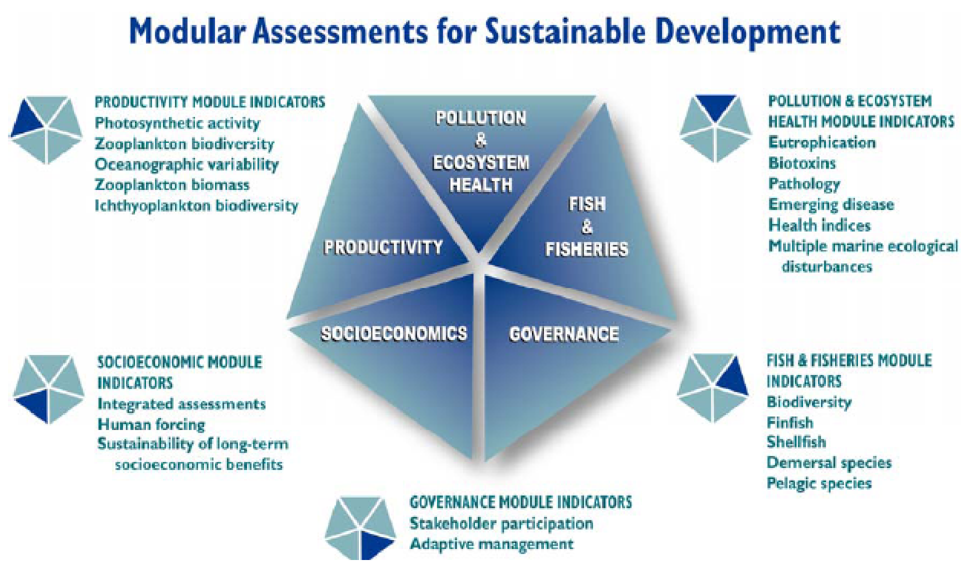

Figure 4. LME modules as suites of ecosystem indicators (Sherman et al. 2005)

1) Productivity Module Indicators

Primary productivity can be related to the carrying capacity of an ecosystem for supporting fish resources (Pauly and Christensen 1995). It has been reported that the maximum global level of primary productivity for supporting the average annual world catch of fisheries has been reached and that further large-scale increases in biomass yields from marine ecosystems are likely to be at trophic levels below fish in the marine food web (Beddington 1995). Measurements of ecosystem productivity can be useful indicators of the growing problem of coastal eutrophication. In several LMEs, excessive nutrient loadings of coastal waters have been related to harmful 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). 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. Plankton can be measured over decadal time scales by deploying continuous plankton recorder systems monthly across ecosystems from commercial vessels of opportunity (SAHFOS 2008). The Mariner Shuttle, an advanced plankton recorder, provides the means for *in situ* monitoring and calibrating satellite-derived oceanographic data. Properly calibrated sensors can provide information on ecosystem conditions including physical state (i.e., surface temperature), fast repetitious rate fluorescence chlorophyll characteristics, primary productivity, salinity, oxygen, nitrate and zooplankton (Aiken et al. 1999; Berman and Sherman 2001).

Satellite and in situ information collected and integrated at sea: Primary productivity trends (1998-2006) are available for each of the 64 LMEs. The LME primary productivity estimates are derived from satellite-borne data archived at NOAA's Northeast Fisheries Science Center, Narragansett Laboratory. These estimates originate from ocean color sensors and satellites including the Coastal Zone Color Scanner (CZCS) Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua and MODIS-Terra). A large archive of *in situ* near surface chlorophyll data, and satellite sea surface temperature (SST) measurements made by Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA satellites was used to quantify spatial and seasonal variability of near-surface chlorophyll and SST in the LMEs of the world. An example for the Bay of Bengal LME is provided in **Figure 5**.

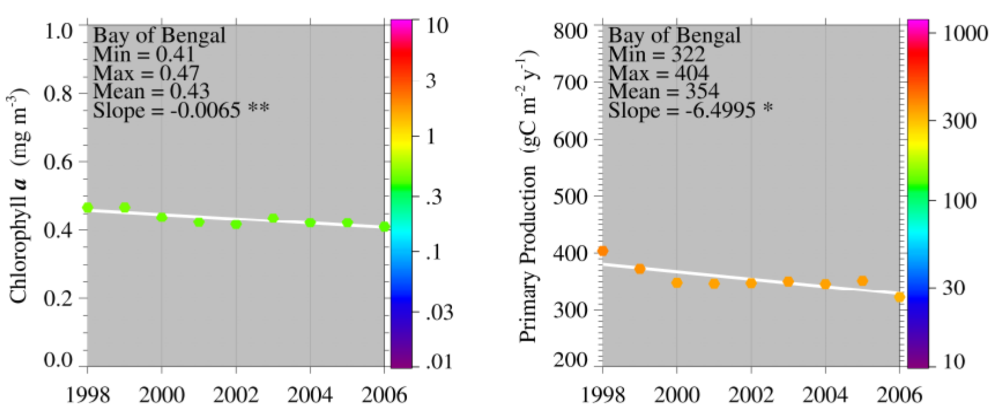

Figure 5. Chlorophyll (left) and Primary productivity (right) trends (1998-2006): Bay of Bengal (from Sherman et al. 2008).

The Mariner Shuttle system for in situ sampling of primary productivity, nutrients, mesozooplankton, and physical water column parameters is shown in **Figure 6.**

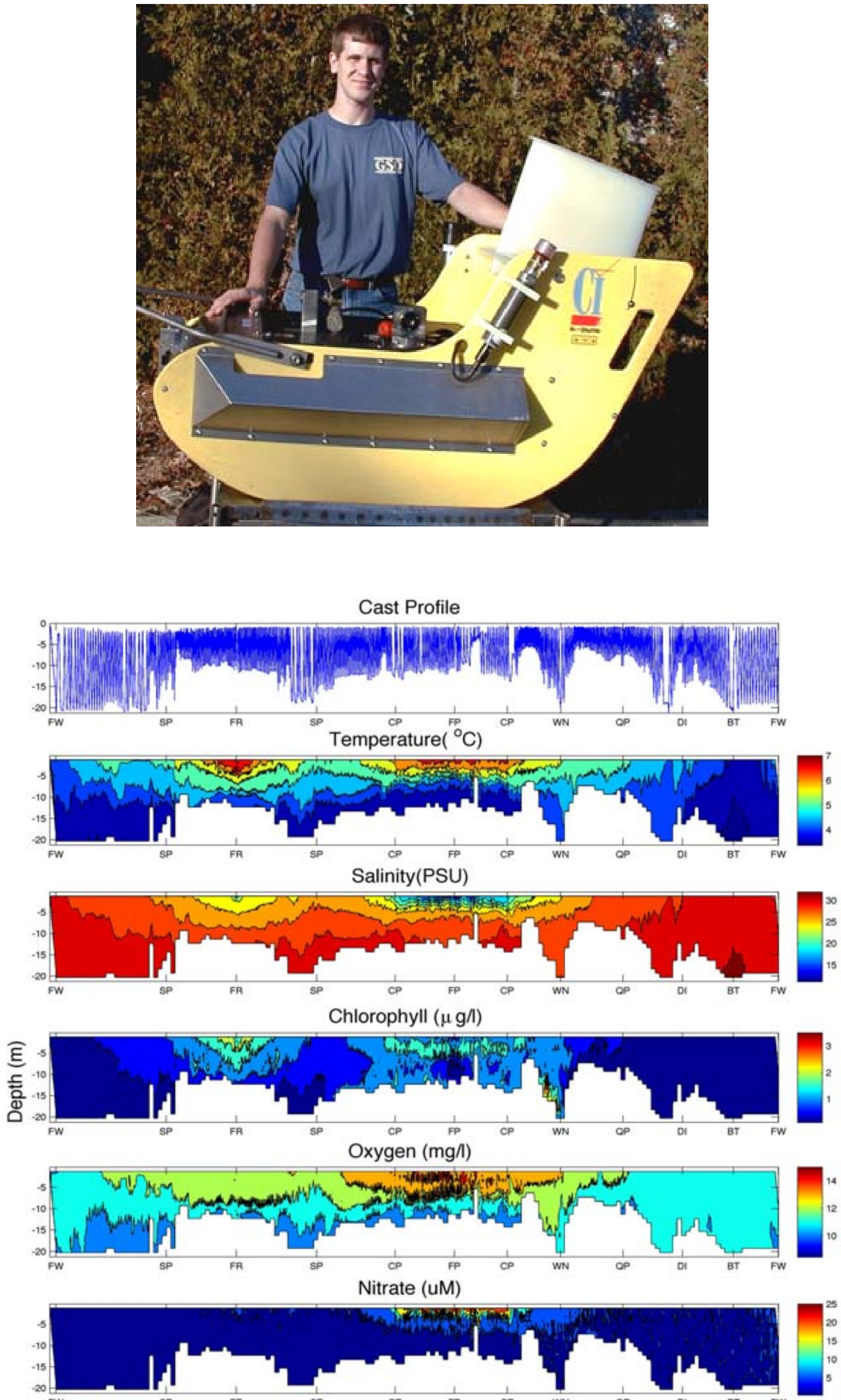

Figure 6. The Mariner Shuttle undulating oceanographic sampling system carries sensors for temperature, salinity, chlorophyll, oxygen and nitrate. The payload output includes vertical profiles of depth, temperature, salinity, chlorophyll, oxygen, and nitrate. The Shuttle also carries a continuous plankton recorder mechanism (Berman and Sherman 2001).

LME observations are integrated into a system of data and information processing for applications to LME projects. An application of satellite remote sensing for linking *in situ* subsurface chlorophyll and temperature data with surface data is depicted in **Figure 7,** illustrating the integration of SeaWiFS chlorophyll data and AVHRR SST data with *in situ* subsurface data. Also included in the suites of indicators for changing conditions in the productivity module are measurements of oceanographic variability.

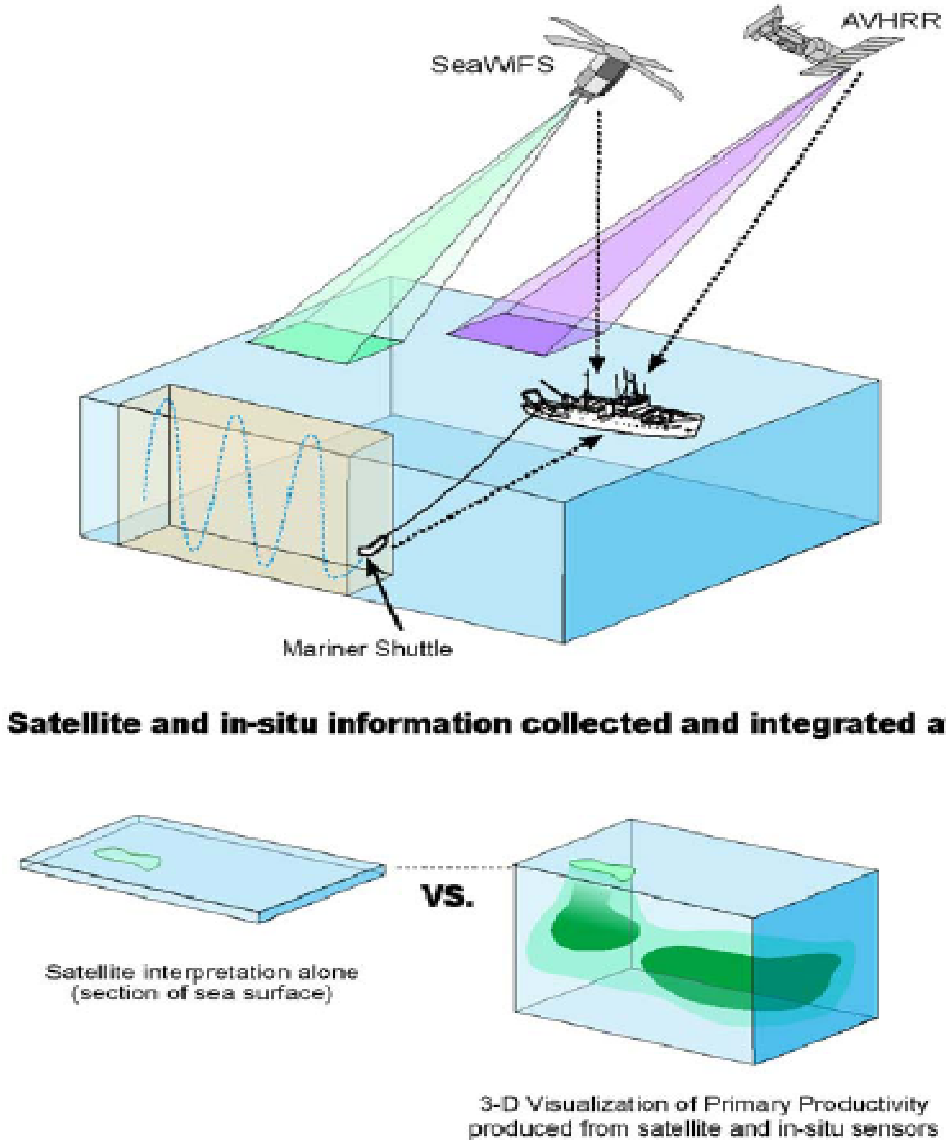

Figure 7. Schematic illustrating the electronic integration of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Chlorophyll data and AVHRR Sea Surface Temperature (SST) data with *in situ* subsurface data. *In situ* sensors add depth to the relatively shallow section of sea surface interpreted remotely from satellite sensors.

Gradient zones (fronts)*:* Oceanic fronts affect LME productivity; therefore front mapping is an important aspect of LME characterization. The first global remote sensing survey of fronts in the World Ocean LMEs was based on a unique frontal data archive assembled at the University of Rhode Island. Thermal fronts were automatically derived by front detection algorithm (Cayula and Cornillon 1992; 1995; 1996) from 12 years of twice-daily global 9-km resolution SST data to produce synoptic (instant) frontal maps and compute long-term monthly frequencies of SST fronts and their gradients.

These synoptic and long-term maps were used to distinguish major quasi-stationary fronts and derive frontal schematics comprising a provisional atlas of fronts in the World Ocean LMEs (Belkin 2009; Belkin et al. 2009). Since SST fronts are associated with chlorophyll fronts (Belkin and O'Reilly 2009) frontal paths in these schematics, once digitized, lend themselves to studies of physical-biological correlations at fronts. Satellite-derived surface thermal fronts are typically co-located with hydrographic fronts determined from subsurface data. An example of frontal schematic is given in **Figure 8:**

Figure 8. Surface thermal fronts in the Yellow Sea. Acronyms: BSF, Bohai Sea Front; JSF Jiangsu Shoal Front; KyBF, Kyunggi (Kyonggi) Bay Front; SPF, Shandong Peninsula Front; WKoBF, West Korea Bay Front. Yellow line, LME boundary. After (Belkin et al. 2009).

Sea surface temperature: The Earth's climate is warming. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007), the global mean surface air temperature increased by 0.74°C while the global mean sea surface temperature (SST) rose by 0.67°C over the last century (Trenberth et al. 2007). World Ocean mean temperature in the 0-3000 m layer increased by 0.037°C between 1955 and 1998 (Levitus et al. 2005). Global warming has already significantly affected marine ecosystems (e.g. (Behrenfeld et al. 2006; Halpern et al. 2008; Richardson and Schoeman 2004), and this impact is expected to increase in the near future owing to the current acceleration of warming (Trenberth et al. 2007). From a global perspective, marine ecosystem-based management can be significantly improved through a better understanding of regional oceanic and atmospheric circulation and physical-biological interactions in specific LMEs. To establish how global warming translates into regional patterns of climate change and how these regional changes in climate affect, data from the U.K. Meteorological Office Hadley Centre SST climatology was used to compute 50-year time-series (1957-2006) of sea surface temperature (SST) and examine SST trends in the World Oceans' 63 LMEs. Reflecting a global trend, warming in most LMEs accelerated in late 1970s-early 1980s. Of the 63 LMEs, 61 warmed and only two cooled in 1982-2006. Linear SST trends for each LME show a distinct global pattern of rapid warming in three regions: around the North Atlantic Subarctic Gyre; in the European Seas; and in the East Asian Seas (Belkin 2009; Sherman et al. 2009), (**Figure 9**).

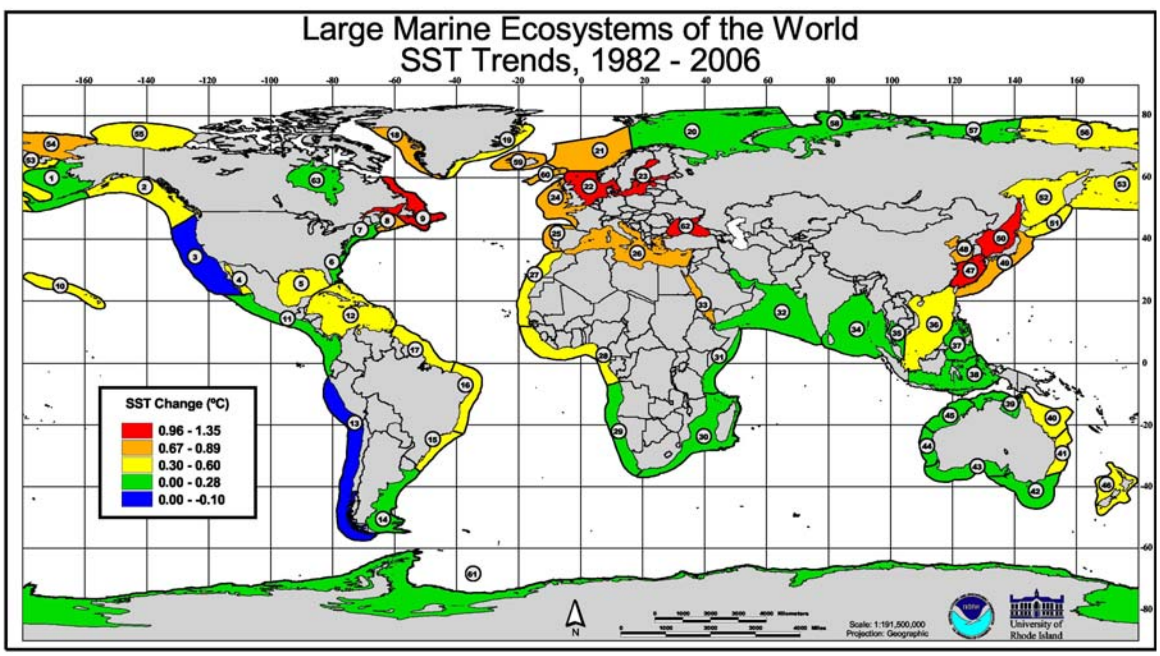

Figure 9. SST trends in the World Ocean LMEs, 1982-2006, modified after Belkin (2009)

Decadal rates of SST warming in these three regions are two-to-four times the global mean. An example of rapid warming is given in **Figure 10.**

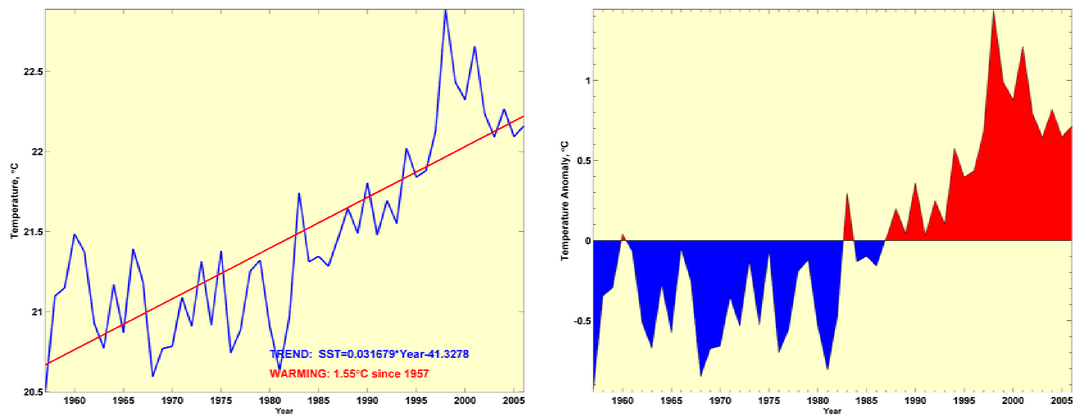

Figure 10. East China Sea LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology (after Belkin 2009).

2) Fish and Fisheries Module Indicators

Changes in biodiversity and species dominance within fish communities of LMEs have resulted from excessive exploitation, naturally occurring environmental shifts caused by climate change, and coastal pollution. Changes in biodiversity and species dominance in a fish community can move up the food web to apex predators and cascade down the food web to plankton 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 (AFSC 2006; NEFSC 2002; NEFSC 2006). Standardized sampling procedures, when employed from small calibrated trawlers, can provide important information on changes in fish species (Sherman 1993) . Fish catch provides biological samples for stock identification, stomach content analyses, age-growth relationships, fecundity, and coastal pollution monitoring for possibly associated pathological conditions, as well as data for preparing stock assessments and for clarifying and quantifying multispecies trophic relationships. The survey vessels can also be used as platforms for obtaining water, sediment, and benthic samples for monitoring harmful algal blooms, diseases, anoxia, and changes in benthic communities. A list of fish and fisheries surveys for demersal and pelagic indicators is given in **Figure 11.**

The Northeast Fishery Science Center (NEFSC) of NOAA has the longest continuous time-series of US data and information on ecosystem changing states. It is in the US Northeast Continental Shelf Large Marine Ecosystem, extending over 260,000 km^2 from the Gulf of Maine southward to Cape Hatteras, NC, where NEFSC scientists, economists, and other marine specialists have been applying ecosystem-based methods for assessing living marine resources and their environments—methods that have served as the principal prototype for the GEF-LME projects. Indicators for fish and fisheries model are based on the results of trawl surveys for demersal species and acoustic surveys for pelagic species (**Figure 12**).

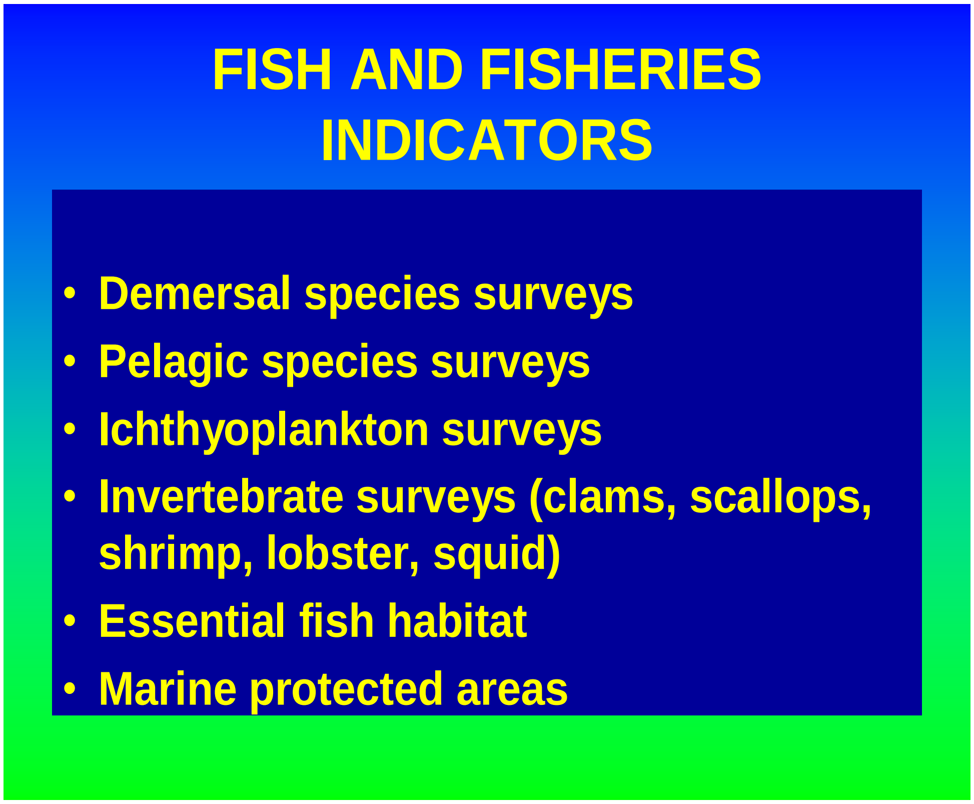

Figure 11. Indicators for the Fish and Fisheries Module.

Sea Around Us Project Fisheries Indicators: Daniel Pauly and his colleagues from the Sea Around Us Project at the University of British Columbia have provided fisheries indicators for 63 LMEs (Sherman and Hempel 2008), including fisheries biomass yields (catch) and dollar value, stock exploitation levels, the amount of primary productivity required to support the catch, Ecopath/Ecosim modeling results depicting mean-annual trophic levels of fish catches and fisheries in balance indices, and levels of exploitation: Graphic time-series examples of these indicators for the fish and fisheries of the Guinea Current LME are given in **Figures 13** through **17** (Sea Around Us Project (SAUP) (Sherman and Hempel 2008).

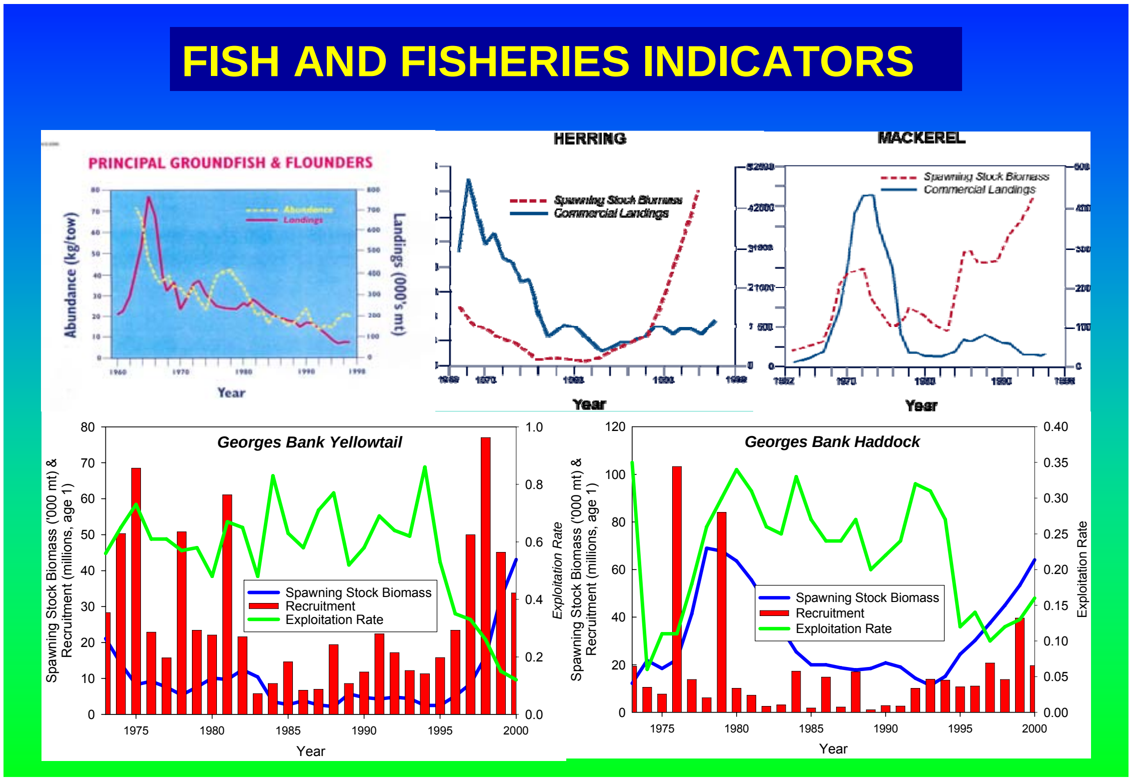

Figure 12. Fish and Fisheries indicators in the Northeast US Continental Shelf LME. The figure shows recovering trends for herring and mackerel and fluctuations in catch for flounders, Georges Bank yellowtail, and Georges Bank haddock in the Northeast US Continental Shelf LME. The initiation of recovery of haddock and yellowtail flounder is linked to the implementation since the 1995 of the Magnuson-Stevens Fishery Conservation and Management Act originally passed in 1976 and most recently amended in 2006, mandating the rebuilding of depleted fish stocks.

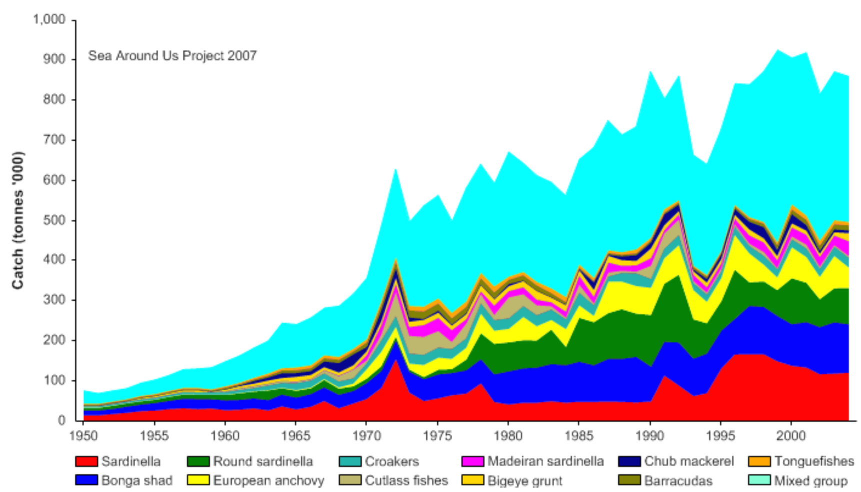

Figure 13. Total reported landings in the Guinea Current LME by species (Sea Around Us 2007).

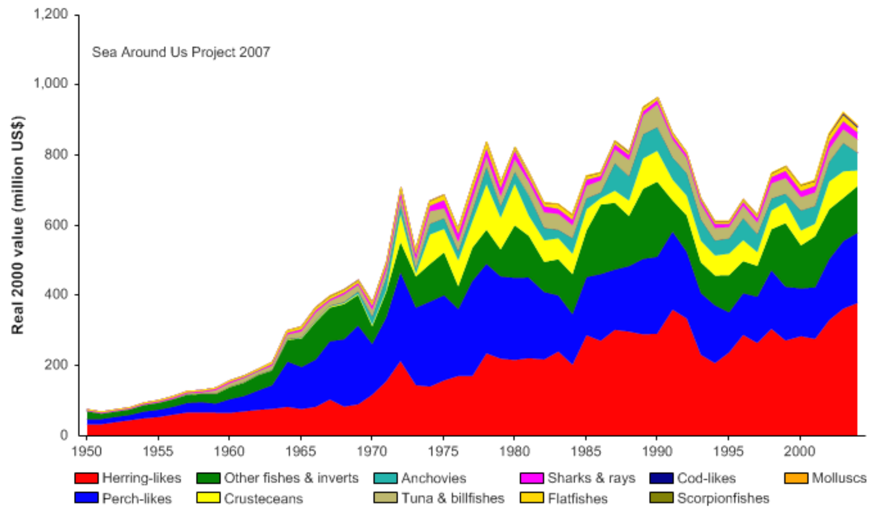

Figure 14. Value of reported landings in the Guinea Current LME by commercial groups (Sea Around Us 2007).

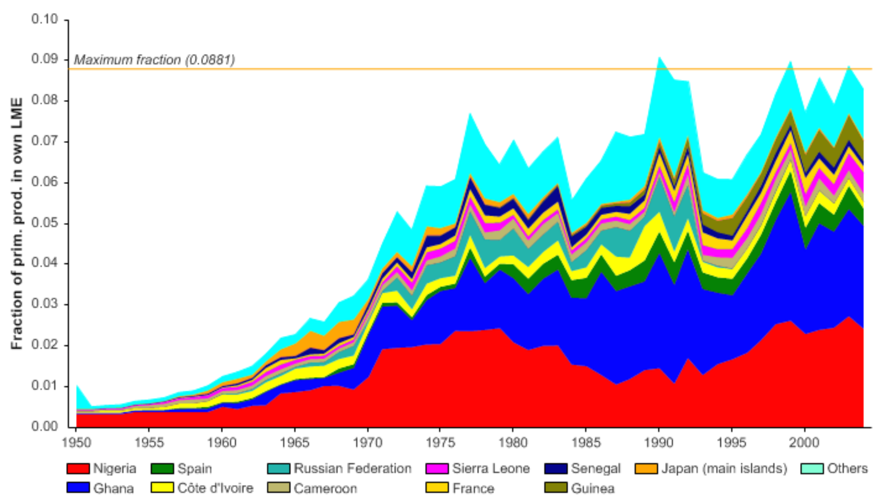

Figure 15. Primary production required to support reported landings by different countries (i.e., ecological footprint) as fraction of the observed primary production in the Guinea Current LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

Since the mid 1970s, the mean trophic level of the reported landings from the Guinea Current LME (i.e., MTI; Pauly & Watson 2005) has declined (**Figure 16**, top), an indication of a 'fishing down' of the local food webs (Pauly *et al*. 1998). The FiB index, on the other hand, has remained stable (**Figure 16**, bottom), suggesting that the increase in the reported landings over this period has compensated for the decline in the MTI (Pauly & Watson 2005). To determine the level of exploitation, stock catch status plots are calculated for both the number of stocks, and catch by stock. Results are plotted for percentages of developing, fully exploited, over-exploited, and collapsed condition of the fish stocks (**Figure 17**).

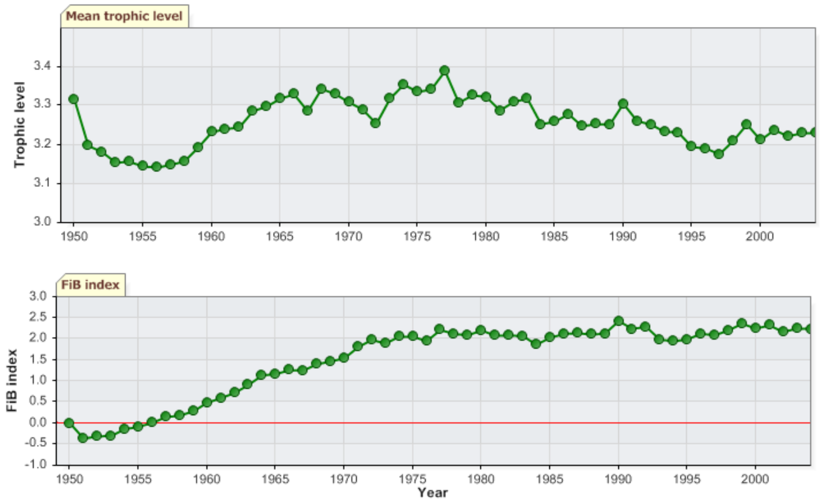

Figure 16. Trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Guinea Current LME (Sea Around Us 2007).

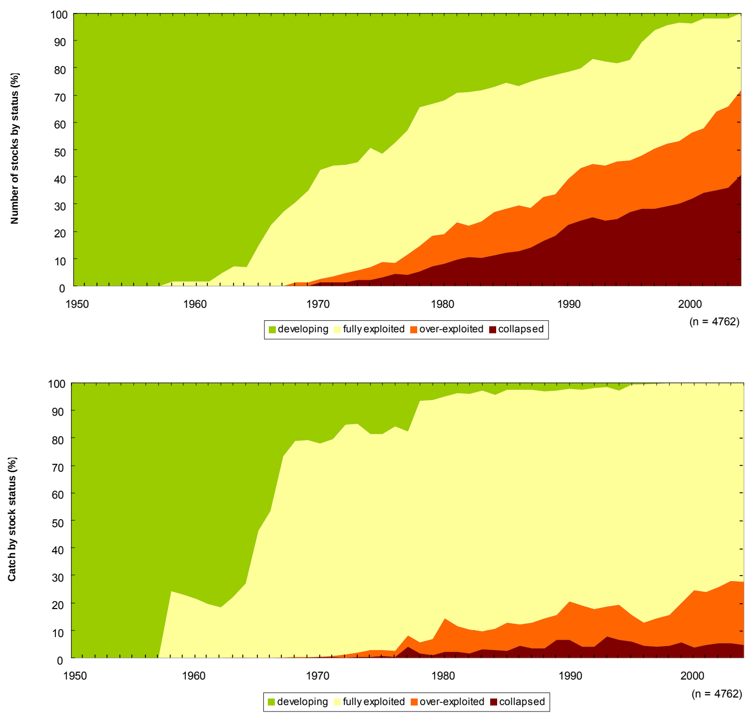

Figure 17. Stock-Catch Status Plots for the Guinea Current LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded. Methodology is given in (Pauly et al. 2008).

3) Pollution and Ecosystem Health Module Indicators

In several LMEs, pollution and eutrophication have been important driving forces of change in biomass yields. Assessment of the changing status of pollution and health in an entire LME requires multiple-state comparisons of ecosystem resilience and stability. To be healthy and sustainable, an ecosystem must maintain its metabolic activity level and its internal structure and organization, and it must resist external stress over time and space scales relevant to the ecosystem (Costanza 1992).

The pollution and ecosystem health module measures pollution effects on the ecosystem through the monitoring strategy of the US EPA; its pathobiological examination of fish and fish tissue; and estuarine and nearshore monitoring of contaminants and contaminant effects in the water column, 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 contaminant-impaired growth. 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 module. The US Environmental Protection Agency (EPA) has developed a suite of five coastal condition indices: water quality, sediment quality, benthic communities, coastal habitat, and fish tissue contaminants, as part of an ongoing collaborative effort with NOAA, the US Fish and Wildlife Service, the US Geological Survey, and other agencies representing states and tribes. EPA's five pollution and ecosystem health indicators for LMEs and stop-light assessments of the indicators are shown in **Figure 18** (USEPA 2004).

The 2004 *National Coastal Condition Report II* (USEPA 2004) includes results from the EPA's analyses of coastal condition indicators and NOAA's fish stock assessments by LMEs aligned with the EPA's national coastal assessment regions. The EPA and NOAA are jointly introducing this approach to the international GEF-supported LME projects, along with a methodology for nutrient assessment. The indicators of pollution and ecosystem health, based on the NOAA and EPA model used for monitoring changes in condition of US coastal waters, include contaminant effects, trophic transfer of contaminants, frequency and effect of harmful algal blooms, emergent diseases, and multiple marine ecological disturbances (MMEDs) (Sherman 2000). The number and frequency of MMEDs in an LME can be used as indicators of a decline in ecosystem health and loss of essential services. Indicators for the Pollution and Ecosystem Health Module also include conditions of habitats such as coral, seagrass and mangroves. Increases in the sizes of oxygen deprived "dead zones" have been documented in coastal areas world wide and serve as additional indicators of declines in large marine ecosystem health.

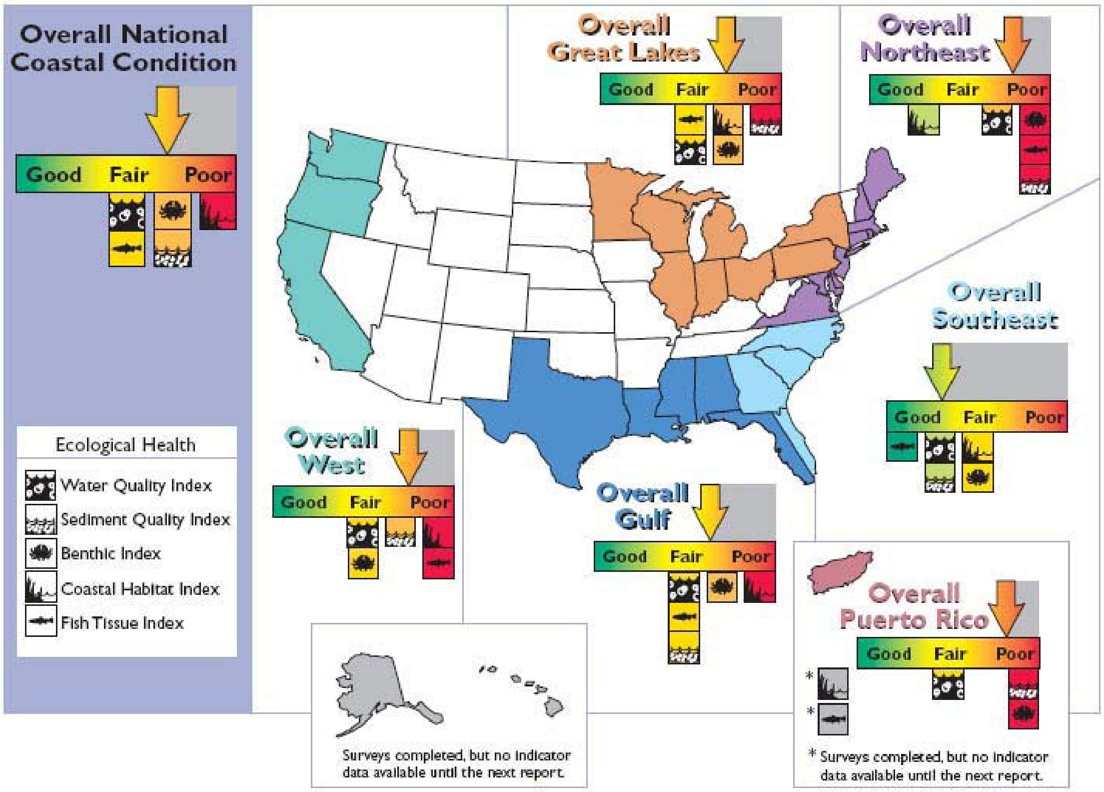

Figure 18. The Environmental Protection Agency's (EPA) five pollution and ecosystem health indicators for coastal areas in the United States, and stop-light assessments of the indicators (USEPA 2004).

In several LMEs, excessive nutrient loadings of coastal waters have been related to harmful 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). Excessive nitrogen loadings and oxygen depletion events are causing significant mortalities among marine resource species. In European LMEs, recent nitrogen flux increases have been recorded ranging from 3-fold in Spain to 4-fold in the Baltic Sea to 11-fold in the Rhine River basin draining to the North Sea LME. Howarth et al. (2000) and Duda and El-Ashry (2000) have described the origin of this disruption of the nitrogen cycle from the Green Revolution of the 1970s, as the world community converted wetlands to agriculture, utilized more chemical inputs, and expanded irrigation to feed the world. For the Gulf of Mexico LME, much of the large increase in nitrogen export is from agricultural inputs, both from the increased delivery of fertilizer nitrogen as wetlands were converted to agriculture and from concentrations of livestock. Industrialized livestock production during the last two decades increased the flux, the eutrophication, and the oxygen depletion even more, as reported by the National Research Council (NRC 2000). Significant contributors to eutrophication are sewage from drainages of large cities and atmospheric deposition from automobiles and agricultural activities, with the amounts depending on proximity of sources.

The Global Environment Facility (GEF) is frequently asked by countries to help support the agreed-upon incremental cost of actions to reduce such nitrogen flux. Actions range from assisting in: (1) development of joint institutions for ecosystem-based approaches for adaptive management; (2) on-the-ground implementation of nitrogen abatement measures in the agricultural, industrial, and municipal sectors; and (3) breaching of floodplain dikes so that wetlands recently converted to agriculture may be reconverted to promote nitrogen assimilation. The excessive levels of nitrogen contributing to coastal eutrophication constitute an emerging global environment problem that is cross-sectoral in nature. Excessive nitrogen loadings and oxygen depletion events causing significant mortalities among marine resource species have been identified as a major coastal problem in several LMEs that are receiving GEF assistance, including in the Baltic Sea, Black Sea, Mediterranean Sea, Yellow Sea, South China Sea, Bay of Bengal, Gulf of Mexico, and Patagonian Shelf LMEs.

Preliminary global estimates of nitrogen export from freshwater basins to coastal waters have been determined by Seitzinger and Kroeze (1998). A GEF/LME global project, “Promoting Ecosystem-based Approaches to Fisheries Conservation and Large Marine Ecosystems”, has filled gaps relating to LME nitrogen loadings and provided forecasts for 64 LMEs (Seitzinger et al. 2008). The project has used GIS-based models relating land use and human activities in watersheds to nutrient transport by rivers to coastal systems (**Figure 19**). The project specifically used an innovative Nutrient Export from Watersheds Model (NEWS) to predict inorganic nitrogen (N) export by rivers to the coast as a function of watershed N inputs (point and diffuse sources), hydrology, and other factors. The model was used to examine dissolved inorganic nitrogen (DIN) export into all 64 LMEs. The aim is to optimize use of land for food and energy production while at the same time conserving coastal habitats, and to understand the links between land-based activities and nutrient inputs to coastal systems. Nutrient sources, sinks, and controlling factors in watersheds are explicit components of the model, and the effect of a range of scenarios on DIN river export can be explored.

A Watershed Perspective: Rivers are a central link in the chain of nutrient transfer from watersheds to coastal systems. Nutrient inputs to watersheds include natural (biological N_2-fixation, weathering of rock releasing phosphate) as well as many anthropogenic sources. At the global scale, anthropogenic nitrogen inputs to watersheds are now greater than natural inputs (Galloway et al. 2004). Anthropogenic nutrient inputs are primarily related to food and energy production to support the over 6 billion people on Earth with major sources including fertilizer, livestock production, sewage, and atmospheric nitrate deposition resulting from NOx emissions from fossil fuel combustion. The single largest change in the nitrogen cycle comes from increased reliance on synthetic inorganic fertilizer, invented and widely used in the last century. Over the next 50 years, human population, agricultural production, and industrialization are predicted to increase especially rapidly in many developing regions of the world, leading to increased nutrient (nitrogen and phosphorus) inputs to the coastal zone (Kroeze and Seitzinger 1998).

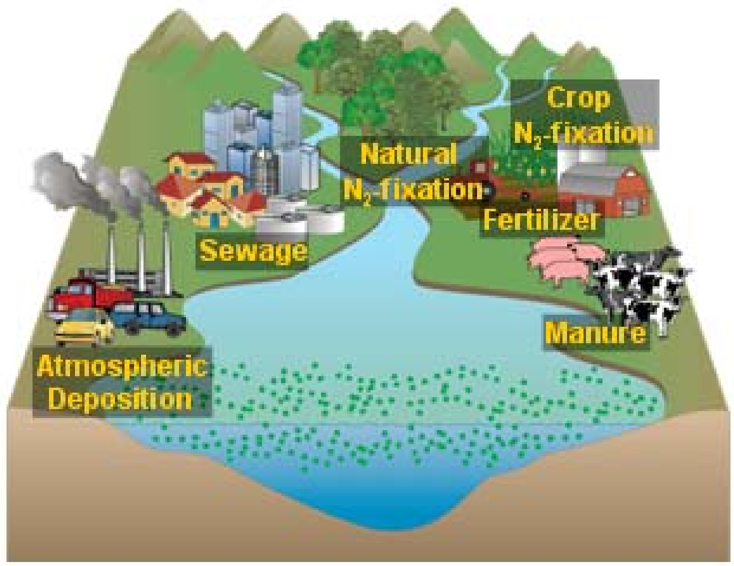

Figure 19. Watershed schematic of nitrogen inputs and transport to coastal systems. Symbols for diagram courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science. (Kroeze and Seitzinger 1998).

Uneven spatial distribution of human population, agriculture, and energy production leads to spatial differences in the anthropogenic alterations of nutrient inputs to coastal ecosystems (Green et al. 2004; Howarth et al. 1996; Seitzinger et al. 2005; Seitzinger and Kroeze 1998). A nutrient export model has been developed to provide a comprehensive and quantitative global view of nutrient sources, controlling factors and nutrient loading to coastal systems around the world under current conditions, as well as to be able to look at past conditions and plausible future scenarios.

***A Global Watershed Nutrient Export Model (NEWS)*:** In order to provide regional and global perspectives on changing nutrient transport to coastal systems throughout the world, an international workgroup (Global NEWS – Nutrient Export from Water Sheds; www.marine.rutgers.edu /globalnews) **(Figure 20)** has developed a spatially explicit global watershed model that relates human activities and natural processes in watersheds to nutrient inputs to coastal systems throughout the world (Beusen et al. 2005; Dumont et al. 2005; Harrison et al. 2005a; 2005b; Seitzinger et al. 2005). Global NEWS is an interdisciplinary workgroup of UNESCO's Intergovernmental Oceanographic Commission (IOC) focused on understanding the relationship between human activity and coastal nutrient enrichment. In addition to current predictions, the NEWS model is also being used to hindcast and forecast changes in nutrient, carbon and water inputs to coastal systems under a range of scenarios.

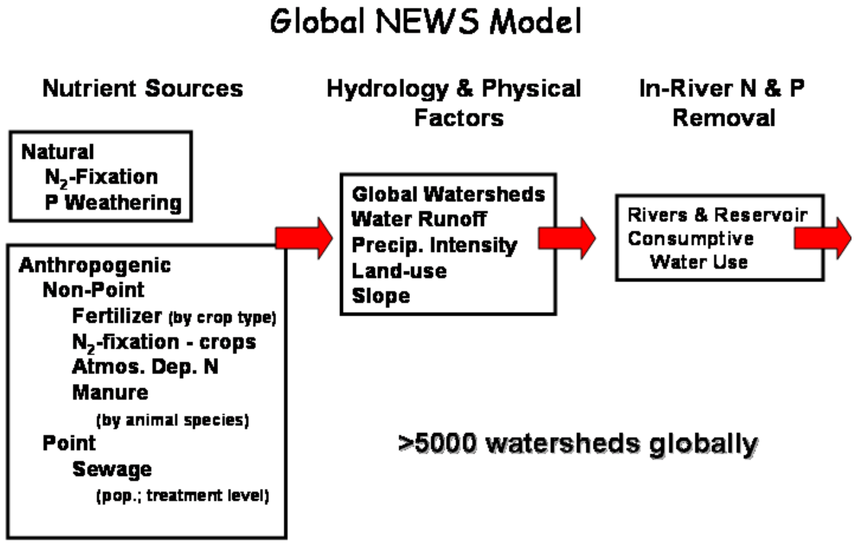

Figure 20. Schematic of some of the major inputs and controlling factors in the Global NEWS watershed river export model (Seitzinger et al. 2008).

NEWS Model Output: The NEWS model has provided the first spatially distributed global view of N, P and C export by world rivers to coastal systems. At the global scale rivers currently deliver about 65 Tg N and 11 Tg P per year according to NEWS model predictions (Tg = tera gram = 10^{12} g). For nitrogen, DIN and particulate N (PN) each account for approximately 40% of the total N input, with DON comprising about 20%. This contrasts with P, where particulate P (PP) accounts for almost 90% of total P inputs. However, while DIP and dissolved organic P (DOP) each contribute only about 10% of total P, both of these forms are very bioreactive and thus may have a disproportionate impact relative to PP on coastal systems (**Figure 21**).

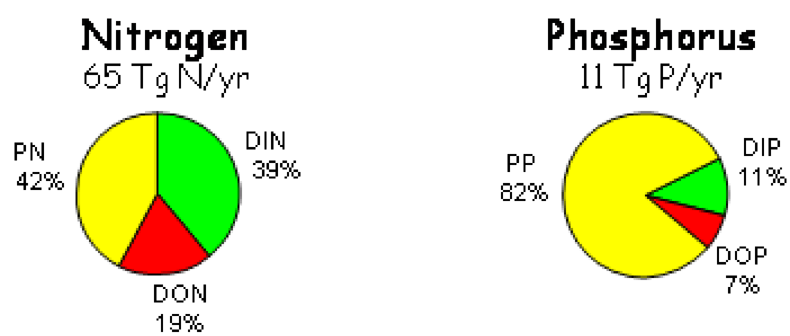

Figure 21. Global N and P river export to coastal systems by nutrient form based on the NEWS model (Dumont et al. 2005; Harrison et al. 2005a).

There is large spatial variation around the world in river nutrient export, including different patterns for the different nutrient forms (DIN, DON and PN) (Seitzinger and Harrison 2008) (**Figure 22**).

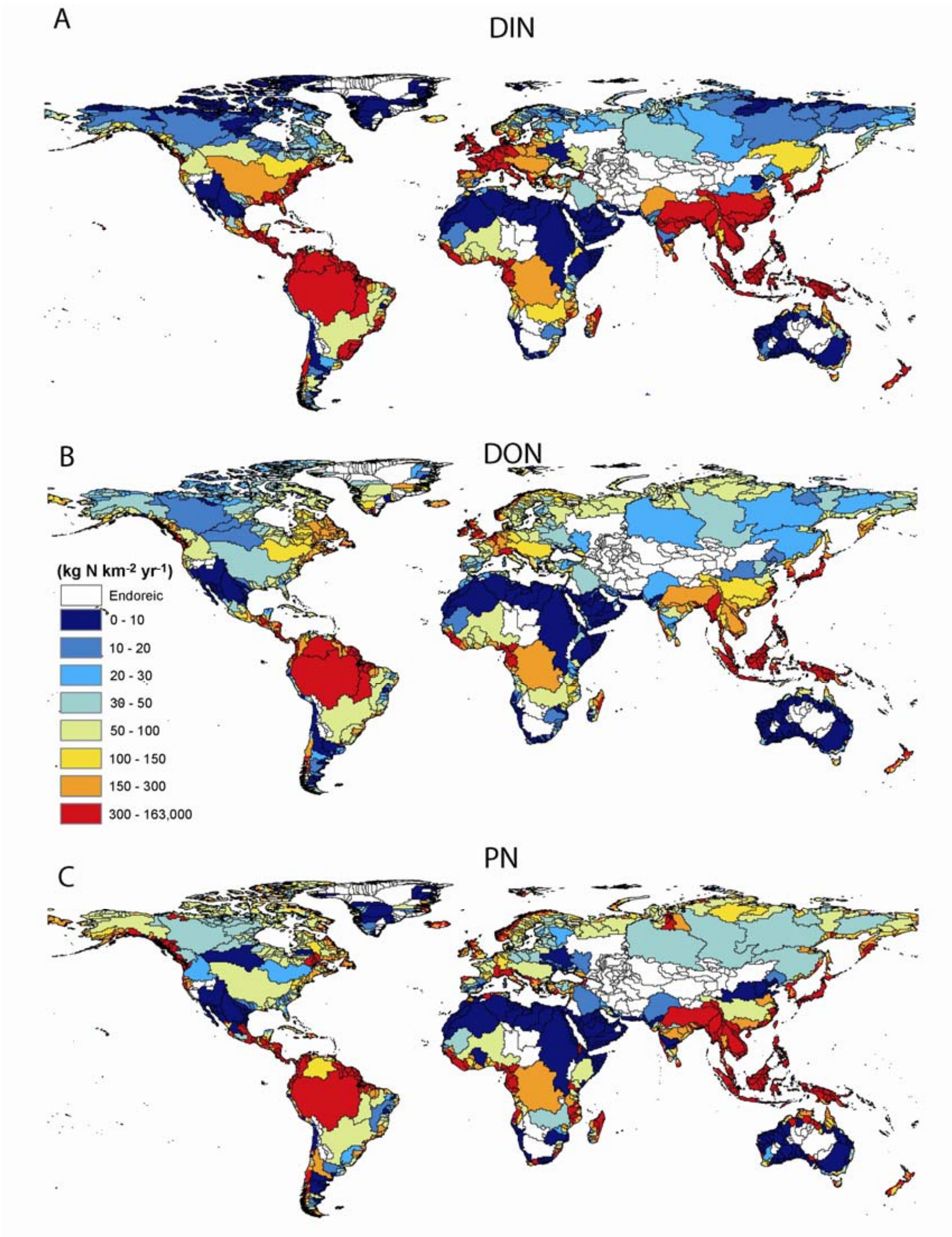

Figure 22. NEWS-model-predicted A) DIN, B) DON, and C) PN yield (kg N km-2 yr-1) to LMEs from basins globally. Figure from Seitzinger and Harrison (2008) based on model output replotted from Harrison et al. 2005b, Dumont et al. 2005, and Beusen et al. 2005.

Using N yield (kg N per km^2 watershed per year that is exported to the river mouth), DIN yield shows considerable variation at regional and continental scales, as well as among adjacent watersheds.

Land-based pollution of coastal waters in LMEs can have sources in multiple countries often located upstream at a considerable distance from the coastal zone. The release of nutrients into rivers can cross national borders and create environmental, social and economic impacts along the way - until reaching the coastal zone, which may be in a different country. Thus an LME transboundary approach is essential for identifying watershed nutrient sources and coastal nutrient loading to support policy development and implementation in LMEs that will reduce current and future coastal eutrophication.

Bridging the gap between land-based activities and LME waters: Few estimates of nutrient loading have been made in individual LMEs, and only in the Baltic Sea LME has source apportionment been investigated (ECOPS et al. 1995; HELCOM 2001). As a first step in bridging the gap between land-based activities and LME waters, the relative magnitude and distribution of DIN loading from watersheds to LMEs globally was examined. The assessment was focused on N because it is often the most limiting nutrient in coastal waters and thus important in controlling coastal eutrophication. DIN is often the most abundant and bioavailable form of nitrogen, and therefore contributes significantly to coastal eutrophication.

Watershed DIN export to rivers predicted by the NEWS model described above was compiled for 63 LMEs (**Figure 23**). The Antarctic LME data base was excluded as information was limited. Total DIN load and yield to each LME was aggregated from all watersheds with coastlines along that LME for point sources and only those watersheds with discharge to that LME for diffuse sources.

DIN loading to each LME was attributed to diffuse and point sources including natural biological N_2-fixation, agricultural biological N_2-fixation, fertilizer, manure, atmospheric deposition and sewage. Dominant sources of DIN to LMEs were also identified. Agriculture is a major source of the anthropogenic DIN export to LMEs (Seitzinger and Lee 2008; Seitzinger et al. 2008). In 91% of the LMEs with agriculture occurring in their related watersheds, over half their anthropogenic export is due to agricultural sources such as agricultural biological fixation, manure, and fertilizer. While the change in model efficiency after removal of the water withdrawal term was low, at a local scale anthropogenic river water removal can have an important impact on DIN export since DIN retention increases as river water is removed (Dumont et al. 2005). The identification of dominant sources of DIN and their relative contribution at the individual LME level is essential for developing effective nutrient management strategies on an ecosystem level.

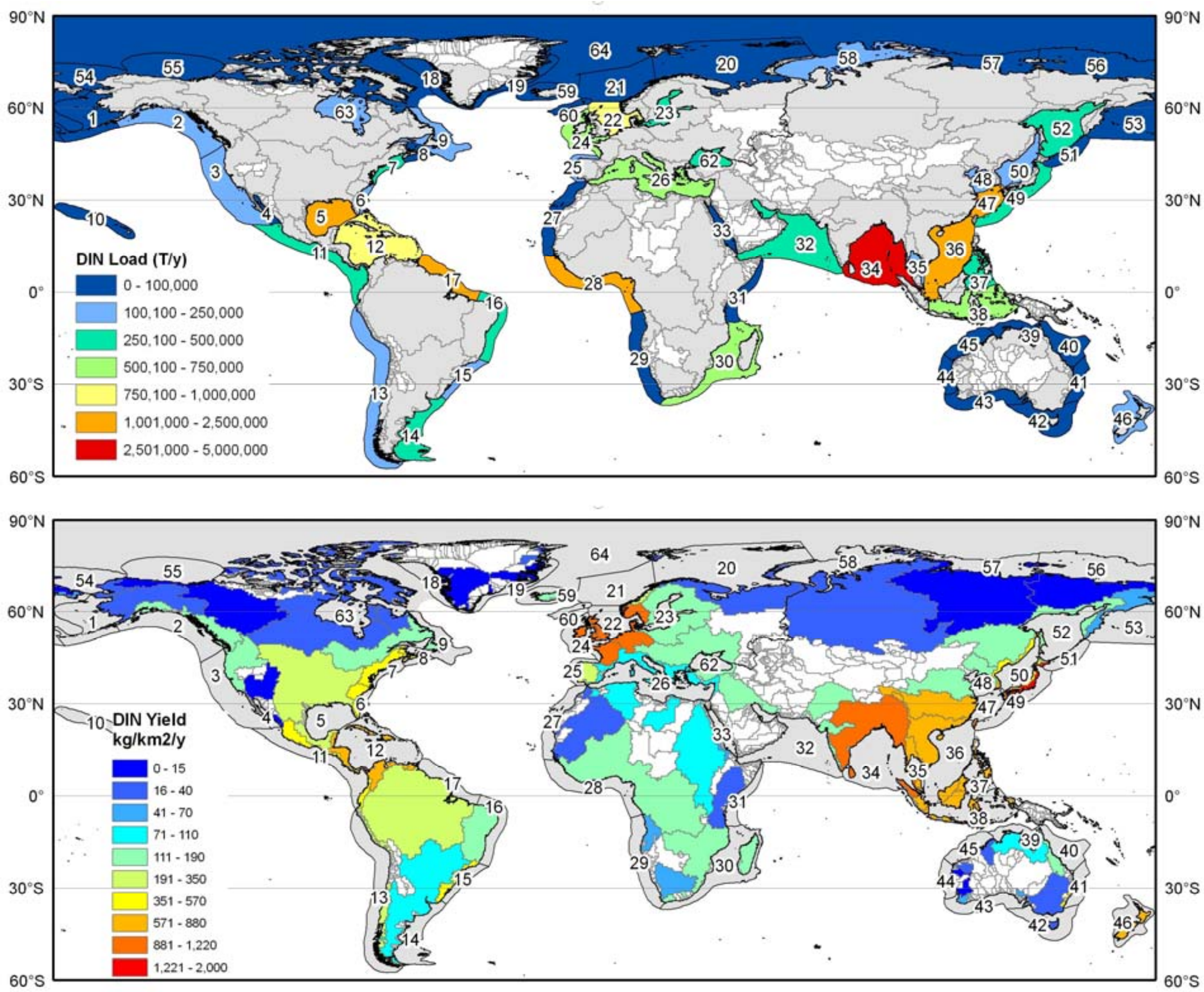

Figure 23. DIN load (top) and yield (bottom) from land-based sources to LMEs predicted by the NEWS DIN model. Watersheds discharging to LMEs are grey; watersheds with zero coastal discharge are white. See Figure 1 this volume for LME identification. (Seitzinger et al. 2008).

Implications of Future Conditions in LME Watersheds: At the global scale, river nitrogen export to coastal systems is estimated to have approximately doubled between 1860 and 1990, due to anthropogenic activities on land (Galloway et al. 2004) Over the next 50 years the human population is predicted to increase markedly in certain world regions, notably southern and eastern Asia, South America, and Africa (UN 1996). Growing food to feed the expanding world population will require increased use of nitrogen and phosphorus fertilizers (Alcamo et al. 1994; Bouwman 1997; Bouwman et al. 1995) Increased industrialization, with the associated combustion of fossil fuels and NOx production, is predicted to increase atmospheric deposition of N (Dentener et al. 2006; IPCC 2001). **Thus, unless substantial technological innovations and management changes are implemented, increasing food production and industrialization will undoubtedly lead to increased export of N to coastal**

ecosystems (Galloway et al. 2004) with resultant water quality degradation. Based on a business-as-usual (BAU) scenario, inorganic N export to coastal systems is predicted to increase 3-fold by the year 2050 (relative to 1990) from Africa and South America (Kroeze and Seitzinger 1998; Seitzinger et al. 2002). Substantial increases are predicted for Europe (primarily eastern Europe) and North America. Alarmingly large absolute increases are predicted for eastern and southern Asia; almost half of the total global increased N export is predicted for those regions alone.

The scenario in **Figure 24** for 2050 was based on projections made from early 1990 trajectories and using a relatively simple DIN model (Kroeze and Seitzinger 1998). The NEWS model has more parameters and more detail behind the inputs (e.g., fertilizer use by crop type, level of sewage treatment, etc.), thus facilitating more advanced scenario development and analyses. For example, it is now possible to explore the effects of a range of development strategies, effects of climate change, production of biofuels, increase in dams for hydropower, and consumptive water use (irrigation) on coastal nutrient loading.

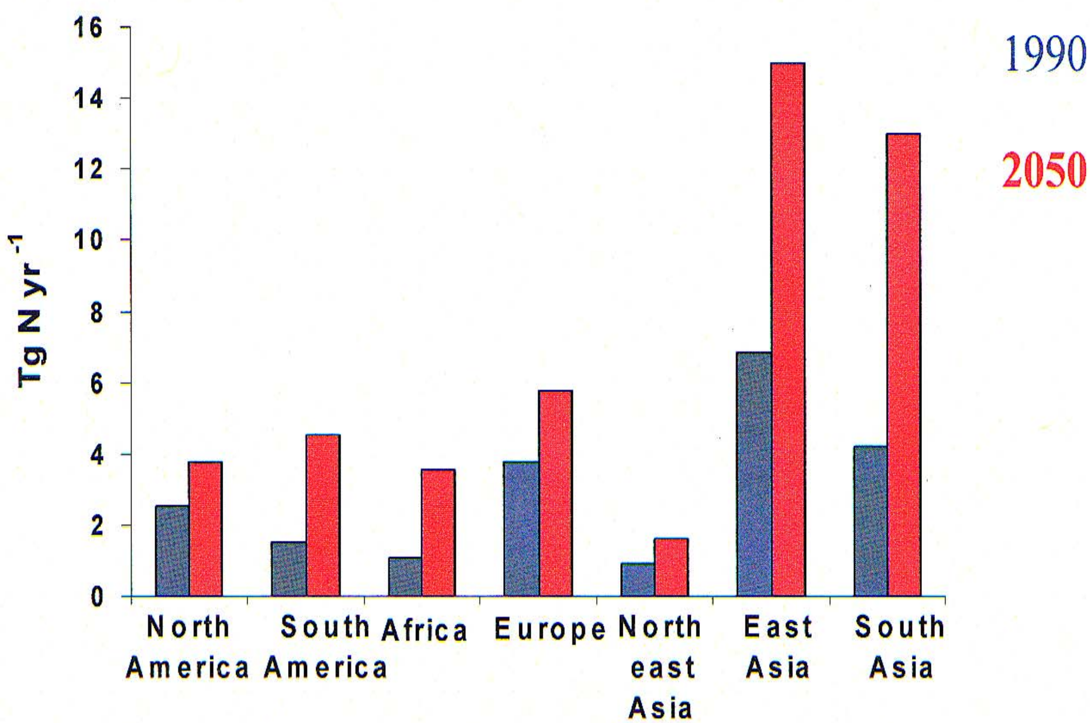

Figure 24. Predicted DIN export to coastal systems in 1990 (blue) and 2050 (red) under a business-as-usual (BAU) scenario. Modified from Kroeze and Seitzinger (1998).

4) Socioeconomics Module Indicators

The economic value of an LME is equivalent to the net present value of goods and services that flow from uses and non-uses of its resources and environment. Costanza et al. (1997) calculate that the coastal waters encompassing LMEs annually contribute US $12.6 trillion to the global economy. Although this estimate does not reflect the benefits or costs of marginal changes in marine ecosystem goods and services, it highlights the critical importance of LMEs to the economies of the world.

The socioeconomic module emphasizes the practical application of scientific findings to managing LMEs and the explicit integration of social and economic indicators and analyses with all other scientific assessments to assure that prospective management measures are efficient. 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 should be closely integrated with science. This component of the LME approach to marine resources management has recently been described as the human dimensions of LMEs (Hennessey and Sutinen 2005). A framework has been developed by the Department of Environmental and Natural Resource Economics at the University of Rhode Island for monitoring and assessment of the human dimension of LMEs and for incorporating socioeconomic considerations into an adaptive management approach for LMEs (Sutinen 2000).

An initial step toward the development of a global overview of the socioeconomic aspect of LMEs was made by the Marine Policy Center at the Woods Hole Oceanographic Institution (Hoagland and Jin 2006). These researchers used indices of socioeconomic activity based on data from several marine economic sectors, including fish landings, aquaculture production, ship building, cargo traffic, merchant fleet size, oil production, oil rig counts, and tourism. The data were examined for the years between 2002 and 2004, to compare marine industry activity with indices for socioeconomic, fishing and aquaculture, tourism and shipping and oil activities. A summary ranking of LMEs by area adjusted marine industry activity (MIA) is shown in **Figure 25**.

From a comparison of ranked socioeconomic and marine industry activity, indices for LMEs (**Table 2)**, countries bordering the Yellow Sea, East China Sea, East Bering Sea and Insular Pacific-Hawaiian are the most economically active LMEs (>40.0 MIA) in contrast to the low marine industry activity level of the Agulhas Current, Guinea Current and Somali Current LMEs (<1.0 MIA). High levels of marine industry activity often are associated with significant levels of environmental degradation.

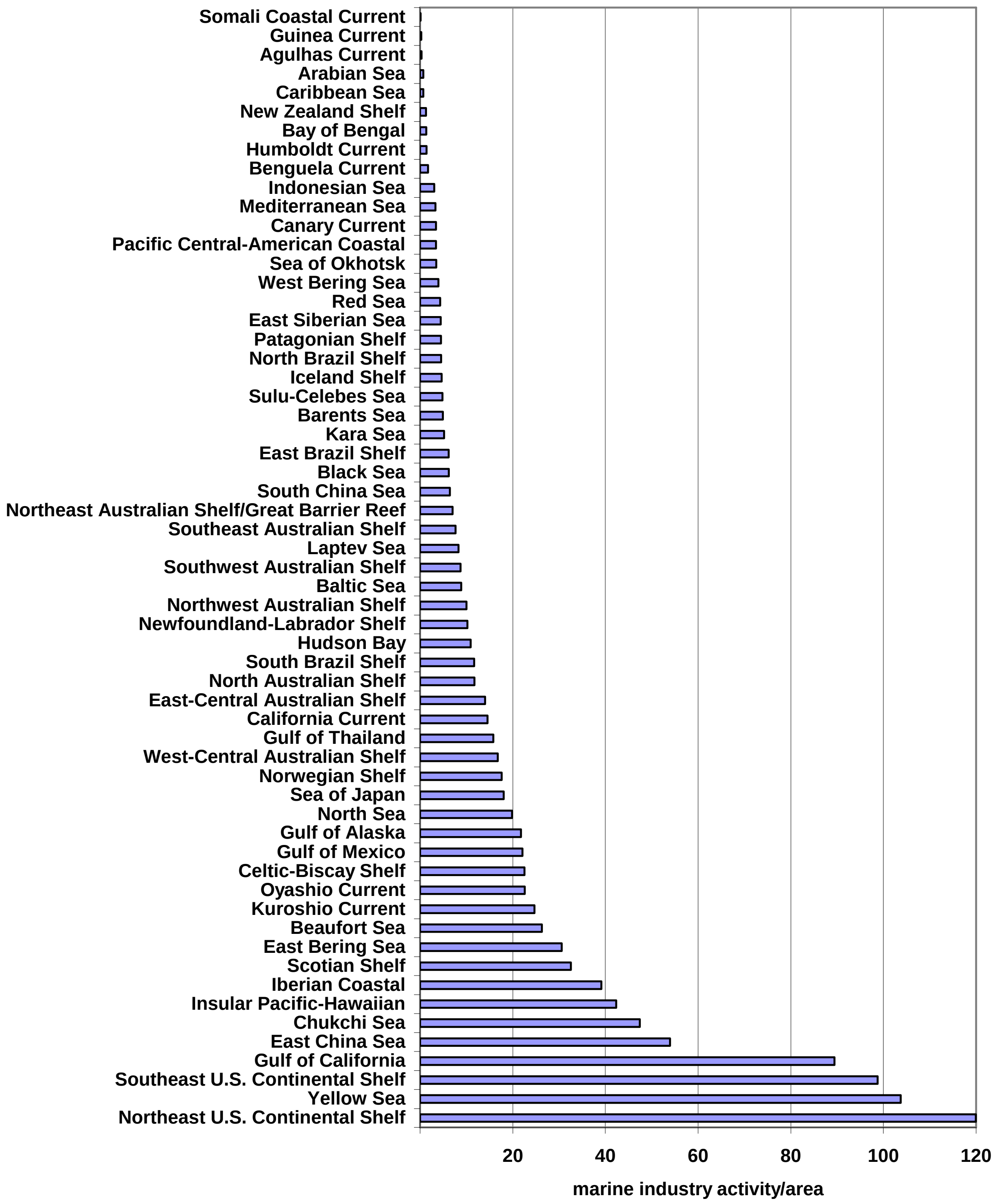

Figure 25. Ranking of LMEs by Area-adjusted Marine Industry Activity (Hoagland and Jin 2006)

Table 2. Socioeconomic and Marine Industry Activity Indexes for LMEs, ranked in order of Marine Activity Index (Hoagland and Jin 2006)

LME	LME#	Socioeconomic Index	Fishery & Aquaculture Index	Tourism Index	Ship & Oil Index*	Marine Industry Activity Index
Yellow Sea	48	73.442	71.837	44.410	36.865	45.369
East China Sea	47	84.076	51.891	30.773	42.147	41.821
East Bering Sea	1	93.900	17.438	57.893	43.969	41.448
Insular Pacific-Hawaiian	10	93.900	17.438	57.893	43.969	41.448
Northeast U.S. Continental Shelf	7	93.963	15.456	52.758	37.861	36.360
Gulf of Mexico	5	89.071	13.021	46.271	36.611	33.825
Kuroshio Current	49	93.628	18.324	6.705	45.846	32.514
California Current	3	88.015	12.055	43.729	35.002	32.158
Gulf of Alaska	2	94.019	13.716	48.248	32.496	31.891
Southeast U.S. Continental Shelf	6	90.830	13.131	44.030	33.082	31.282
Chukchi Sea	54	87.433	14.683	34.858	27.524	26.422
South China Sea	36	73.777	34.521	22.269	14.902	20.299
Beaufort Sea	55	94.163	9.198	36.539	18.570	20.289
Gulf of California	4	80.200	4.907	24.923	23.096	19.823
Norwegian Shelf	21	95.600	10.703	3.662	27.969	19.654
Sea of Japan	50	83.263	13.262	3.529	23.976	17.744
Celtic-Biscay Shelf	24	92.204	2.482	38.841	14.639	17.048
North Sea	22	94.021	5.275	14.384	16.405	13.775
Oyashio Current	51	83.278	13.031	2.138	14.904	11.976
Iberian Coastal	25	91.188	2.482	47.324	3.155	11.854
Scotian Shelf	8	94.300	4.880	25.351	5.262	9.204
Hudson Bay	63	94.300	4.880	25.351	5.262	9.204
LME	LME#	Socioeconomic Index	Fishery & Aquaculture Index	Tourism Index	Ship & Oil Index*	Marine Industry Activity Index
Newfoundland-Labrador Shelf	9	93.668	4.848	25.182	5.227	9.142
North Australian Shelf	39	94.600	0.836	6.587	12.727	9.121
East-Central Australian Shelf	41	94.600	0.836	6.587	12.727	9.121
Southeast Australian Shelf	42	94.600	0.836	6.587	12.727	9.121
Southwest Australian Shelf	43	94.600	0.836	6.587	12.727	9.121
West-Central Australian Shelf	44	94.600	0.836	6.587	12.727	9.121
Northwest Australian Shelf	45	94.600	0.836	6.587	12.727	9.121
Northeast Australian Shelf/Great Barrier Reef	40	94.006	0.833	6.491	12.540	8.989
Mediterranean Sea	26	83.262	1.087	27.192	4.595	8.413
Barents Sea	20	83.939	10.839	1.288	9.972	8.409
West Bering Sea	53	80.956	11.553	6.199	7.251	7.901
Indonesian Sea	38	69.200	16.159	6.686	3.872	6.892
Pacific Central-American Coastal	11	77.304	2.431	8.856	7.634	6.838
East Brazil Shelf	16	77.500	2.257	4.676	8.716	6.616
South Brazil Shelf	15	77.525	2.249	4.662	8.679	6.589
Gulf of Thailand	35	73.826	7.309	13.395	3.268	6.102
Sea of Okhotsk	52	80.125	11.245	0.675	5.071	5.426
Patagonian Shelf	14	86.846	2.763	8.225	5.085	5.249
Bay of Bengal	34	63.400	7.675	4.571	4.088	4.902
Sulu-Celebes Sea	37	74.778	10.078	4.420	3.212	4.827
North Brazil Shelf	17	77.055	1.772	3.364	6.284	4.798
East Siberian Sea	56	79.500	10.891	0.385	3.122	4.128
Laptev Sea	57	79.500	10.891	0.385	3.122	4.128
Kara Sea	58	79.500	10.891	0.385	3.122	4.128
Canary Current	27	61.160	2.365	14.278	0.806	3.812
Humboldt Current	13	83.015	15.241	1.721	0.178	3.499

LME	LME#	Socioeconomic Index	Fishery & Aquaculture Index	Tourism Index	Ship & Oil Index*	Marine Industry Activity Index
Baltic Sea	23	90.324	2.120	8.086	2.378	3.468
Black Sea	62	77.323	2.859	7.941	1.176	2.865
Arabian Sea	32	62.635	2.895	2.300	2.766	2.698
Benguela Current	29	53.103	1.805	2.127	2.791	2.461
Caribbean Sea	12	73.177	1.010	3.603	2.197	2.241
Red Sea	33	62.564	0.268	5.583	1.381	1.999
Iceland Shelf	59	94.100	6.865	0.417	0.029	1.474
New Zealand Shelf	46	92.600	2.092	2.876	0.403	1.235
Agulhas Current	30	47.616	0.878	1.813	0.604	0.900
Guinea Current	28	47.619	0.350	0.294	0.718	0.560
Somali Coastal Current	31	34.710	0.098	0.357	0.025	0.106

* Including shipbuilding, shipping, and offshore oil.

At the LME scale, Hoagland and Jin (2006) examined economic sector activity for the Yellow Sea LME. The four sectors examined included (1) socioeconomic activity, (2) shipping and offshore oil, (3) fisheries and aquaculture, and (4) tourism. The calculated index values for the three industry sectors were greater than the world average (**Figure 26**).

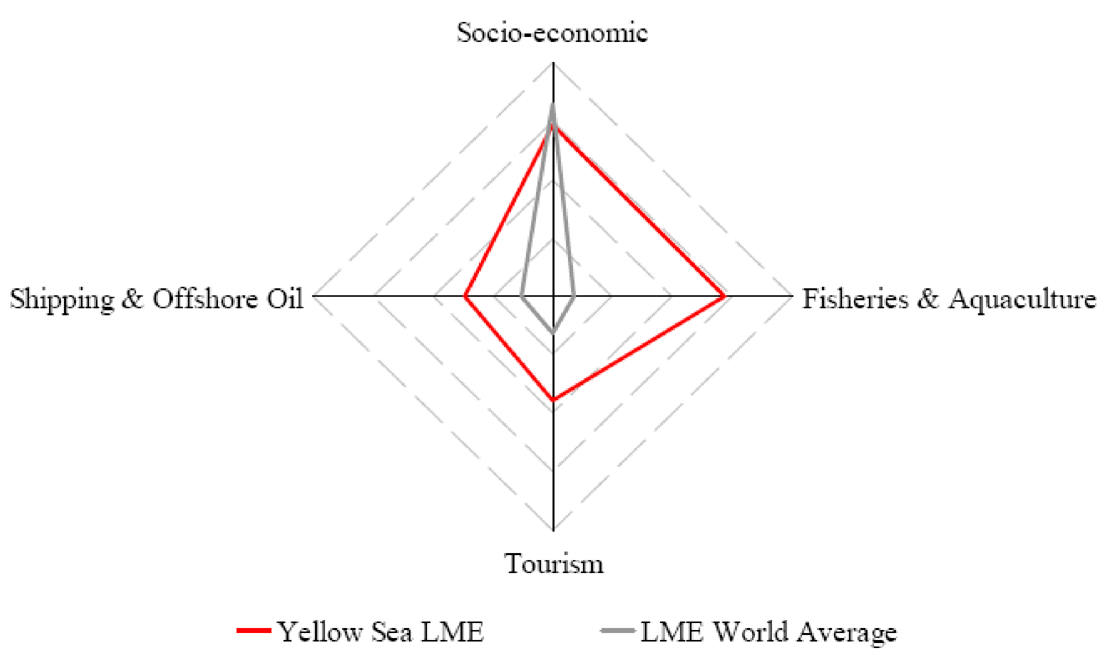

Figure 26. YSLME activity index values for three major marine sectors and the socioeconomic sector in comparison to the LME world average.

From the analyses it is clear that the countries bordering the YSLME—China and Korea—are significantly challenged to recover depleted fisheries, restore degraded habitat, control nutrient over enrichment, halt the loss of biodiversity, and abate coastal pollution (Sherman and Hempel 2008). Both countries are moving forward within the framework of a GEF-supported joint strategic action plan (SAP) to recover and sustain the critically important environmental goods and services of the YSLME. Management actions based on findings of the SAP are presently being implemented. They are described in the paper by Walton and Jiang in this volume. Both countries are planning continuing joint efforts to assess and manage the shared resources of the YSLME (www.YSLME.org) through the development of a joint YSLME Commission (UNDP/GEF 2008).

5) Governance Module Indicators

The LME Governance Module engages multiple scales of national, regional, and local jurisdictional frameworks needed to select and support ecosystem-based management practices leading to the sustainable use of resources. There are inherent difficulties in a changing world to measure governance, whether effective, moderately effective or ineffective, using data measurements and views coming from the public sector, the private sector and LME stakeholders. 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 (Olsen et al. 2006). An example of multiple governance-related jurisdictions is shown in **Figure 27** for the Northeast US Continental Shelf LME (NESLME).

The 260,000 km^2 spatial extent of the NESLME ecosystem encompasses multiple levels of marine management (governance) jurisdiction. The fisheries are managed in the New England area of the ecosystem by the New England Fishery Management council, and the fisheries in the Mid-Atlantic area of the ecosystem, by the Mid-Atlantic Fishery Management Council. The estuaries and near-coastal areas within 3 miles of the coast are under jurisdiction of the coastal states from Maine to North Carolina where the USEPA provides grants to the states for monitoring changing ecological conditions using the 5 LME pollution and ecosystem health indicators. Other governance/management units are the National Estuarine Research Reserve System (NERRS), several marine fisheries protected areas and management sites, and a national marine sanctuary (**Figure 27**). Each of the governance jurisdictions within the NESLME represents an input component to an additive and integrated ecosystem assessment (IEA). The process for preparing IEAs requires scaling up from urban coastal municipality levels for applying the five module indicator suites through NEERS to the marine sanctuary, the Fishery Management Council jurisdictions, and the full scale of the LME. Similarly, in operationalizing GEF-LME projects, the governments of all the countries bordering the LME (e.g., 16 countries for the Guinea Current LME project) and their ministries of fisheries and agriculture, education, tourism, health and human services together with major industrial groups and local stakeholders are all actively involved in reaching agreement for prioritizing actions to achieve integrated ecosystem assessments and optimize management decision-making.

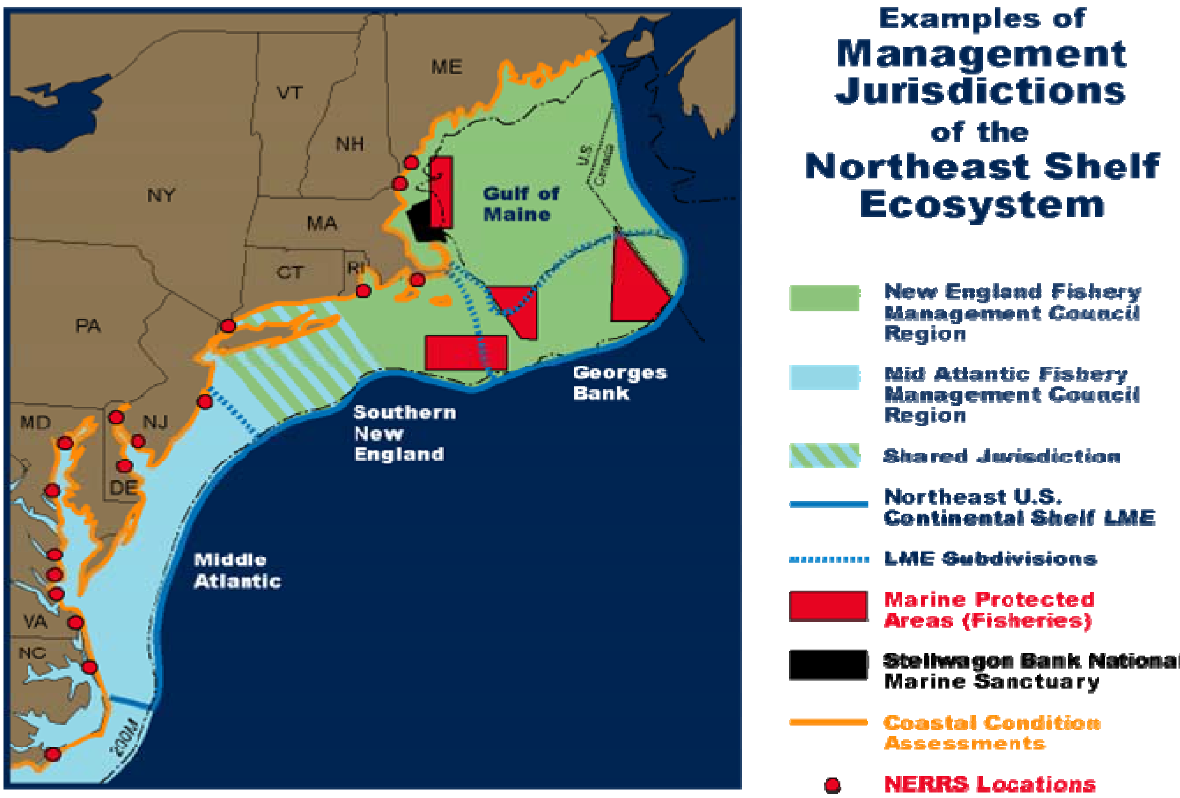

Figure 27. Multiple jurisdictions of the U.S. Northeast Continental Shelf LME.

In GEF-supported LME projects, the countries bordering an LME jointly prepare analyses that rank coastal resource issues, identify and prioritize transboundary problems, analyze socioeconomic impacts, outline root causes and advance possible remedies and actions for sustaining LME goods and services. The planning and implementing of these LME projects to recover depleted fisheries, reduce coastal pollution and restore damaged habitats in an LME is supported financially by the GEF for two 5-year phases. Following consensus reached on priority transboundary issues to be addressed based on a12-month period of Transboundary Diagnostic Analysis (TDA) and agreement on a Strategic Action Program (SAP), the participating countries proceed (Duda and Sherman 2002) to operationalize the 5-module LME assessment and management approach.

Governance arrangements for the use of marine goods and services are being developed and implemented in an additive and integrated manner across the multiple sectors of the LME, including fish and fisheries, marine transportation, tourism, offshore oil and gas production, mining and other sectors. A system of indicators for measuring the changing conditions of those human activities in relation to gains or losses of benefits to the coastal communities is essential input to ecosystem sustainability accounting. LME monitoring and assessment indicators of changing economic and ecological conditions are examined annually and included as input added and integrated into adaptive management decisions (**Figure 28**).

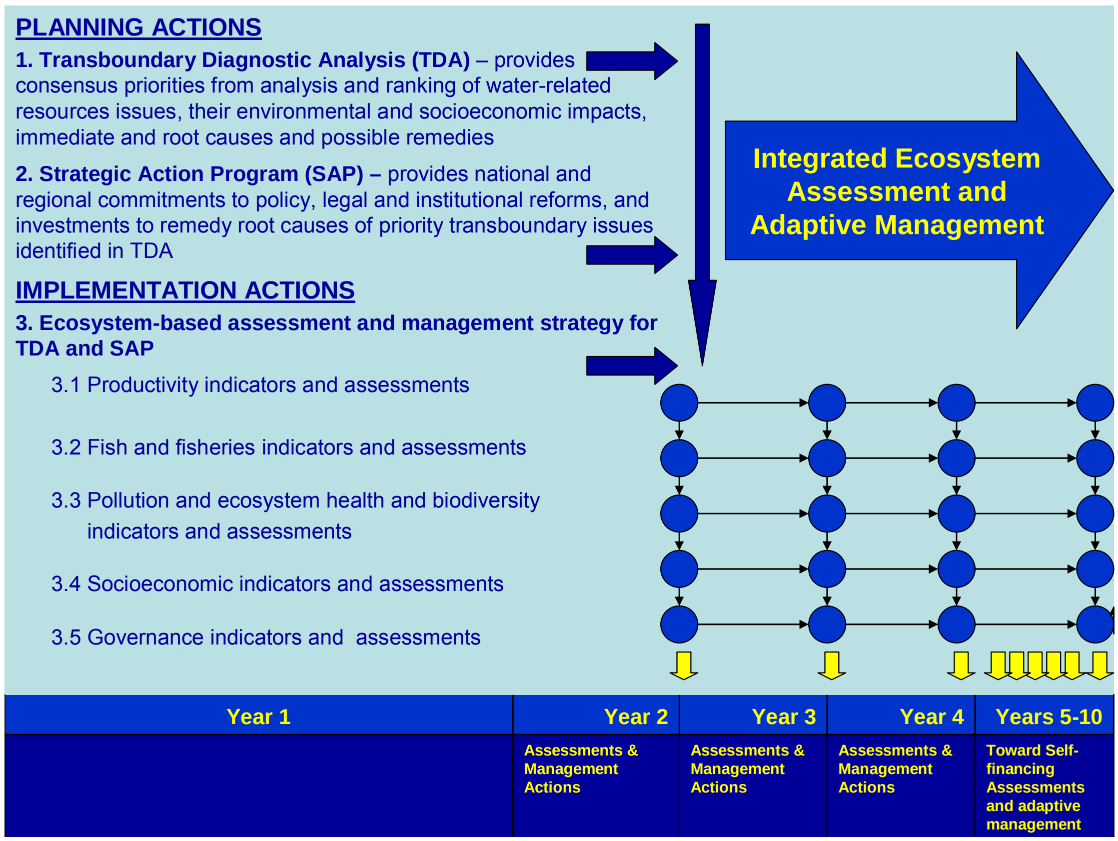

Figure 28. Large Marine Ecosystems Program planning and implementation process and schedule. The countries bordering an LME jointly prepare analyses based on the five module suites of indicator matrices used to rank coastal resource issues, identify and prioritize transboundary problems, analyze socioeconomic impacts, outline root causes and advance possible remedies and actions for sustaining LME resources. The process to recover depleted fisheries, reduce coastal pollution and restore damaged habitats in an LME adjacent to developing countries is funded by the Global Environment Facility and donor contributions over a period of 10 years. The Project is subsequently expected to be supported through self-financing (Sherman et al. 2004).

As discussed by Sutinen et al. (2005) governance arrangements have traditionally developed along sectoral lines and this has resulted in intersectoral problems as decisions are made without regard to any additive or integrative processes from a complete ecosystems-wide perspective. Ecosystem based governance actions need to consider multiple legal jurisdictions and governance levels (e.g. municipal, state, regional, national, international) as well as the interests of multiple user sectors (e.g. fisheries, mining, oil and gas production, waste disposal, transportation, recreation) and stakeholders (e.g. fishermen, corporations, real estate interests). As problems across sectors increase in complexity, legislative efforts are undertaken for advancing ecosystem based management (Hennessey 1994; Juda 1996; Juda 1999; Juda and Hennessey 2001).

The multisectoral approach to LME assessment and management has been adopted in the establishment of the three-country Benguela Current Commission. South Africa, Namibia, and Angola signed an agreement in August 2006 to formally establish the Benguela Current Commission (BCC) that provides for joint management of the goods and services of the Benguela Current LME. Establishment of the BCC is a culmination of 10 years of effort by scientists, stakeholders, resource managers, and multisectoral ministerial representatives (e.g. fisheries, mining, energy, tourism, environment) from the three countries who began to share their knowledge and understanding of the Benguela Current LME in 1995 during the first operational phase of the Global Environment Facility (GEF) supported BCLME assessment and management project (www.bclme.org /news). The three Southwest African countries will collectively manage transboundary environmental and resource issues including recovering and sustaining fish stocks, mitigating effects of offshore mining and oil and gas production, mariculture, shipping, and transport, energy production, tourism, and mining, and improving the condition of degraded habitats (see O'Toole, this volume). The BCC in partnership with the GEF, UNDP, and other agencies including US-NOAA, Norwegian, German, and Icelandic marine specialists is advancing the understanding of the physical and biological drivers of change through research and assessment actions that will support management actions for protecting and sustaining the highly valued goods and services of the BCLME. Now in its fifth year, the Benguela Current Large Marine Ecosystem Program has allocated US$10 million in support of 75 scientific and economic research projects in the region. Considerable effort is presently underway by the BCLME Project in bringing the information from each of the five assessment modules together into an integrated ecosystem-based assessment (IEA), describing the overall ecological condition and prospects for recovery and sustainability of the goods and services of the ecosystem.

Based on the Benguela Current Commission activities and structures, an effort is now underway to extend the LME Commission approach to the 16 countries bordering the Guinea Current participating in a GEF-supported Guinea Current LME Project (igcc.gclme.org). The 16 participating countries have agreed to establish an Interim Guinea Current Commission. In addition, initial steps for establishing a joint LME Commission for the Yellow Sea are under consideration by the GEF-supported Yellow Sea LME project (www.yslme.org/ doc /rstp4/reg%20gov.pdf). The LME indicators have also been brought to the Baltic Sea LME through the efforts of a GEF-supported Baltic Sea regional project headed by Dr. Jan Thulin on behalf of the International Council for the

Exploration of the Sea, and the Helsinki Commission (HELCOM) (see Thulin, this volume).

The Way Forward to Ecosystem-based Management

In the 10-year timeline of annualized adaptive management actions depicted in **Figure 28**, the SAP provides the participating countries opportunity to continue the LME assessment and management practice as a self-financing activity supported with partnerships among stakeholders and engaged ministries vested with responsibility for marine resource development and sustainability.

In the mid-1990s the scientific basis for moving toward ecosystem based assessment and management of marine goods and services was put forward by (Lubchenco 1994) and the Ecological Society of America (Christensen et al. 1996). This movement represents a paradigm shift moving from single species assessments to multiple species assessments and the LME scale for measuring changing ecosystem states on an annual basis with a focus on not only ecosystem goods but also ecosystem services (**Figure 29**). More recent attention has been focused on the diminished services to humans of marine ecosystems and the concern that small changes in ecosystem resilience and robustness can lead to non-linear interactions, regime shifts, and collapses (Levin and Lubchenco 2008). Risks of ecosystem collapse are significantly diminished under resilient and robust ecosystem conditions wherein depleted fish populations can successfully be rebuilt (Worm et al. 2009). It is important to maintain close linkages among management activities framed to sustain socioeconomic ecosystem benefits. Monitoring and assessment methodology for measuring changing states using the 5-module suites of indicators: ecosystem productivity, fish and fisheries, pollution and ecosystem health (e.g. robustness and resilience) provide a scientific foundation for management policy that must also provide for socioeconomic benefits under a mutually agreeable governance regime.

FROM	TO
Individual species	**Ecosystems**
Small spatial scale	**Multiple scales**
Short-term perspective	**Long-term perspective**
Humans: independent of ecosystems	**Humans: integral part of ecosystems**
Management divorced from research	**Adaptive management**
Managing commodities	**Sustaining production potential for goods and services**

Figure 29. A paradigm shift to ecosystem-based management. (from Lubchenco 1994). The scientific basis of ecosystem management. 103rd Congress, 2d session, Committee Print. U.S. Government Printing Office.

The paradigm shift toward ecosystem based management described by Lubchenco (1994) and further defined and endorsed by 212 senior researchers (McLeod et al. 2005) is now being operationalized in the 16 GEF-supported LME projects in Africa, Asia, Latin America, and eastern Europe (**Figure 1**).

The Chief Technical Advisors of the projects are adopting the 5-module approach to accommodate the unique attributes relative to present ecosystem conditions. Common to all projects is the GEF TDA and SAP process for project planning and implementation. To ensure the country-drivenness of the project, a period of 12 to 18 months is allocated to move ahead on adding and integrating multiple sectoral indicators of changing conditions of ecosystem goods and services across the five modules. The TDA and SAP provide the programmatic framework for focusing actions for recovery of depleted fisheries, restoring degraded habitats, controlling nutrient overenrichment, reducing coastal pollution, conserving biodiversity, and adapting to climate change while ensuring sustainability of socioeconomic benefits of ecosystem goods and services to the populations of coastal nations participating in the GEF-supported LME projects.

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Ocean Governance in the Benguela Large Marine Ecosystem – Establishing the Benguela Current Commission

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The Benguela Current Large Marine Ecosystem (BCLME) project (2002-2008) was a joint initiative funded by the Global Environment Facility (GEF) and by the governments of Angola, Namibia and South Africa to manage and utilise the resources of the BCLME in a sustainable and integrated manner. It was designed to address transboundary problems, including the management and migration of valuable fish stocks across national boundaries, harmful algal blooms, alien invasive species and pollutants that can be advected by winds and currents from the waters off one country into the waters off another. One of the major goals of the BCLME was to establish a Benguela Current Commission (BCC), which would enable the three countries to engage constructively and peacefully in resolving transboundary issues that threaten the integrity of the BCLME. It would also provide a framework to implement an ecosystem based management approach, increase the benefits derived from the management and harvesting of shared fish stocks, and improve the capacity and overall management of human impacts on the BCLME. This chapter briefly describes the BCLME project and the processes leading to the formation of the BCC, and summarises the present institutional structures, future plans and lessons learned from over a decade of development work in southern Africa. The regional body is the first of its type in the world to be based on a Large Marine Ecosystem concept of ocean governance, and it will undergo further evolution from this transitional phase into a fully developed, legally binding environmental Commission over the next five years.

PROJECT DESCRIPTION

The Benguela Current LME is one of the most productive upwelling regions of the world (**Figure 1**). It supports an important global reservoir of biodiversity and biomass of zooplankton, fish, sea birds, and marine mammals, while nearshore and offshore sediments hold rich deposits of precious minerals (particularly diamonds), as well as oil and gas reserves.

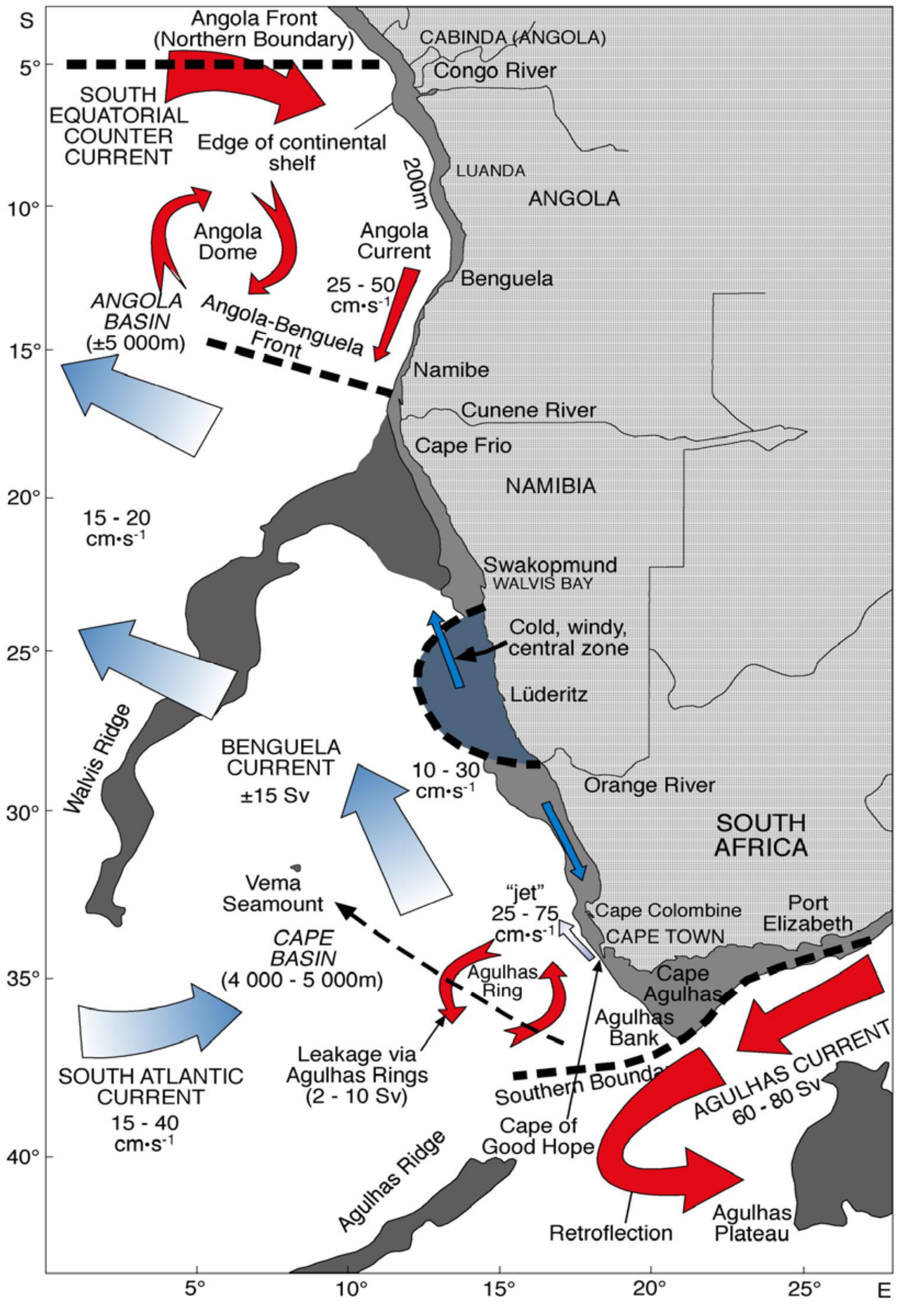

Figure 1. The Benguela Currrent Large Marine Ecosystem: boundaries, bathymetric features and circulation.

The development of the BCLME project proposal known as the Project Development Facility (PDF) phase was a long and complicated process taking over two years to complete, but it was viewed as essential in laying down the groundwork and structures for the very successful implementation phase. It was carried out in 1997-2000 and consisted of the following milestones:

a) Synthesis and assessment of information on the BCLME

This important part of the process was the gathering of data to synthesize and assess the existing information which was then compiled into a suite of six comprehensive reports on fisheries, oceanography and environmental variability, marine diamond mining, the coastal zone, offshore oil and gas and socio-economics. These reports that identified key issues, threats and gaps in knowledge, were reviewed by experts and submitted as supporting appendices with the PDF proposal to the GEF.

b) First Stakeholder Workshop – Broad Consultations

The first stakeholder workshop was held in Cape Town in July 1998. It brought together the key players and stakeholders from the region as well as representatives from outside international agencies. This workshop was an important milestone in building trust, co-operation and consensus on forging a way ahead for the development of a co-ordinated integrated approach to BCLME management. The use of a professional moderator ensured broad involvement and a bottom up approach with regional scientists and managers driving the agenda.

The workshop defined the broad issues and agreed on a work plan that outlined responsibilities and a timetable to achieve the necessary actions. It also established formal mechanisms for communication and consultation between key stakeholders. There was broad stakeholder participation including from all the government ministries and relevant agencies, the three countries, and from the commercial and artisanal fisheries sectors, mining, oil and gas, port authorities, tourism sectors, various NGOs and some donor agencies.

c) Second Stakeholder Workshop – Transboundary Diagnostic Analysis (TDA)

The second regional workshop, smaller and more focused, was tasked with developing a Transboundary Diagnostic Analysis (TDA) for the BCLME. It was held in Okahandja, Namibia in April 1999 and was attended by key government ministries from the region as well as by representatives of the private sector, NGOs, donors and GEF consultants. The main objective of the workshop was to define and agree on the major elements of the TDA, achieve consensus on a framework for the Strategic Action Plan (SAP), and ensure ownership of the process and outputs by the stakeholders.

The workshop used a logic framework analysis process and focused on three main areas of programme activities: (a) resource use; (b) environmental variability; and (c) pollution and ecosystem health. The essential elements of the TDA were identified and prioritised by smaller working groups following the path (issues > problems > causes > impacts > risks > uncertainties > socio-economic consequences > transboundary consequences > activities/solutions > priorities > outputs > costs) outlined in **Figure 2**. What the working groups produced formed the basis for developing a comprehensive TDA report which led to the development of the SAP. A framework for the SAP was also defined by the stakeholders, for later development by a small group of experts into a more comprehensive document. The TDA workshop produced excellent results and generated a great spirit of cooperation and goodwill among the participants of the three countries.

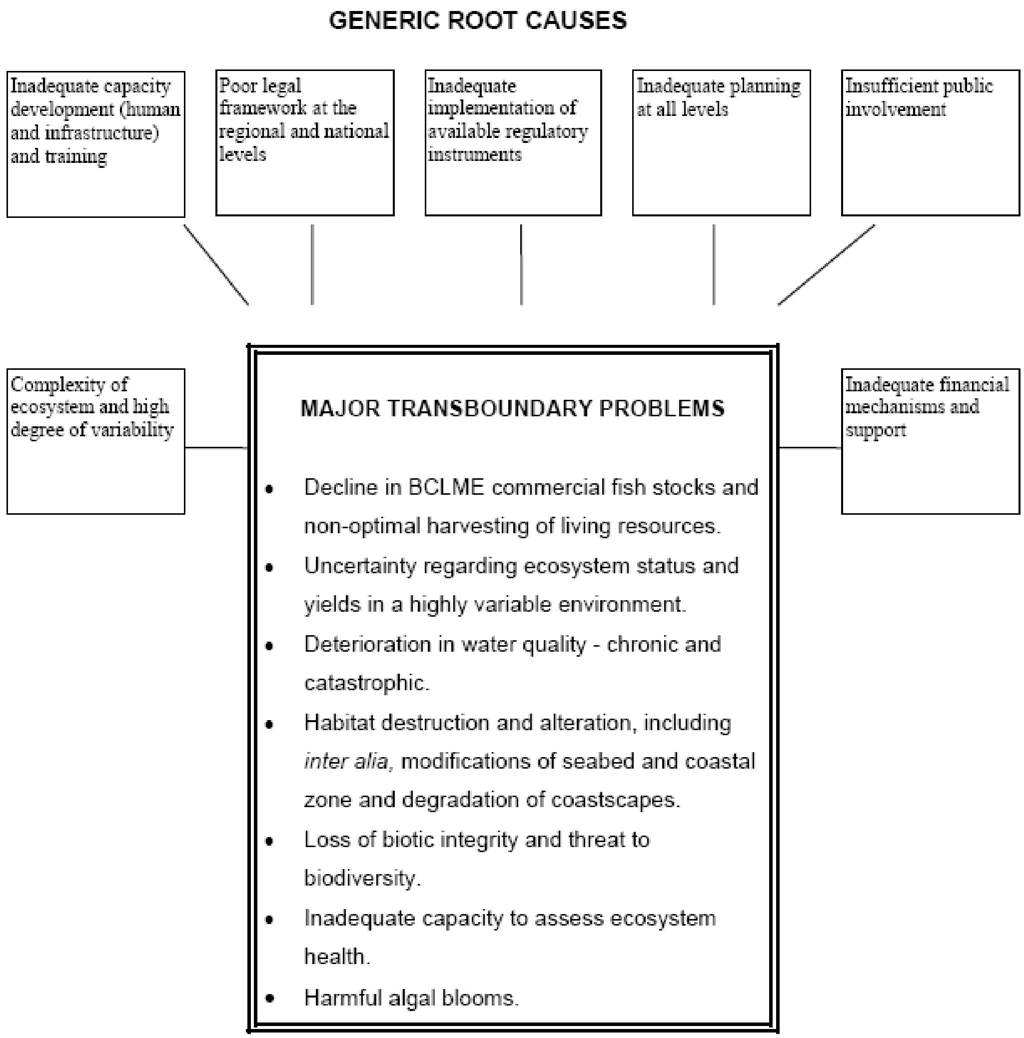

Figure 2. Major transboundary problems of the BCLME and generic root causes as determined by the TDA process.

The main issues and threats identified by the stakeholders to be addressed by the SAP were:

The sustainable utilisation and management of resources

- The facilitation of optimal harvesting of living marine resources
- An assessment of seabed mining and drilling impacts and policy harmonisation
- A responsible development of mariculture
- The protection of vulnerable species and habitats
- An assessment of non-harvested species and their role in the ecosystem.

Assessments of environmental variability, ecosystem impacts, and improvement of predictability

- Reducing uncertainty and improving predictability
- Capacity building and strengthening
- Management of consequences of harmful algal blooms.

The maintenance of ecosystem health and the management of pollution

- The improvement of water quality
- The prevention and management of oil spills
- The reduction of marine litter
- The reversal of habitat destruction and habitat alteration
- The conservation of biodiversity.

d) The Strategic Action Plan (SAP)

The SAP was developed as a concise planning document that outlined the principles and policy actions necessary for the integrated management of the BCLME based on an ecosystems approach. The draft was produced by a small working group and later circulated to the stakeholders for comments. The document clearly defined the challenges facing the BCLME region, established principles fundamental to integrated management, and specified the nature, scope and timetable for deliverable policy actions based on the TDA. It also provided details on the required institutional arrangements, elaborated on how to achieve wider cooperation, and specified how the BCLME project would be financed during the start-up and implementation phase for long-term sustainability.

The SAP adopted the precautionary approach for fisheries, the use of clean technologies, and the principle of transparency and public participation. It included environmental health in all its policy and sectoral plans. The SAP called upon the three countries to pursue a policy of co-financing with industry and donor agencies.

The institutional arrangements outlined in the SAP included the establishment of a Project Steering Committee (PSC) and a Project Coordination Unit (PCU) as well as three Activity Centres (i.e. the Activity Centre for Living Marine Resources, in Swakopmund, Namibia; the Activity Centre for Environmental Variabilty, in Cape Town, South Africa; and the Activity Centre for Biodiversity, Ecosystem Health and Pollution, in Luanda, Angola. These centres were designed to facilitate the coordination of project activities with the partner countries, and were supported by special advisory groups comprising experts, scientists, and managers from the Benguela region.

The key objective of the SAP was to form an Interim Benguela Current Commission (IBCC), to be established within the first five years of the project. This body would later become a permanent Benguela Current Commission responsible for the integrated management, conservation and protection of the BCLME using the ecosystem approach.

The SAP encourages the three countries individually and jointly to enhance co-operation with other regional organisations such as the Southern African Development Community (SADC), the South East Atlantic Fisheries Organisation (SEAFO), NGOs, UN agencies, other African LME Programs, donors, and other states with an interest in the Benguela Current region.

The BCLME project was designed primarily to deal with transboundary environmental and fisheries management issues. However, its objectives and outputs were to be under-pinned by science and technology of the highest international standard. In this respect, strong links and partnerships among regional fisheries, science, and the training program BENEFIT (Benguela Environment Fisheries Interaction and Training) were forged early on. Significant funding was routed to BENEFIT to conduct applied fisheries research and environmental monitoring to support a more management orientated mandate. Regional capacity building and training of scientists, technicians, and managers were core activities of both initiatives.

CHALLENGES AND EXPERIENCES

The BCLME project began in 2002 with the aim of establishing a regional mechanism for the integrated management of shared stocks, sustainable development, and the protection of the BCLME, using an ecosystems approach to management. It focused on key areas of transboundary management, covering living marine resources, environmental variability and predictability, biodiversity, pollution and ecosystem health. Over 100 projects were designed and implemented in six years, many of which were awarded to universities, national institutions, BENEFIT, and consultancy groups from the Benguela region.

In hindsight, the timelines for these research projects were too optimistic. However, many were completed by 2008, and recommendations are presently being adopted by the countries or will be taken on by the newly formed Bengeula Current Commission. Some of the main policy actions are:

- The harmonisation of shared stocks management through joint surveys and assessments of key species
- A regional aquaculture policy and implementation plan
- The development and adoption of an ecosystems approach to fisheries management (EAF)
- An early warning system for adverse environmental events including harmful algal blooms (HABs)
- Guidelines for regional water quality management in coastal waters
- The harmonisation of national environmental policy and legislation, including guidelines for responsible seabed mining
- A regional oil spill contingency plan and assessment
- A regional marine biodiversity conservation plan
- A state of the ecosystem information system (SEIS), which will report on the annual state of fish stocks.

A BCLME project objective was to encourage compliance with several key international conventions and agreements which support resource sustainability, the ecosystems approach to management, the rebuilding of fish stocks, the conservation of biodiversity and protection of the environment. These conventions and agreements are: the UN Conference on Environment and Development (UNCED); Agenda 21; Rio 1992; the UN Convention of Biological Diversity (1992); the UN Fish Stock Agreement; the Kyoto Declaration (1995); the FAO Code of Conduct for Responsible Fisheries (1995); the International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78 Agreement); the Reykjavik Declaration on Responsible Fishing in the Marine Ecosystem (2001); the 2002 World Summit for Sustainable Development (WSSD); the UN Millennium goals (2000); and the UN Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (2006). Many of these agreements have been ratified by Angola, Namibia and South Africa over the past decade and some of the targets have already been reached.

The Benguela Current Commission started to take form in 2004 when a feasibility study was commissioned to establish a regional organisation that would promote integrated management and the sustainable use of the BCLME. This was followed by a second study focusing on economics which analysed the costs and benefits of cooperative research and management. Both reports recommended establishing a regional organisation that would implement an ecosystem approach to ocean governance in the Benguela Current LME.

Further consultations were held with regional stakeholders between 2004 and 2006 to determine the structure and organisation of the Commission including its mandate. These negotiations finally resulted in an interim agreement by the three countries and the subsequent formation of the Benguela Current Commission. The structure of the regional body includes a Management Board, with which sub-committees on marine living resources, minerals and oil, ecosystem health and environment would directly liaise. The Management Board is served by a Secretariat, with an Executive Secretary and Ecosystem Coordinator, and by an Ecosystem Advisory Committee supported by various scientific working groups (**Figure 3**).

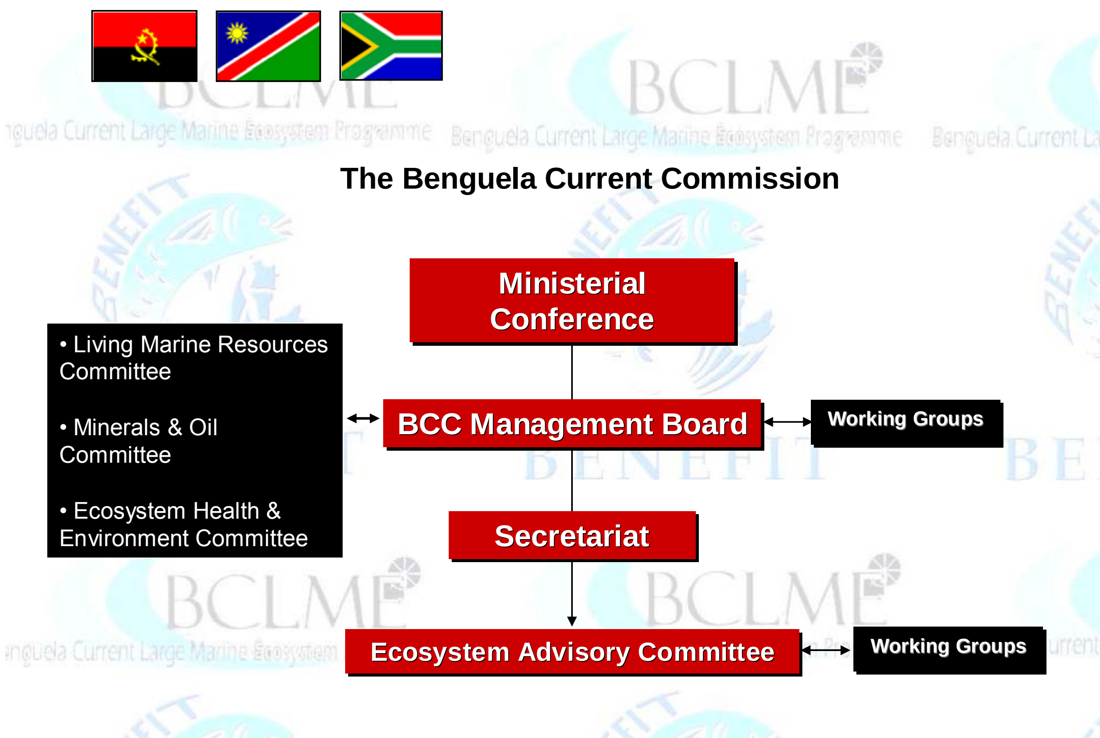

Figure 3. Structure and organization of the Benguela Current Commission.

The advisory mandate of the Commission is broad. The Commission will determine optimal levels of harvesting with respect to shared fish stocks, the establishment of marine protected areas, the restoration of environmentally degraded areas, and the conservation of biological diversity. The Commission will also adopt regulatory frameworks on the discharge of sewage, pollutants and other waste matter, and provide guidelines on water quality standards.

The interim agreement of the BCC was formally signed in August 2006 by the Namibia ministers of Fisheries and Marine Resources, Environment and Tourism and Mines and Energy, and by the South Africa Minister for Environmental Affairs and Tourism. The agreement was subsequently signed by the Angola ministers of Fisheries, Urbanism, the Environment and Petroleum in Luanda in January 2007. The first meeting of the Ministerial Conference of the BCC was held in Windhoek in July 2007.

LEARNING FROM EXPERIENCE

Our knowledge and understanding of the dynamics and functioning of the Benguela Current ecosystem has advanced substantially. Angola, Namibia and South Africa have taken significant strides towards meeting the targets set for fisheries and the environment at the Johannesburg World Summit for Sustainable Development in 2002. Regional research institutes, universities, and consultancy groups have worked closely to build regional scientific research and management capacity and to gather and analyse a wide range of information that is vital for the responsible management of the LME and its natural resources. Management tools have been developed and recommendations made that translate policy into actions. Much of the work has been transboundary in nature and has contributed to our knowledge of the Benguela Current and how best to rebuild, conserve and manage its resources.

Support and encouragement by NOAA, the IUCN, the IOC/UNESCO and UNEP provided to other LMEs world-wide through the annual LME consultative committee meetings in Paris, was of great assistance in achieving our objectives. The partnership with FAO in developing an ecosystem approach to fisheries (EAF) in the region also played a key role in building confidence and empowering fisheries agencies to broaden their perspective and approach to fisheries management.

In the last five years, the BCLME project has forged strong links with the GEF-supported Guinea Current, Canary Current, and Agulhas and Somali Current LME projects through consultative meetings, training, capacity building activities, shared transboundary fisheries, pollution surveys, and regional workshops.

Close cooperation was also developed with the Global Ocean Observation System (GOOS) through GOOS-Africa, which led to strong partnerships in building capacity and training in operational oceanography and ocean monitoring systems particularly satellite remote sensing. A highlight of this cooperation was the Pan-African Forum on Large Marine Ecosystems held in Cape Town in

November 2006. LMEs, GOOS, GEOSS and the UNEP Regional Seas Programme shared a common vision and identified the needs and areas of future collaboration, knowledge sharing, and the application of operational oceanographic skills.

REPLICATION

While the BCLME project was underway, we provided assistance to other African LME projects at various stages of development, and applied our experience and the lessons learned from cooperative marine scientific research and management. The experience gained in producing a comprehensive TDA and SAP and planning and executing the project has been invaluable and can easily be replicated in other GEF projects. Our practical experience in strategic planning and institutional building, and the models used can be of great value especially with regard to their application to eastern boundary upwelling systems.

The BCLME project also assisted the Secretariat of the Abidjan Conventions (UNEP) in developing policy on how best to apply the mandate of the Convention to protect the coastal and marine environment. The Benguela Current Commission provided a useful model as a regional mechanism for implementing the Convention.

International linkages were successfully established with the GEF—supported Humboldt Current LME project and with the Pacific Islands through collaborative workshops and exchange visits, some of which were sponsored by GEF IW:LEARN. These contacts led to the cooperation of scientists in the Benguela and in the Humboldt Current upwelling regions, with a sharing of knowledge on the ecosystems approach to fisheries management and the monitoring of top predators as a measure of ecosystem health.

Good outreach, high visibility and focused public relations were central to the success of the BCLME project and in obtaining the necessary political will for establishing the Benguela Current Commission. The appointment of a media liaison officer who coordinated the production of annual newsletters, supervised the operation of a comprehensive website, and wrote featured articles in regional and international marine publications, ensured that a high profile for the project was maintained. A BCLME brand and logo were also established, which are now internationally known. Two published books, "The Benguela – Predicting a Large Marine Ecosystem" (Elsevier Press), and "Benguela – Current of Plenty" – a History of International Cooperation in Marine Science and Ecosystem Management" (Benguela Current Commission), provided a record of ongoing scientific achievements, capacity building and institutional development and change.

SCOPE OF THE PROJECT AND COMMISSION

The Benguela Current Commission has been an African success story in marine environmental management and sustainable development. It is the first regional institution of its type in the world that is based on the LME approach to ocean governance. It has a mandate from the three participating countries, Angola, Namibia and South Africa, to pursue and promote an integrated approach to the sustainable management and protection of the environment, using an ecosystem-based approach to ocean governance. Its success is due to the bottom-up, country driven approach taken in the early development stages of the project and continued through to its implementation and completion. Having BENEFIT as a partner, with a well funded regional fisheries science and training programme in place before hand, did much to set the scene. The GEF funding support, together with the strong commitment of the three countries, the in kind contributions, the political will to move forward, the regional cooperation in marine science, resource management and environmental protection, ensured a positive and beneficial outcome.

The recommendations put forward by the BCLME project are now being considered, prioritised and incorporated into national action plans to be implemented by the three governments. These priority actions will be formally endorsed and adopted by the newly established Benguela Current Commission.

Significant resources have been secured to support and strengthen the BCC over its initiation phase (2009-2011). The GEF has pledged further funds to build the institutional and legal structure of the Commission. Norway and Iceland have agreed to provide generous funding for a comprehensive scientific programme of activities, capacity building, and further use of the research vessel *Dr Fridtjof Nansen* for surveying transboundary BCLME productivity, oceanography, fish stocks, pollution and ecosystem health.

The appointment of an executive secretary to lead the BCC and an ecosystem coordinator to manage its scientific programme marks an important new chapter in the history of regional cooperation in the Benguela Current LME region. Following these appointments, marine scientists, managers and administrators in Angola, Namibia and South Africa, in partnership with industry and other stakeholders, will implement a unique form of ecosystem management, apply a holistic approach to ocean governance, conserve and rebuild fisheries, protect the marine environment, and support the sustainable development of Benguela Current LME goods and services.

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BCLME Website: www.bclme.org

This website contains all publications, reports and outputs resulting from the BCLME Programme and includes copies of the TDA, SAP, the BCC Interim Agreement and six annual newsletters (2003-2008).

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The Recovery and Sustainability of the Baltic Sea Large Marine Ecosystem

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The Baltic Sea Large Marine Ecosystem (BSLME) is a unique and productive ecosystem under stress from harmful and unsustainable human activities and practices. Efforts are now gaining momentum to enhance cooperation between the riparian countries and the main international institutions involved in the science, advice and management of the marine environment including the region's fisheries, with a view to the recovery of the Baltic Sea Large Marine Ecosystem (BSLME) and the sustainability of socioeconomic benefits for the coastal nations and their communities.

Main characteristics of the Baltic Sea Large Marine Ecosystem

Geologically, biologically and in human terms, the Baltic Sea LME is a young, relatively shallow semi-enclosed sea. About 15,000 years ago, the thick ice belt which then covered the whole of Scandinavia started melting and a fresh water Baltic ice lake was established. During the following 9,000 years, this water area developed into a wholly marine area, then, once more, into an enclosed fresh water area before it again developed into a marine area, about 6,000 years ago. At its present state of development, the Baltic Sea's marine life is less than 4,000 years old.

Today, the Baltic Sea LME is a semi-enclosed brackish water area, the second largest in the world after the Black Sea, with a surface area of about 415,000 km^2. The average depth of the Baltic Sea is around 50 meters. The deepest waters are in the Landsort Deep in the Baltic proper, where depths of 459 meters have been recorded. More than 200 rivers empty into the Baltic Sea, providing a catchment or drainage area of about 1,700,00 km^2, that is approximately four times larger than the Baltic Sea itself. This catchment area is viewed as a component of the Baltic Sea LME, as it is now recognized that natural (e.g. precipitation and floods) and anthropogenic (e.g. pollution) effects occurring in the land-based watershed result in impacts on the living resources of the Baltic Sea LME.

The Baltic Sea is characterized by a persistent vertical stratification of its water layers, with a residence (turn-over) time for full exchange of its water mass estimated at 30 years. These features are major factors that increase the susceptibility of the Baltic Sea to accumulate pollutants.

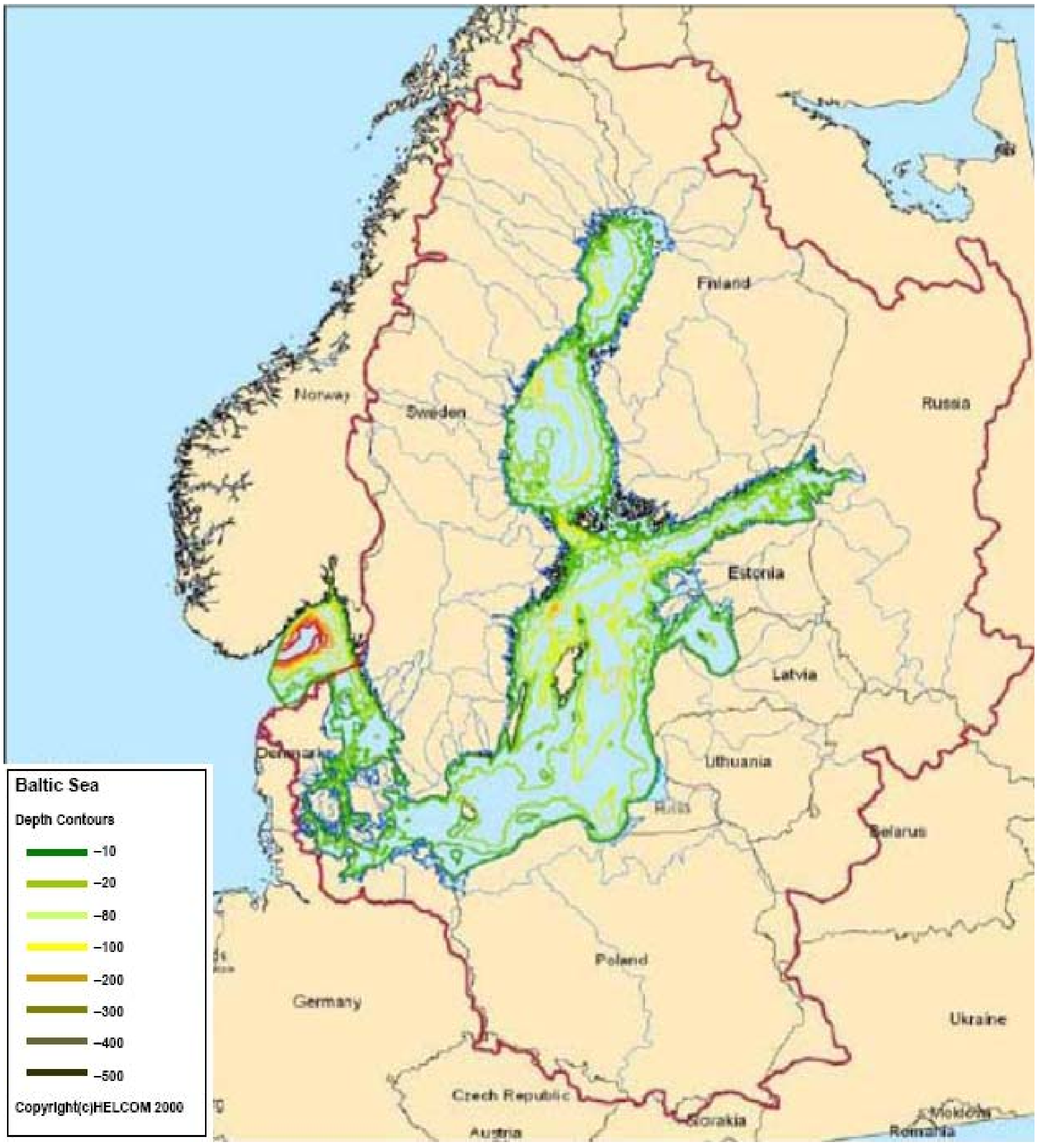

Figure 1. The Baltic Sea LME catchment area (outlined in dark red).

The Baltic Sea comprises three deep basins separated by shallow sills: the Arkona Deep, at the entrance to the Baltic Sea, the Bornholm Deep, and the Gotland Deep, farthest inwards. Saltier, heavier and oxygen-rich water from the North Sea enters the Baltic Sea through the shallow, narrow entrance and propagates along the deeper regions, while a counter current of freshwater flows outwards at the surface. This results, throughout most of the ecosystem, in two vertically stratified parts of the water column, which rarely mix. This stratification significantly limits the passage of oxygen from the surface into the deeper waters. The inflows of oxygen-rich water are of vital importance for the well-being and productivity of the biota and determine the environmental quality of the Baltic Sea LME. Unfortunately, these inflows causing flushing of the Baltic Sea are unpredictable and infrequent, with periods of stagnation between flushing events that last as long as several decades, such that oxygen levels decline over time between each inflow due to the biological oxygen demands of living organisms and the breakdown of organic material. Although the influxes are basically random and connected with climatic variability that is not due to human influences, it appears that these influxes since the second half of the 20th century are decreasing in both frequency and magnitude.

Because of its history and brackish environment, the Baltic Sea LME is characterized by the low number and biodiversity of plant and animal species than in more saline waters. The brackish water is too salty for most freshwater species and too fresh for most marine species. For example, the number of macroscopic and microscopic animal species west of Sweden is roughly 1,500; in the southern Baltic there are only about 150 species, and in the water around Gotland only about 80 species. The same applies to fish: the Kattegat has around 100 marine fish species, while the Sound has only 55 and the Archipelago Sea only about 20. Other fish species are representative of those normally found in freshwater lakes and rivers all over the region, so that a single catch in the Bothnian Bay might consist of a unique combination of cod, herring, perch, and pike. The salinity gradient is paralleled by a climatic gradient with up to six months of ice cover, a productive season of 4-5 months in the northern Gulf of Bothnia, and an 8-9 month productive season in the southern sounds near its entrance. Besides these variations in biodiversity, it is typical that the few species penetrating into brackish waters are typically slower growing and of smaller size than in their original habitats, irrespective of whether their original habitats are marine or freshwater. Thus, the Baltic Sea environment and its biological diversity are unique. Its associated biota is facing a special challenge in living under a difficult natural environment that is particularly vulnerable to pollution and other human-caused stresses.

Despite the limited number of species, the structure and functioning of the BSLME is not simple. Typically, energy flows in shorter or longer food chains of up to a maximum of about five trophic levels, from the primary production originating from plants living in the sea and coastal areas, via grazing by herbivorous animals (e.g. zooplankton), and successive levels of predation to the higher level predators such as fish, seabirds and shorebirds, and marine mammals. Besides this typical ‘grazing’ food chain, we also have a microbial food chain that is longer and accordingly less efficient but no less important. The whole picture is complicated by important multispecies interactions, e.g. predator-prey relationships, interlinking the various food chains into a food web. The abundance of species and the structure and function of the food webs and ecosystems vary as a result of changing environmental conditions and human impacts.

Since the 1940s, the accelerated industrialization and exploitation of natural resources in the Baltic Sea have resulted in the deterioration and degradation of this vulnerable marine ecosystem. Today, close to 90 million people inhabit the Baltic Sea drainage basin, and their activities impact and change the Baltic Sea environment. The Baltic Sea LME is among the most scientifically investigated sea areas in the world. Its environmental conditions, the possible impacts of human activities and the major threats to the ecosystem have been known and well documented for a long time. The key environmental issues and threats to the Baltic Sea ecosystem are: eutrophication, overfishing, chemical pollution, changes in biodiversity and, especially in recent years, climate change.

International Management and Advisory Systems

In the Baltic Sea LME, fisheries management (e.g. the setting of total allowable catches and quotas) was conducted between 1973 and 2005 by the International Baltic Sea Fishery Commission (IBSFC), situated in Warsaw, Poland. In 2004, with the accession to the European Union (EU) of Estonia, Latvia, Lithuania and Poland, the EU, via the European Commission, and Russia began managing Baltic Sea fisheries. The management of environmental issues (e.g. pollution and biodiversity conservation) is conducted by the Helsinki Commission–Baltic Marine Environment Protection Commission (HELCOM), in Helsinki, Finland). The Contracting Parties of these commissions are the 8 Baltic EU countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, and Sweden), and the Russian Federation. These management bodies receive the best available and politically neutral scientific information and advice for regulatory purposes from the International Council for the Exploration of the Sea (ICES), situated in Copenhagen, Denmark. ICES utilizes a consensus-based peer-reviewed advisory process with national representation. Fundamental inputs are the annually compiled reports of its numerous oceanographic, environmental and fisheries working groups that address key practical tasks as required. HELCOM and the European Commission together with their member states use the ICES advice to make management decisions. However, they are not obliged to act in accordance with the advice provided to them.

In response to calls from stakeholders in the fisheries sector who wanted to be more involved in fisheries management, the EU in 2006 created the Baltic Sea Regional Advisory Council (BS RAC) in Copenhagen, Denmark. Similar advisory councils have been established in six other EU regions. The main aim of the BS RAC is to prepare and provide stakeholder advice on the management of Baltic Sea fisheries in order to support the implementation of the EU’s Common Fisheries Policy. The BS RAC meets frequently with ICES for cooperation and mutual updates on fisheries and science-based activities.

The last two decades have seen considerable political and socioeconomic changes in the Baltic Sea area. A major change was the collapse of the Soviet

Union in 1991 and disappearance of the “iron curtain” which separated the people of the eastern Baltic from the richer western countries. This resulted in the re-establishment of the three Baltic republics of Estonia, Latvia, and Lithuania, the reunion of East and West Germany, and, as mentioned earlier, the accession to the European Union of the Baltic Republics and of Poland. This led to improved communication and cooperation both in science, management and societal issues among the nine Baltic Sea countries. However, the countries in transition are still hampered, mainly for economic reasons, in meeting scientific standards and fulfilling their obligations to the managing bodies of the Baltic Sea. The transboundary nature of threats to the BSLME requires the coordinated actions of all riparian countries for their solution.

The Baltic Sea Regional Project

In the late 1990s, Estonia, Latvia, Lithuania, Poland and Russia, requested the funding support of the Global Environment Facility (GEF) and western Baltic countries to participate in coordinated actions to establish the sustainable management of the Baltic Sea LME’s natural resources.

After several years of preparation, the Baltic Sea Regional Project (BSRP) was launched in 2003 and continued through the first phase until July 2007. The main aim of Phase one of the BSRP was to create conditions for the application of the ecosystem approach in managing the Baltic Sea Large Marine ecosystem and sustaining its biological productivity. The BSRP was coordinated, monitored and evaluated by HELCOM (Executing Agency) and ICES in collaboration with the IBSFC (dissolved in January 2006), and with the Swedish Agriculture University (SLU) in Uppsala, Sweden. The GEF and World Bank provided a grant of $5.5 million to support the project. Other co-financing was provided by Denmark, Finland, Germany, Norway, Sweden, the United States (NOAA), the World Wildlife Fund (WWF), and the Nordic Environment Finance Corporation (NEFCO) increased the total budget to $16 million. Thirty partner institutions in the beneficiary countries and about 10 institutions in the donor countries were involved in the BSRP which had an overall staff of over 70 people during the first phase.

The BSRP and its two main components, the LME activities and the land and coastal activities, were based on the Large Marine Ecosystem concept launched by Dr. Kenneth Sherman in the US. The LME concept advances activities and assessments of key environmental issues within 5 modules: (1) Productivity, (2) Fish and Fisheries, (3) Pollution and Ecosystem Health, (4) Socioeconomics, and (5) Governance. The BSRP working structure (**Figure 2**) was built in accordance with this 5-modular system through the establishment of Coordination Centers for each of the 5 modules and with activities reported from designated Lead Laboratories (LL).

Over the years the BSRP has produced over 3,000 pages of scientific and public outreach reports and made about 150 power point presentations. It is considered a major key player in strategies and actions to improve the status of the Baltic Sea environment. The following is a brief review of some of the key problems and threats to the Baltic Sea LME, and some of the BSRP activities and solutions to cope with them.

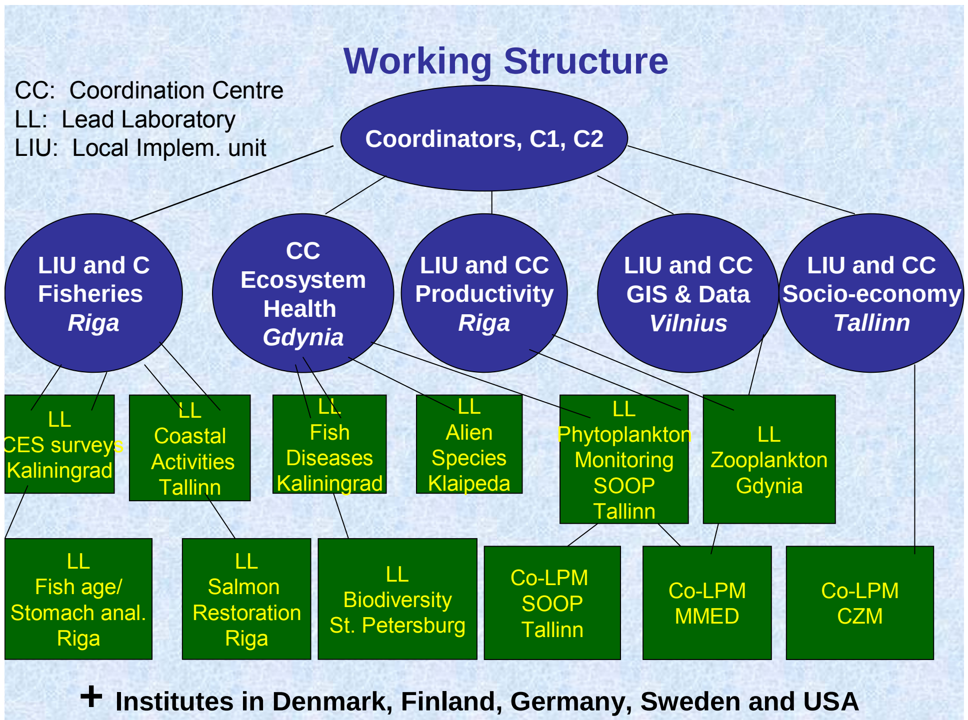

Figure 2. The working structure of the Baltic Sea Regional Project (BSRP), with Coordination Centers, Lead Laboratories and Local Implementation Units in different countries adjacent to the Baltic Sea LME.

Productivity and Ecosystem Health

Eutrophication, or nutrient over-enrichment, is the biggest problem facing the Baltic Sea. Increasing amounts of nutrients in the marine environment result in increased plant biomass and production, which in turn lead to elevated amounts of organic matter circulating in the ecosystem. The excess organic matter requires more oxygen, both when it is alive and when it is decaying. In the Baltic Sea LME, which experiences only rare major flushing events, eutrophication frequently leads to serious oxygen depletion and the formation of toxic hydrogen sulphide in the deeper regions. This has resulted in so-called dead bottom areas, nearly devoid of typical benthic animals and bottom living fish, covering nearly a third of the bottom area of the Baltic Sea LME. The input of nutrients to the Baltic Sea has increased greatly since about the 1940s, with nitrogen and phosphorous rising by about three to five times the 1940s level. The most important human-related source of these nutrients in the Baltic Sea is agriculture, where farmers use excessive manure and artificial fertilizers for the production of their crops, and the surplus runs into the sea via streams and rivers. This is especially true for the eastern Baltic countries, i.e. the BSRP recipient countries. Additionally, the situation is exacerbated by changes in land use and the loss of wetlands, as well as by the discharge of sewage from urban and industrial sources. Other complicating environmental factors affecting eutrophication trends are increased temperatures due to climate change in the Baltic Sea area.

Plankton production often gives rise to harmful blooms such as the potentially toxic blue-green cyanobacteria blooms in the summer that can be seen from satellite imagery. These excessive blooms of plant material and associated decay cause major problems by reducing water quality through oxygen deficiency and increased turbidity. This makes it difficult to meet bathing water standards on the beaches. Thus, eutrophication is often associated with declining recreational and tourist amenities. Furthermore, increased levels of nutrients lead to the loss of rare species and habitats that are adapted to low nutrient levels.

Due to the major impact of agriculture on eutrophication in the Baltic, the BSRP component "Land and Coastal activities, C2" concentrated its efforts on increasing awareness in the agricultural sector on environmentally sustainable farm management practices. For this purpose, a series of seminars was held in all rural districts of the beneficiary countries and the seminars were attended by approximately 1,200 farmers. Furthermore, economic support and subsidized loans were given to follow the results. In addition these BSRP activities included the establishment of a system for monitoring and assessment of non-point source pollution originating from farms. In cooperation with WWF, the BSRP C2 intensively promoted community based coastal zone management activities by holding training and awareness activities in more than 120 schools for about 16,000 pupils. The BSRP further performed a series of demonstration activities including work in rivers to restore crayfish and trout habitats, and restoration of over 300 hectares of coastal wetlands/meadows in the three Baltic republics.

The BSRP Coordination Center of Productivity (CCPROD) together with its Lead Laboratories (LLs) (Figure 2) have performed a number of major and innovative activities to improve cooperation and assessment of productivity parameters. Soon after its establishment, the CCPROD integrated environmental aspects and productivity into fisheries assessments. This was one significant step that improved the sustainable management of Baltic Sea fisheries. The CCPROD also tested and implemented ECOPATH modeling for comparative productivity analysis, and improved zooplankton modeling by methodological inter-comparisons. These activities and the results thereof were discussed and considered in projects and working groups at both HELCOM and ICES. In collaboration with the Algaline project at the Finnish Institute of Marine Research, and with the Swedish Meteorological and Hydrological Institute (SMHI), the BSRP established a contract with the Stena Line, the owner of the passenger ferry *Stena Nordica*, for this ferry to be used as a Ship of Opportunity (SOOP) on the route from Karlskrona, Sweden to Gdynia, Poland. This aimed to extend existing spatial and temporal sampling of SOOP vessels to the Southern Baltic east of Bornholm, a key area for the Baltic cod stock. The new route is now contributing to the re-establishment of lower trophic level productivity assessments, including pelagic autotrophs, phytobenthos and zooplankton, and is improving the data needed to develop spring bloom and other relevant indices.

For several decades many toxic substances have been known to threaten the Baltic Sea environment. This includes heavy metals, persistent organic pollutants (POPs), oil pollution, artificial radionuclides and dumped munitions. Many of the heavy metals and POPs can become magnified in the higher levels of the food chain. Halogenated hydrocarbons such as polychlorinated biphenyl congeners (PCBs), the pesticides DDT, Lindane, their metabolites and isomers, and unintentional by-products of combustion processes, are classed as xenobiotics, i.e. unknown to the environment before their human production. Most are accumulated in the fatty tissues of organisms, and many are harmful even at low concentrations. The PCBs and DDT are toxic substances that became well known and frightening to the public around the Baltic Sea in the late 1960s and 1970s. At that time, the Baltic grey seal population decreased considerably and it was discovered that up to 80% of their females were sterile, mainly due to total or partial obstruction of the uterine tubes (Bergman and Olsson, 1985). It was thought that the main reason was the high concentrations of PCBs and DDT in their tissues. At that time the presence of these pollutants in guillemots and white eagles were also correlated to their decrease in populations. After international measures were implemented in the late 1970s to reduce and ban the input of PCBs and DDT, concentrations decreased in body tissues for all three species mentioned and their populations have steadily increased. The DDT and PCB problem in the Baltic has successfully been addressed through legislation and governance. Since the implementation of the 1988 HELCOM Ministerial Declaration, the load of hazardous substances to the Baltic Sea has diminished by 20-50%. However, there are many hundreds of potentially hazardous chemicals emitted to the Baltic Sea and some new contaminants have been recently reported for the area that may create future environmental problems. These are endocrine disrupting chemicals, polybrominated flame retardants (PBBs and PBDEs), complex chlorinated chemicals from pulp and paper mills, and dioxins that accumulate in fatty fish such as herring and sprat.

With the establishment of a BSRP ICES Study Group on Baltic Ecosystem Health Issues (SGEH), the concept of Ecosystem Health was introduced into the Baltic Sea science community and into the work of ICES and HELCOM. The SGEH became instrumental in linking conventions, stakeholders and science. In the application of the ecosystem approach for the management of the Baltic Sea, ecological quality objectives (EcoQOs) were developed. This became a key issue for the CCEH and its three lead laboratories. Since such indicators had been developed and applied earlier by the US Environmental Protection Agency (EPA) in the Great Lakes, the EPA was invited and a highly qualified person participated in the whole process. The work resulted in a list of indicators to be used in assessments of the Baltic Sea LME. The indicators will likely be used in HELCOM's thematic assessments on biodiversity, hazardous substances, and monitoring of biological effects of harmful substances.

New alien species appearing in the Baltic Sea have been the responsibility of the Lead Laboratory (LL) for Alien species. In the last 150 years, with accelerating speed over the last two decades, the Baltic Sea has received over 100 alien species, several of which may cause biodiversity loss and adverse environmental, economic and social impacts. Most of them have been transported and released into the Baltic Sea by ships, especially tankers releasing their ballast water. The best known alien fish species in the Baltic is the Ponto-Caspian round goby, *Neogobius melanostomus*. This 25 cm long, edible fish was first observed in the Gulf of Gdańsk in 1990. Today it is distributed all along the southern and eastern part of the Baltic Sea where its aggressive and territorial behavior dominates the habitat (Almqvist 2008). Its successful reproductive and opportunistic behavior makes it a threat to native fish species and their habitats. A recent invader to the Baltic Sea also represents a major threat to the ecosystem: the American comb jelly *Mneiopsis leidyi*. It was found for the first time in the southern Baltic in the Fall of 2006 and in the northern Baltic in 2007. Its abundance in August 2008 was 40-60% higher than in August 2007, thus indicating an adaptation to Baltic Sea conditions (Letiniemi 2008).

Fish and Fisheries

The commercially most important fish species in the open Baltic Sea are cod, herring, sprat and Baltic salmon. The total annual catch of these fish stocks has increased 10-fold during the past 50 years. Until the 1930s, catches remained at about 120,000 tonnes, then increased to about 500,000 tonnes in the late 1950s and, after a steep rise in the mid 1960s, reached almost a million tonnes by the end of the 1970s. In the last 20-30 years however, overfishing and the failure of fisheries management to maintain sustainable fisheries and conserve commercial fish stocks have become increasingly more pronounced. Nearly all commercially important fish stocks have been severely depleted and have been outside of safe biological limits due to decades of unsustainable fishing effort resulting from excessive fishing capacity and inappropriate fishing practices. Cod is the most important fish in the Baltic. From a maximum annual catch of cod in the mid 1980s of nearly 450,000 tonnes, the nominal catch steadily declined by 1992 to about 50,000 tonnes and has hovered around 100,000 tonnes since then (**Figure 3**).

Landings in Baltic Sea LME

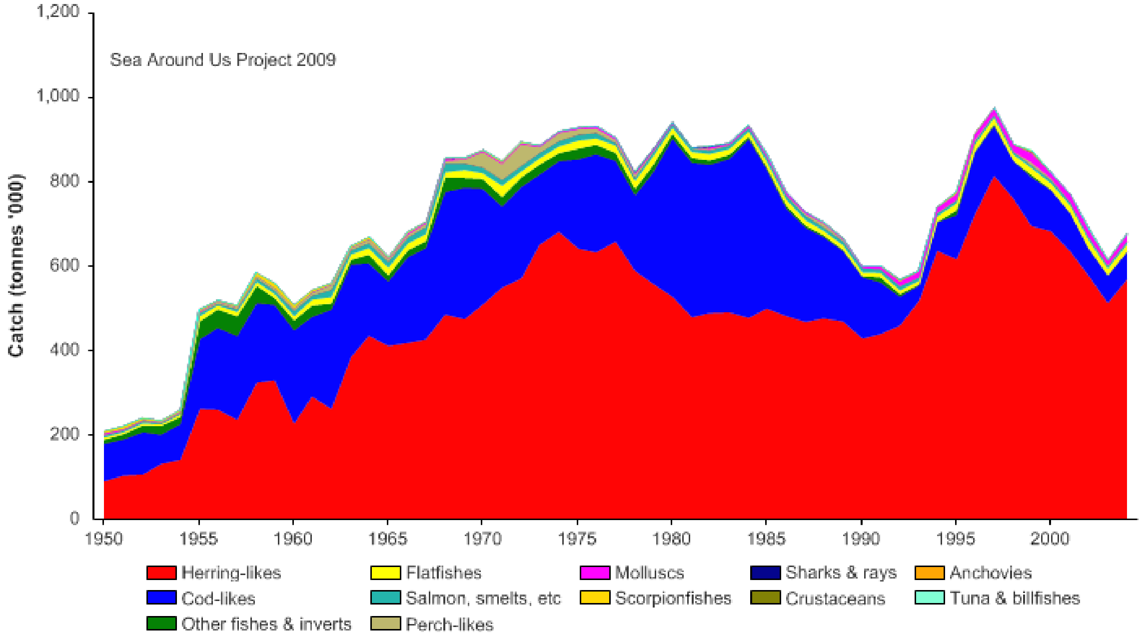

Figure 3. Fish landings in the Baltic Sea. Herring and cod are the most important fish species. From the SeaAroundUs Project at www.seaaroundus.org.

As a result of management failures due to the managing agencies setting cod total allowable catches (TACs) that have frequently exceeded the levels advised by ICES, the stock size of Baltic Sea cod reached its lowest level on record in 1991. Levels since then and up to 2007 have been close to this historic minimum. Overfishing of larger fish-eating fish, e.g. cod, has allowed increased industrial fishing of sprat and herring. The economic yield per unit biomass of the fishery has declined, with a smaller proportion of the catch being directed for human consumption and food security. Unsustainable fishing has also caused further impacts on marine ecosystems through by-catch and the discarding of fish, and on bottom living animals, seabirds and marine mammals. Bottom trawling has degraded vulnerable habitats. This has had a negative impact on ecosystem structure and function. Fisheries enforcement has been ineffective against bad fishing practices. Catch statistics misreport landings outside legal channels to the detriment of official statistics on catches and landings, the exceeding of quotas, fishing in closed areas and unacceptable discards. Where regional international regulatory commissions have agreed on remedial actions, there has often been a lack of political will at the national level to fully implement agreed actions to restore depleted fish stocks and protect marine ecosystems.

However, in the last two years, public awareness of the Baltic and its fish and fisheries, especially cod, has grown considerably in most of the Baltic riparian countries. The media has dealt in detail with the failure of the Common Fisheries Policy, and in Sweden, for example, the publication of the book “Tyst Hav” (Silent

Sea) which in a popular way deals with the political, biological and economical issues of Baltic fisheries, received a strong reaction from the public (Lovin 2007). As a result, people started to boycott cod, fish dealers stopped selling cod, restaurants stopped serving it, and NGOs red-listed many Baltic Sea fish species. In Poland, fishermen and fisheries officials admitted to the heavy overfishing of TACs and high frequency of illegal fishing. Baltic Sea managers had long been aware of the situation and had already prepared a recovery plan for the Baltic cod. For the first time in years, ICES made a statement about the eastern Baltic cod population in 2008 indicating that "an increase in spawning stock biomass has been observed since 2005 although it is still at a historical low level." ICES in 2008 classified the stock as being harvested sustainably (ICES 2008).

In 2003, the BSRP coordinator stated in an interview that "Baltic fisheries have to get rid of the Klondyke mentality and stop overfishing." He referred to a possible 30-50 percent gap between reported and real amounts of fish caught in the Baltic Sea (Baltic Times 2003). From the very start of the BSRP, the Coordination Center for Fish and Fisheries (CCFF) has been engaged in the improvement of fish stock assessments, data reporting and advisories. It has improved commercial fish stock assessments by extending survey areas into northern and coastal parts of the Baltic and by initiating joint surveys. It has improved on the quality of fish stock assessment data by coupling bottom trawling with pelagic acoustic surveys of the stocks and by harmonizing fish growth and feeding analysis methodology. The CCFF was also able to improve landing statistics by upgrading the biological data collection from commercial catches. In a series of workshops, the BSRP Lead Laboratory (LL) for Coastal Fish has acted as co-chair and has cooperated with HELCOM, ICES and the Swedish National Board of Fisheries to improve the coastal fish monitoring programmes around the Baltic Sea with an aim to contribute to overall assessments of the Baltic Sea LME.

Present and Future

In recent years and paralleling the activities of the BSRP a series of management and science activities, crucial for the future of the BSLME, have been initiated. A European Maritime Policy and a Marine Strategy have been developed by the European Commission for the Baltic Sea, considered as one of three European regional seas. For each regional sea the Marine Strategy calls on the parties to: (1) Assess the current environment status; (2) Define good ecological status; (3) Establish environmental targets and indicators; (4) Develop monitoring programs; and (5) Achieve good environmental status by 2020. For this activity, HELCOM has developed a Baltic Sea Action Plan (BSAP) which was adopted by the contracting parties at the end of 2007. The plan aims "to safeguard the Baltic's natural ecosystem while allowing valuable marine resources to be used sustainably in the future." The action plan is based on the ecosystem approach and is in a broad sense using the LME approach of the BSRP. In fact, the BSRP has been instrumental in the preparation of the action plan. For example, the plan will be based on Ecological Quality Objectives and indicators. The key issues prioritized for actions in the BSAP are eutrophication, hazardous substances, maritime activities, and biodiversity.

To address future needs for scientific advice ICES has produced a science plan built on the ecosystem approach, which integrates fisheries and environmental issues. One BSRP group that has been a driving force in this work of integration and in bridging ICES and HELCOM activities is the WG on Integrated assessment in the Baltic (WGIAB).). ICES has also been re-organized from thematic advisory committees to a single Science committee and a single Advisory Committee, both supported by expert groups.

Through the BSRP and its LME activities, ICES has become involved in an EU project called "Baltic Sea Science–a Network of Science Agencies" (BONUS). In 2005, this project was charged by the EU to produce a Baltic Sea science plan and implementation strategy. The task to accomplish this was given to BSRP/ ICES. This plan will convert research needs arising from management agencies into scientific questions to which the Baltic Sea science community can respond with research ideas. The Baltic Sea Science Plan is written in accordance with the LME concept and contains all its major elements (Figure 4) (Hopkins et al. 2006). In September 2007, the BONUS science plan called for project proposals. In June 2008, 16 projects were granted money for three years with a total budget of 22 million Euros.

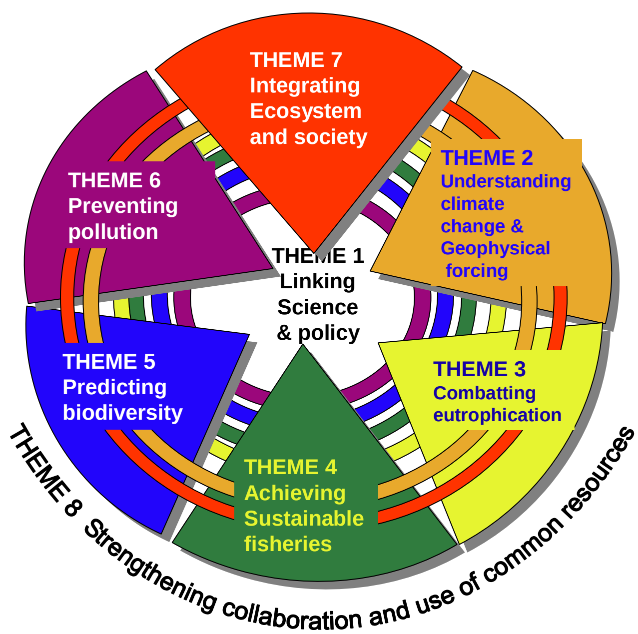

Figure 4. Illustration of the Baltic Sea Science Plan of the **BONUS** project.

To summarize the ecological and management status of the Baltic Sea Large Marine Ecosystem, we can state that it looks much brighter and more hopeful today than it did five years ago. There is public awareness of its environmental issues and a political will to improve and care for the marine environment and its resources.

BSRP activities were recently evaluated (ICR 2008) and it may be relevant to quote the last paragraph on lessons learned: "The lessons of the project have been incorporated into the BSAP, BONUS +, and other programs whereby they will inform improved management of the Baltic environment in the future." Through these initiatives, the Baltic Sea LME is also providing a pioneering example for implementation of the new EU Marine Strategy Directive, as well as global commitments made under the convention on Biological Diversity, The World Summit on sustainable Development and the Rio Declaration. Although the BSRP was officially completed in 2007, its spirit is still in the area, its network is still up and running and its footprint is clearly visible.

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Changing States of the Yellow Sea Large Marine Ecosystem: Anthropogenic Forcing and Climate Impacts

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The Yellow Sea Large Marine Ecosystem is a semi-enclosed shelf sea with distinctive bathymetry, hydrography, productivity, and trophically dependent populations. Shallow but rich in nutrients and resources, the Yellow Sea LME has productive and varied coastal, offshore, and transboundary fisheries. Over the past several decades, the resource populations in the Yellow Sea have changed greatly. Many valuable resources are threatened by unsustainable exploitation and by natural perturbations. To promote sustainable exploitation of the sea and implement effective management strategies is an important and urgent task.

The purpose of this chapter is to describe the Yellow Sea LME, emphasizing the changing states of productivity and biomass yields in the ecosystem and their causes, affected by both anthropogenic forcing and climate impacts. Suggestions for adaptation actions for ecosystem-based management in the LME are discussed in the final section.

The Setting

The Yellow Sea LME is located between continental North China and the Korean Peninsula. It is separated from the West Pacific Ocean by the East China Sea in the south, and is linked with the Bohai Sea, an arm of the Yellow Sea in the north. It covers an area of about 400,000 km^2, with a mean depth of 44 m. Most of the Sea is shallower than 80 m. The central part of the sea, traditionally called the Yellow Sea Basin, ranges in depth from 70 m to a maximum of 140 m.

The general circulation of the Yellow Sea LME is a basin-wide cyclonic gyre comprised of the Yellow Sea Coastal Current and the Yellow Sea Warm Current. The Yellow Sea Warm Current, a branch of the Tsushima Warm Current from the Kuroshio Region in the East China Sea, carries water of relatively high salinity (> 33 PSU) and high temperature (> 12°C) northward along 124°E and then westward, flowing into the Bohai Sea in winter.

This current, together with the coastal current flowing southward, plays an important role in exchanging the waters in this semi-enclosed sea (**Figure 1**).

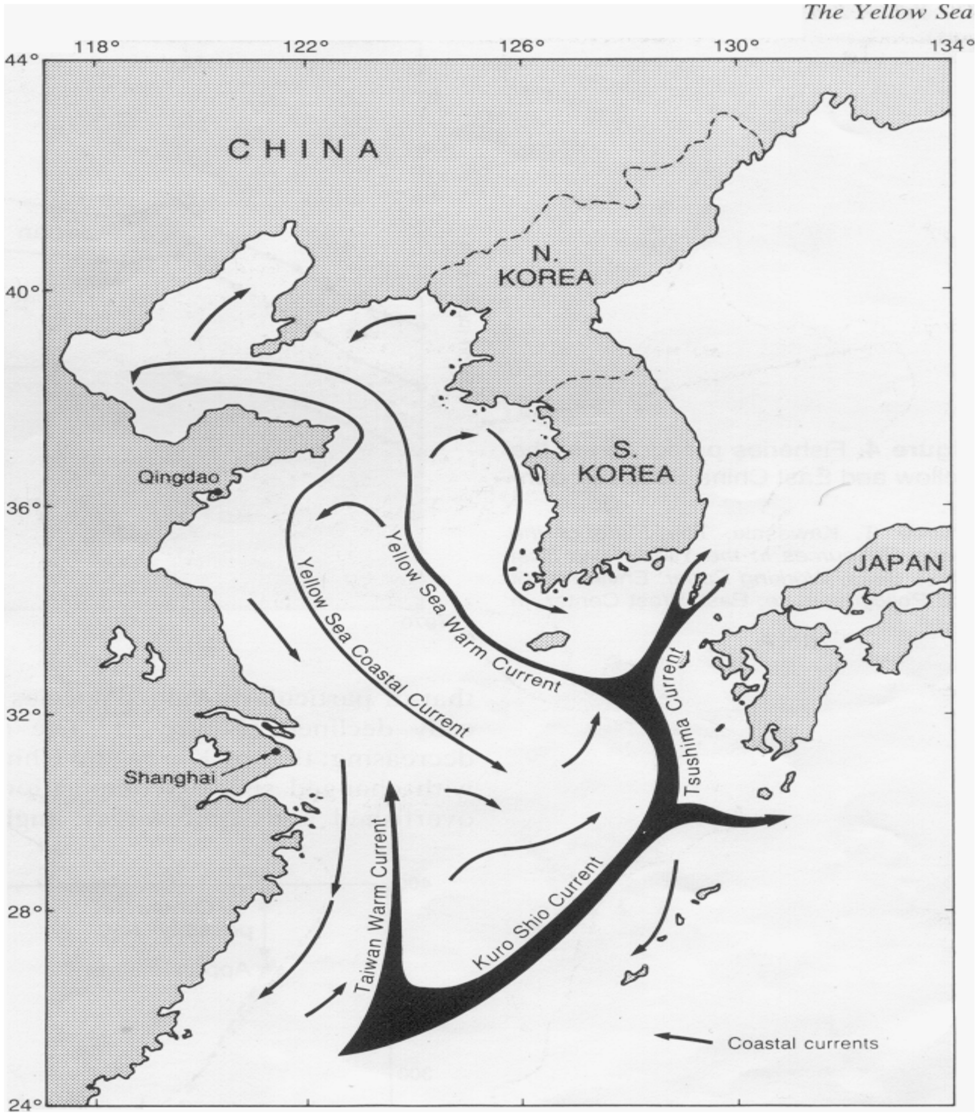

Figure 1. Schematic diagram of the winter current system in the Yellow Sea LME (from Gu *et al*. 1990).

Below 50 m, the Yellow Sea Cold Water Mass forms seasonally and is characterized by low temperature with the bottom temperature lower than 7°C in its central part. It is believed to be the remnant of local water lifted over from the previous winter due to the effect of cold air from the north (Ho *et al.* 1959; Guan 1963). Stratification is strongest in summer, with a vertical temperature gradient greater than 10°C/10 m. All rivers into the Yellow Sea LME have peak runoff in summer and minimum discharge in winter, which has important effects on salinity of the coastal waters.

The Yellow Sea LME lies in the warm temperate zone, and its communities are composed of species with various ecotypes. Warm temperate species are the major component of the biomass, accounting for about 60 percent of the total biomass of resource populations; warm water species and boreal species account for about 15 percent and 25 percent, respectively. The Yellow Sea LME food web is relatively complex, with at least four trophic levels (Tang 1993). There are two trophic pathways: pelagic and demersal. Japanese anchovy and macruran shrimp (e.g., *Crangon affinis* and southern rough shrimp) are keystone species. About 40 species, including almost all of the higher carnivores of the pelagic and demersal fish, and the cephalopods, feed on anchovy. *Crangon affinis* and southern rough shrimp, which are eaten by most demersal predators (about 26 species) are numerous and widespread in the Yellow Sea LME. These species occupy an intermediate position between major trophic levels and interlock the food chain to form the Yellow Sea food web.

The resource populations in the Yellow Sea LME are multispecies in nature. Approximately 100 species are commercially harvested, including demersal fish (about 66 %), pelagic fish (about 18 %), cephalopods (about 7 %), and crustaceans (about 9 %); about 20 major species accounted for 92 percent of the total biomass of the resource populations, and about 80 species accounted for the other 8 percent. With the introduction of bottom trawl vessels in the early twentieth century, many stocks began to be intensively exploited by Chinese, Korean, and Japanese fishermen (Xia 1960). The stocks remained fairly stable during World War II (Liu 1979). However, due to a remarkable increase in fishing effort and its expansion to the entire Yellow Sea LME, nearly all the major stocks were fully fished by the mid-1970s, and the resources in the ecosystem began to be over-fished in the 1980s (Tang 1989). Aquaculture is a major utilization of the Yellow Sea coastal waters. Major species of mariculture include scallops, oysters, clams, mussels, seaweed, shrimp and some fish.

Changing States of the Yellow Sea Ecosystem

(1) Changes in Ecosystem Biodiversity

Over the past 50 years, dramatic changes in species composition, dominant species and community structure of resource populations in the Yellow Sea LME have been observed — from small yellow croaker and hairtail in the 1950s and early 1960s to Pacific herring and chub mackerel in the 1970s to Japanese anchovy and sandlance after the 1980s. Small-sized, fast-growing, short-lived, and low-valued species increased markedly in abundance during the 1980s and assumed a prominent position in the ecosystem’s resources and food web thereafter (**Figure 2** and **Figure 3**).

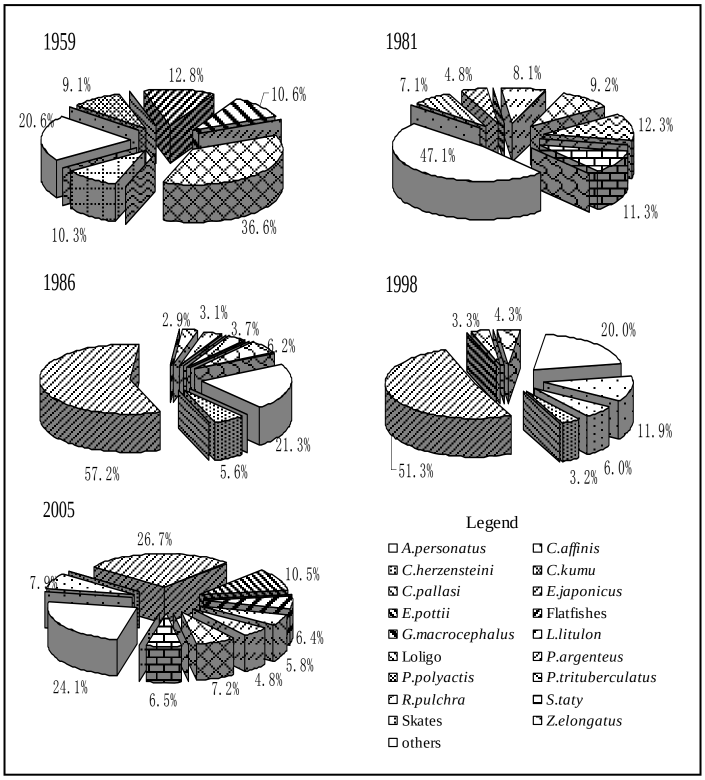

Figure 2. Changes in species composition of resource populations in the Yellow Sea LME (based on biomass yields data of spring survey).

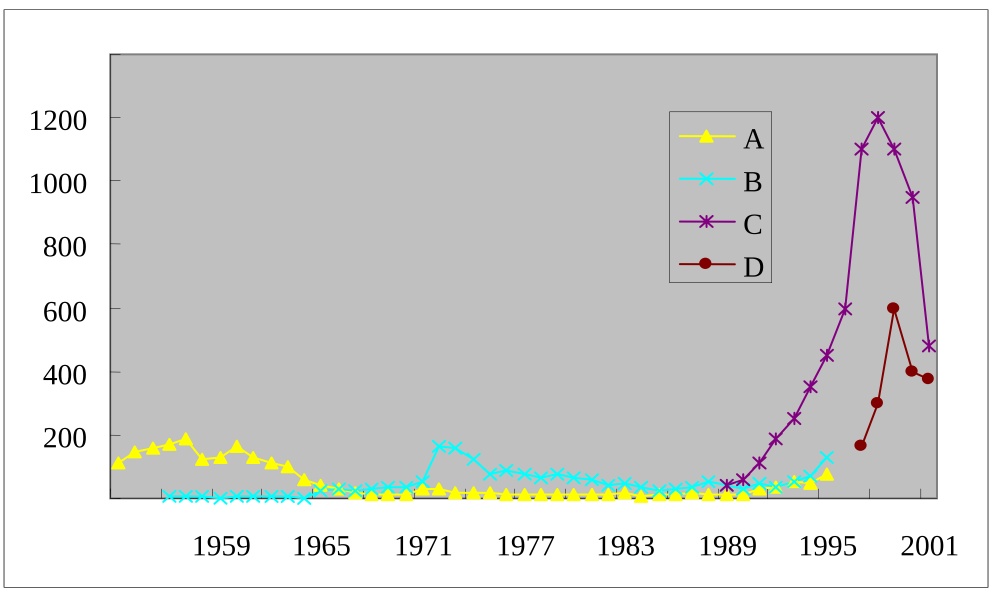

Figure 3. Changes of annual catch in dominant species of resource populations in the Yellow Sea: (A) small yellow croaker and hairtail, (B) Pacific herring and chub mackerel, (C) anchovy, and (D) sandlance.

As a result, larger, higher trophic level, and commercially important demersal species were replaced by smaller, lower trophic level, pelagic, less-valuable species. The most recent surveys indicate that the abundance of pelagic species such as the Japanese anchovy is declining, while the biomass of demersal species is increasing (**Figure 4**). The stock of small yellow croaker has shown a recovery trend since middle 1990s.

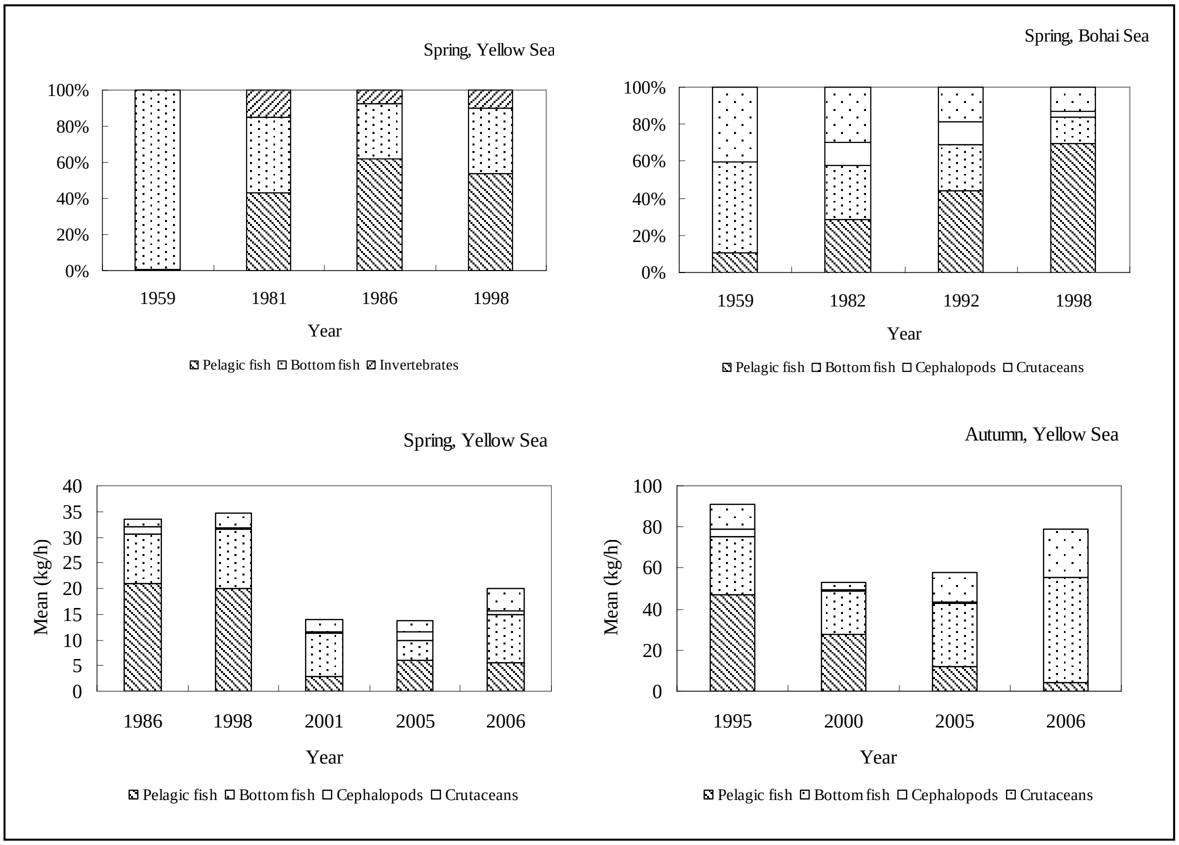

Figure 4. Changes in community structure of resource populations in the Yellow Sea LME (based on biomass yields data of survey).

Changes in Ecosystem Productivity

Annual variation of ecosystem productivity has been observed in the Yellow Sea LME. As shown in **Figure 5**, primary productivity in the Bohai Sea decreased noticeably from 1982 to 1998. Over the past 40 years, a trend of obvious decline of phytoplankton biomass has been observed, seemingly linked with nutrient changes (Tang 2003). Zooplankton is an important component in Yellow Sea communities. The dominant species, *Calanus sinicus*, *Euphausia pacifica*, *Sagitta crassa*, and *Themisto gracilipes*, are all important food for pelagic and demersal fish and invertebrates. The annual biomass of zooplankton in the Bohai

Sea has decreased noticeably since 1959. However, zooplankton biomass increased in the sea in 1998, possibly due to the decline of the anchovy stock, which was the most abundant species before 1998. Fish stocks have decreased since the 1980s, although biomass yields were at a high level in 1998-2000 in the Yellow Sea LME. As a result, the trophic level of fish stocks declined from 4.1 in 1959-60 to 3.4 in 1998-99 in the Bohai Sea; and from 3.7 in 1985-86 to 3.4 in 2000-01 in the Yellow Sea (Zhang and Tang 2004). `

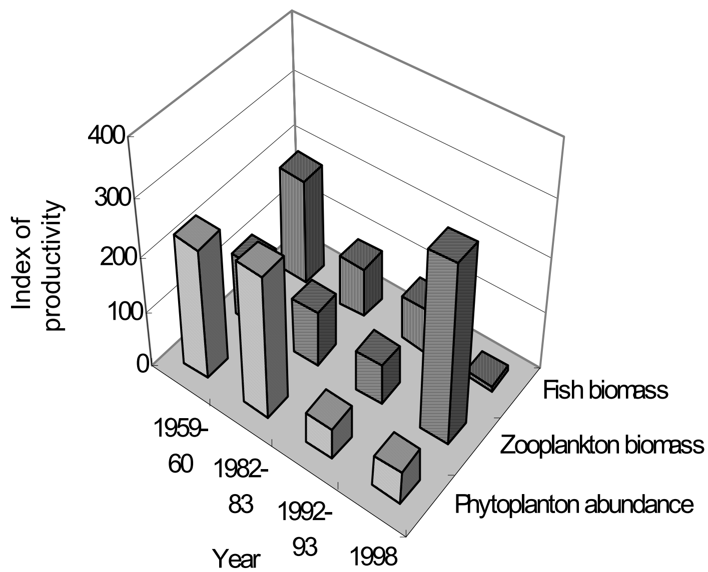

Figure 5. Decadal-scale variations of ecosystem productivity at different trophic levels in the Bohai Sea (phytoplankton abundance, $\times 10^4$cell m^{-3}, zooplankton biomass, mg m^{-3}, fish biomass, kg $haul^{-1}$ h^{-1}; from Tang et al. 2003.

Changes in Ecosystem Health

Major pollutants entering the Yellow Sea LME are organic material, oil, heavy metals and pesticides. Pollutants from municipal, industrial and agricultural wastes and run-off, as well as atmospheric deposition, are 'fertilizing' coastal areas triggering harmful algal blooms and oxygen deficient 'dead zones'. The harmful algal blooms and low levels of dissolved oxygen in the water make it difficult for fish, benthic fauna and other marine creatures to survive and for related social and economic activities to be sustainable. Since the 1970s, the annual mean of water temperature and dissolved nitrogen in the sea increased by 1.7°C and 2.95 μmol $L^{-1,}$ respectively, while those of dissolved oxygen, phosphorus, and silicon decreased by 59.1, 0.1 and 3.93 μmol L^{-1}, respectively (Lin *et al.* 2005). As a result, the frequency of occurrence of harmful algal blooms has gradually increased, and the size of hypoxic areas (where DO≤2mg/l) is on the rise in coastal areas (**Figure 6**). These events affect the most productive areas of the marine environment leading to the destruction of habitats of vital importance for maintaining ecosystem health.

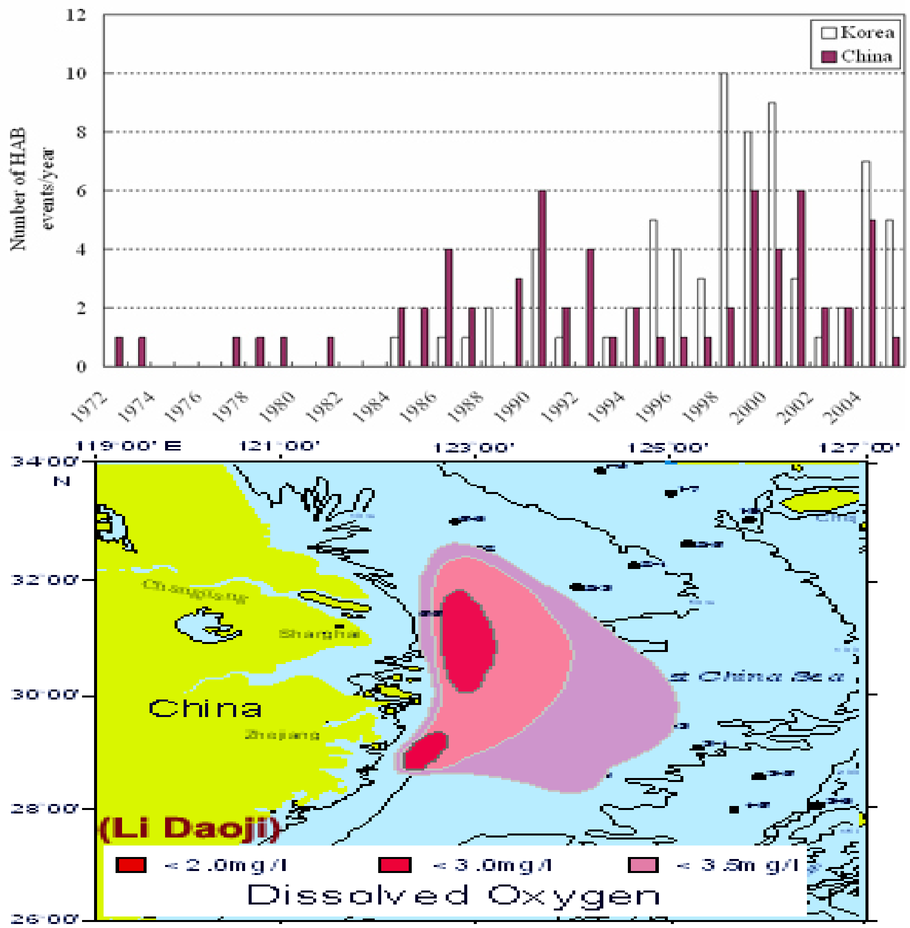

Figure 6. Serious eutrophication, harmful algal blooms and dead zones in coastal areas.

Changing Courses

Generally speaking, changes in the quantity and quality of marine ecosystem resources are attributed principally to human predation, as demonstrated by many studies (e.g., Tang 1989, 1993; Zhang and Kim 1999). However, an analysis of inter-decadal variations of ecosystem production in the Bohai Sea indicates that it is difficult to use traditional theory (e.g. top-down control, bottom-up, or wasp-waist control) to explain directly and clearly the long-term variations of production levels in the coastal ecosystem (Tang *et al.* 2003). We observe that under the same fishing pressure, the biomass yields of some exploited stocks in the Yellow Sea appear to be fairly stable (e.g. Spanish mackerel), or recovered (e.g. small yellow croaker). Changes in biomass yields and species shifts in dominance cannot be explained merely by fishing pressure. Climate change may have important effects on the recruitment of pelagic species and shellfish in the Yellow Sea LME. A new study identifies four SST regimes in the Yellow Sea LME over the past 138 years: a warm regime (W) before 1900, a cold regime (C) from 1901 to 1944, a warm regime with a cooling trend (WC) from 1945 to 1976, and a warm regime with a warming trend (WW) from 1977 to 2007 (**Figure 7**). SST regime shifts and fluctuations in herring abundance in the Yellow Sea LME show a very good match.

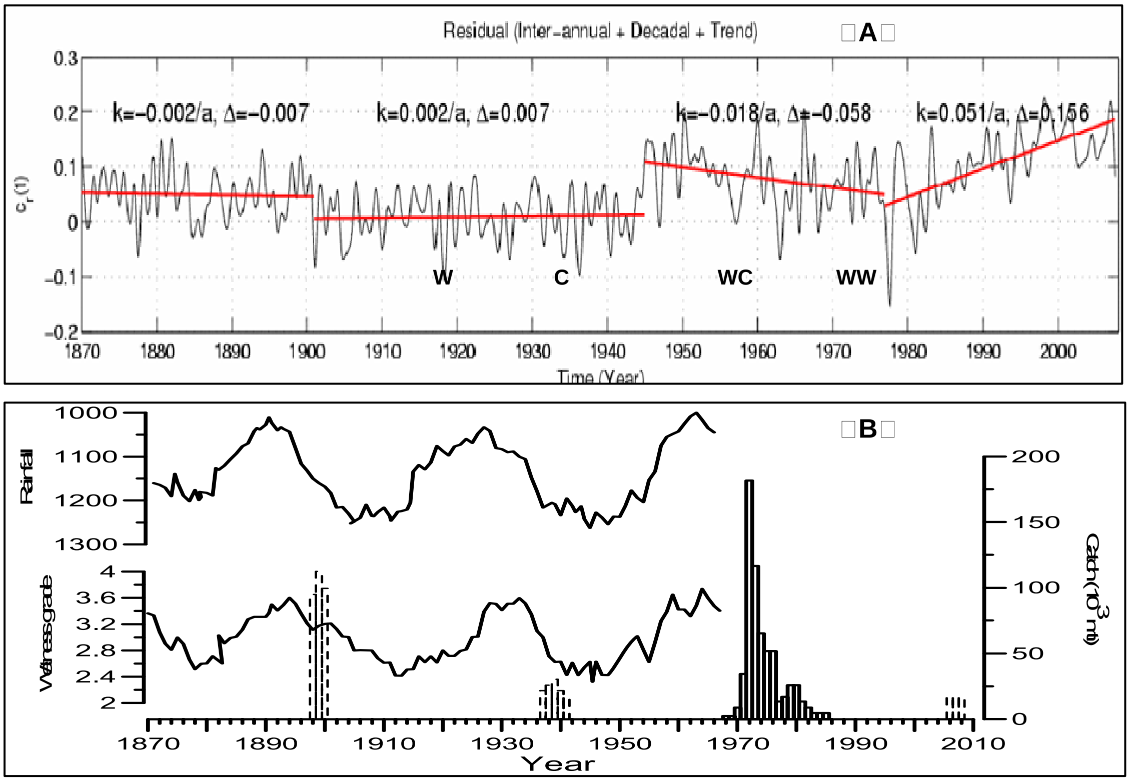

Figure 7. (A) The residual SST after removing its annual signal. W, C, WC and WW refer to the four regimes characterized by, respectively, warm, cold, warm with cooling trend, and warm with warming trend (unpublished data, from Daji Huang et al.); **(B)** Relationship between the fluctuations in herring abundance of the Yellow Sea and the 36-yr cycle of wetness oscillation in eastern China (adapted from Tang 1981).

Pacific herring in the Yellow Sea LME has a long history of extreme variability in exploitation. In the last century, the commercial fishery experienced three peaks (1900, 1938 and 1972), followed by periods of little or no catch (Tang 1995). Since 2005, both herring stocks and eelgrass, where herring spawn, have increased in Sungo Bay, a former major herring spawning ground and now a large scale mariculture area. However, the recovery is not complete. At the same time, several unusual events have occurred in the coastal areas. A false killer whale visited Qingdao Bay. The last time local people saw false killer whales was more than 30 years ago. On 18 January 2008, a sperm whale landed on 'Herring Beach' in Sungo Bay. This was the first time local people saw a species this large (body length, 19.6 m; weight, 51.1 t). We believe that there may be two types of shifts in ecosystem resources: systematic replacement and ecological replacement. Systematic replacement occurs when one dominant species declines in abundance or is depleted by overexploitation, and another competitive species uses the surplus food and vacant space to increase its abundance. Ecological replacement occurs when minor changes in the natural environment affect stock abundance, especially pelagic species. In the long term, the effects of the two types of shifts on the marine ecosystem may be mingled. The regime shifts in the Yellow Sea LME are likely to have important effects on ecosystem resources as found in other areas of the North Pacific Ocean.

Adaptation Actions

Mitigation and Recovery Practice

There are many ways to recover the resources in a stressed LME, such as reducing excessive fishing mortality, controlling point sources of pollution, and gaining a better understanding of the effects of natural perturbations. After 1995, China closed fishing in the Yellow Sea and East China Sea LMEs for 2-3 months in the summer. This fishing ban has effectively protected juvenile fish, leading to an increase in the quantity and quality of fish catches. In addition to these efforts, artificial enhancement in the Yellow Sea LME has been encouraged. Since 1984, the release of penaeid shrimps in the Bohai Sea, the north Yellow Sea and in the southern waters off the Shandong Peninsula has achieved remarkable ecological, social, and economic benefits. The release of scallops, abalone, and arkshell was also successful. These successes point the way forward for artificial enhancement programs in the Yellow Sea LME, and also bring hope for the recovery of ecosystem resources. Artificial enhancement practices are an effective resource recovery strategy that should be expanded to the LME scale.

In studies of the trophodynamics of many important species at high trophic levels, we observed a negative relationship between ecological conversion efficiency and trophic level (**Figure 8**). This new finding indicates that the ecological efficiency of species at the same trophic levels would increase when fishing down marine food webs at lower trophic levels. Based on this new finding, several ecosystem-based management strategies should be considered:

- **Develop a new harvest strategy**: the strategy of ecosystem resource use and management depends on different requirements. If we are concerned with big fish, **A** (harvest species at high trophic levels) will be selected; if we want more seafood, **B** (harvest species at low trophic levels) will be selected. In the case of China, **B** should be selected.

- **Develop a new mariculture model:** integrated multi-trophic aquaculture (IMTA), and shellfish and seaweed mariculture (e.g. scallop, oyster, mussel, clam, Laminaria) should be given priority, because these species not only provide more production but also indirectly or directly reduce atmospheric CO_2 (Zhang *et al.* 2005).

Scientific Support

An essential component of effective ecosystem management is the inclusion of a scientifically based strategy to monitor and assess the changing states and health of the ecosystem by tracking key biological and environmental parameters (Sherman and Laughlin 1992; Sherman 1995). Under this requirement the Strategic Action Program supported by the Global Environmental Facility (GEF) for the Yellow Sea LME is currently underway. (UNDP/GEF 2009)

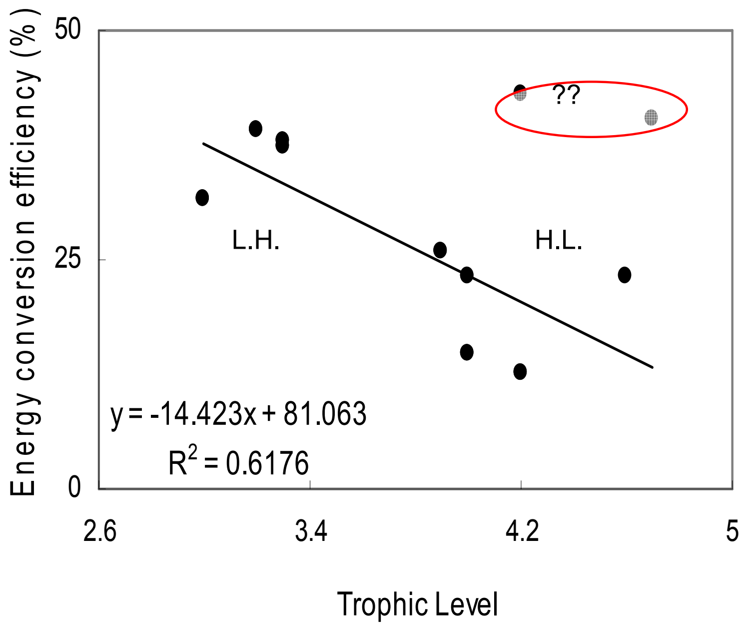

Figure 8. The relationship between ecological conversion efficiency and trophic level in high trophic levels in the Yellow Sea ecosystem, (LH), low Trophic level (TL) and high Energy Conversion Efficiency (ECE): rednose anchovy, sand lance, gizzard shad and finespot goby. H.L., high TL and low ECE: red seabream, black porgy, tiger puffer, fat greenling, black rockfish, and chub mackerel. From Tang et al. 2007.

The long-term objective of the project is to ensure environmentally sustainable management and use of the Yellow Sea LME and its watershed by reducing stress and promoting the sustainable development of a marine ecosystem that is bordered by a densely populated, heavily urbanized, and industrialized coastal area (Project Brief of the Yellow Sea LME, 2000). In order to further understand the Yellow Sea LME, the ongoing China-GLOBEC III/IMBER I Program, entitled “Key Processes and Sustainable Mechanisms of Ecosystem Food Production in the Coastal Ocean of China” (Tang *et al.* 2005), has been approved for the National Key Basic Research and Development Plan of the People’s Republic of China (2006-2010). The program goals are to identify key processes of food production in the coastal and shelf ecosystems and provide a scientific basis for ensuring food supply in the new century, by establishing a marine management system based on sustainable food production and protection of the ecosystem before the year 2015. Therefore, it is necessary to promote further synergies with other research projects and establish joint programmes for monitoring and assessment for ecosystem-based management in the Yellow Sea LME:

- Monitoring and assessing the changing states and health of the ecosystem represents a scientifically based strategy for effective ecosystem management and recovery.
- A comprehensive process-oriented study of ecosystem goods and services should be considered, for a better understanding of the interactions among the important physical, chemical and biological characteristics of the ecosystem. This will increase the predictive capability of Yellow Sea LME managers.

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Some Considerations of Fisheries Management in the Yellow Sea Large Marine Ecosystem

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426-744 Republic of Korea

Background Information from TDA and SAP

In 2007 the UNDP/GEF Yellow Sea Large Marine Ecosystem (YSLME) Project published the Transboundary Diagnostic Analysis (TDA) (UNDP/GEF 2007a). This report identifies the environmental issues and problems, outlines the root causes and provides suggestions for management interventions. Under the fisheries section, the major problems were a decline in the catch of some commercial species and a change in the composition of the fisheries catches with an increase in the landings of low value species (UNDP/GEF 2007a) based on scientific findings (Jin 2003; Jin and Tang 1996; Zhang et al. 2007). The root cause was identified as overexploitation of fish stocks as a result of over capacity in the fishing fleets of China and Republic of Korea.

In response to the identified problems, the Strategic Action Programme (SAP) for the YSLME set 2 targets for capture fisheries to be realised by the year 2020: (i) a 25-30% reduction in fishing effort; and (ii) the rebuilding of fish stocks (UNDP/GEF 2009). To achieve these targets various management actions are recommended such as: a reduction by 25-30% of boat numbers with strict control in the building of new boats; the closure of areas and seasons for fishing to protect spawning fish and nursery grounds; improved monitoring, an increase in the mesh size to reduce the catch of juvenile and introduction of more selective gears; continued use of habitat improvement and stock enhancement using healthy, genetically diverse fry; and the introduction of individual transferable quotas (ITQs) and ecosystem based management of the existing fisheries.

Both China and the Republic of Korea are already implementing many of the proposed management actions and both are firmly committed to reducing fishing effort. Under the current 5 year plan ending in 2010 China plans to reduce the number of fishing boats by 10% and the marine catch by 15%; and by the year 2020 aims to reduce the fishing fleet and marine catch by 33%. To implement these plans the Chinese government has invested significant funds, more than 270 million Yuan each year for scrapping old fishing boats, with extra funding from local governments, and an additional 90 million Yuan specifically for enforcement of fisheries legislation. Further funds are also available for retraining, job creation and tax breaks for ex-fishermen and for stock enhancement and habitat improvement. The Republic of Korea has invested similar amounts with over a million US dollars invested in boat-buy back annually.

Logical Considerations on the Management Actions

In order to solve the identified problem of over-fishing, there is a need to reduce fishing effort. However, cutting fish catches by one third will leave China, in particular, with a substantial deficit in fish protein. Until stocks recover, there is a need to make up this shortfall with protein provided by marine aquaculture or mariculture. To ensure the negative impacts from mariculture are minimized, while productivity is enhanced, the issue of sustainability needs to be addressed. One of the solutions from the management actions of YSLME is to introduce integrated multi-trophic aquaculture (Figure 1).

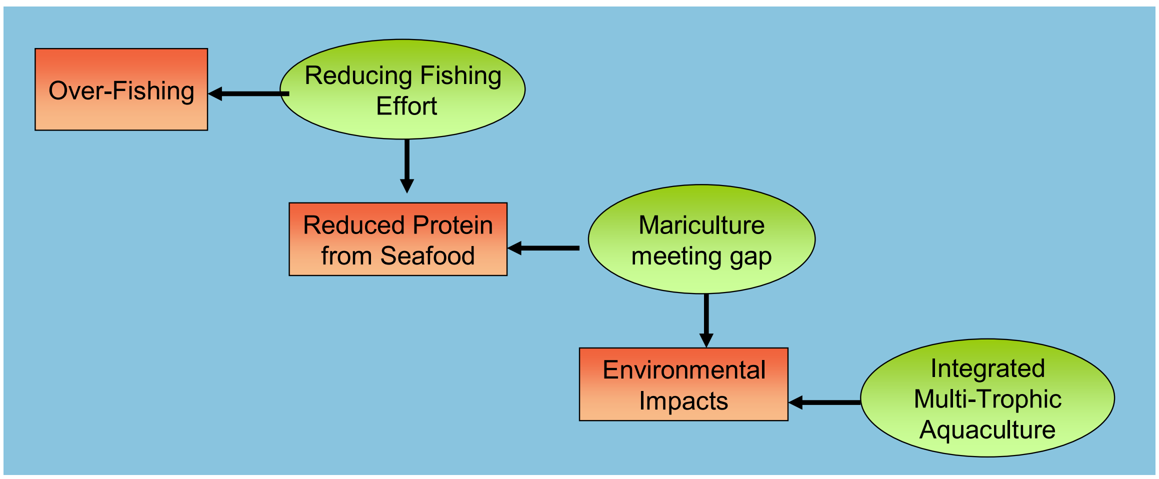

Figure 1. Logical considerations of management implementation

Currently, the total capture fishery production is almost 15 million tonnes annually (1998-2007) (FAO 2009). To compensate for the initial shortfall in fish catches, production from mariculture will have to increase, and indeed production in China has already dramatically increased from 5 to more than 30 million tonnes in the last 20 years (Figure 2) and there is high probability of this growth continuing. However, finfish/crustacean production has only reached 310,000 tonnes (UNDP/GEF 2007b). Just in order to compensate for the decreased wild catch from the Yellow Sea, production needs to rise by over a million tonnes by 2020. Moreover, to keep pace with the likely increase in demand for fish, shrimp and other crustaceans from an increasingly wealthy population could require a six or seven fold rise in production. This is going to be quite a challenge given the spatial and environmental constraints. Unregulated mariculture can have huge environmental impacts contributing to the already stressed coastal environment through inputs of nutrients and chemicals, the introduction of disease causing pathogens and alien species. As a result of the increase in stress, survival and growth of the cultured organism suffers and productivity decreases. This has already happened. Moreover, most fish and crustacean culture requires large amounts of fish protein and fish oil that comes from species which in many parts of the world and particularly in China and R. Korea, are consumed by humans.

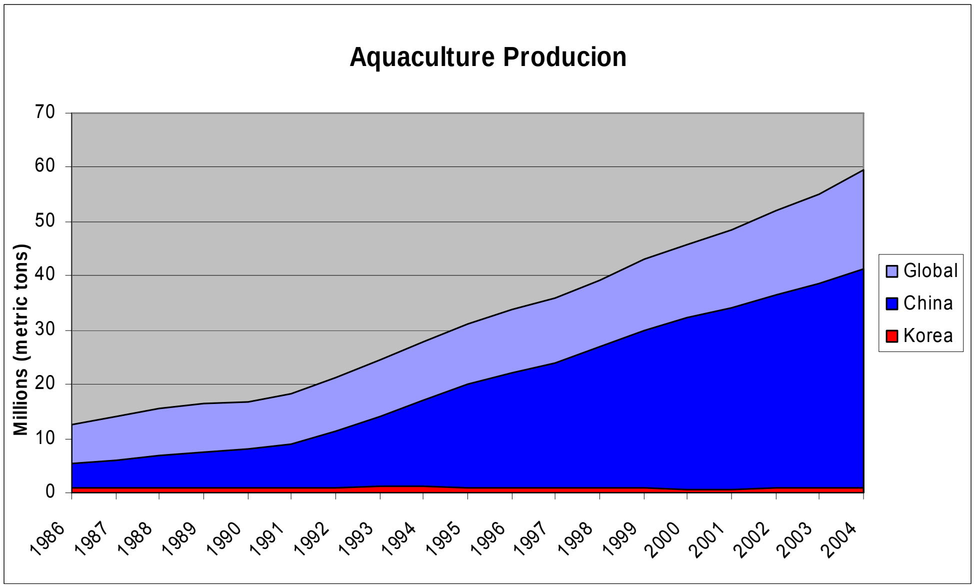

Figure 2. Aquaculture production (fresh, salt and brackish water culture) since 1986 (millions of tonnes).

The YSLME project is using a novel approach in environmental management. We realise that every management decision and all human activities have an impact on more than one sector of the marine environment. We, therefore, decided to use the idea of ecosystem carrying capacity (ECC) as defined as the sum of the ecosystem services (provisioning, regulating, supporting and cultural) that benefit mankind. This helps conceptualise the idea that all ecosystem services are linked and interdependent. Consequently, ecosystem based management is the only logical method for managing the environment, as traditional sector-based approaches cannot manage these inter-linkages inferred in ecosystem carrying capacity. For example, reducing fishing effort by 25-30% will not necessarily result in the recovery of fish stocks. We also need to manage the other impacts on the ECC. Hence, the YSLME SAP also sets targets for reducing pollution, improving sustainability of mariculture, and controlling habitat loss as these all affect fisheries production.

Current Capture Fisheries Activities.

The SAP proposed a target of a 25-30 % reduction of fishing effort to be achieved through: the control of boat numbers with 25-30% of the fishing fleets being decommissioned by 2020; the stopping of fishing in certain areas and seasons, to protect vulnerable stocks or life stages of certain species; and improved monitoring and assessment of fish stocks (UNDP/GEF 2009). The SAP also proposed that fish stocks should be rebuilt through: an increase in mesh sizes and the use of more selective fishing gear; stock enhancement by restocking of overexploited stocks and through habitat improvement; and improved fisheries management and the use of Total Allowable Catch (TAC) and Individual Transferable Quotas (ITQ) (UNDP/GEF 2009).

Currently there are three activities to demonstrate the effectiveness of these fisheries SAP management actions:

a) Demonstrate the effectiveness of closed areas and seasons in fisheries management.
   Outputs: Assessment of the reduction in fishing effort due to closed areas and seasons, and their impact on fish stocks and fish catches.
   Progress: Monitoring the catches of selected fishing boats before and after the area closures, carrying out a cost benefit analysis of the area closures, and collecting historical records to compare the species composition changes that are currently being recorded after the area closure.

b) Demonstrate the effectiveness of stock enhancement
   Outputs: Assessment of the effectiveness of the release of hatchery-raised juvenile olive flounder (*Paralichthys olivaceus*) in rebuilding fish stocks using mark-recapture techniques in Shandong province. Assessment of restocking of Chinese fleshy shrimp (*Fenneropenaeus chinensis*) in Liaoning province.
   Progress: Currently monitoring the recaptures and conducting independent trawl surveys.

c) Demonstrate the effectiveness of boat-buy back
   Outputs: Description of the success of the R. Korea government's fishing boat buy-back and its impact on reducing fishing effort.
   Progress: Currently interviewing fisherfolk to assess the perception of the impact on fish stocks and assessing the government's policy on reducing fishing effort.

The project is also involved in the organisation of the first ever joint regional fisheries stock assessment exercise between China and R. Korea. The results are currently being analysed. Early results of harmonisation exercises in ageing of fish and stomach contents analysis suggest that diets of fish species on each side of the Yellow Sea are very different and that earlier differences in growth rates in such fish as small yellow croaker and chub mackerel maybe real and not the result of differences in measuring techniques as previously suggested. These surveys have now sparked interest in further collaboration.

The assessment also showed that jellyfish occupied as much as 86% by weight of the total autumn catch in the west side of the Yellow Sea and that the species of the jellyfish in the east and west sides are different. These findings provided important scientific information to improve management of the Yellow Sea ecosystem.

Current Mariculture Activities

Although finfish and crustacean production have made substantial improvements in recent times, their culture has one of the worst environmental records in the industry. The increased demand for fish protein as a result of the decreased wild catches and increased wealth of the population presents some serious challenges for both China and R. Korea. To ensure that this increase in fish and shrimp production is sustainable, the SAP proposed a target of an improvement in mariculture techniques to reduce environmental impact by: developing and promoting environmentally friendly mariculture techniques; reducing nutrient discharges from mariculture facilities; and controlling disease.

Currently there are two demonstration activities on integrated multi-trophic aquaculture (IMTA) and heterotrophic shrimp culture that will show producers how increased productivity and profitability can be achieved without damaging the environment.

a) IMTA

   Polyculture is where two or more species are cultured together, usually with some added benefit in terms of productivity. IMTA is a type of polyculture where species from different trophic levels (eg. algae, fish and oysters) are cultured together so that the waste products of one species are utilised by another (Figure 3).

   In Sanggou Bay on the eastern tip of Shandong province, a number of different IMTA systems are being tested and evaluated. In China, more than 11 million tonnes of shellfish were cultured in 2006 (Fang et al. 2009). Shellfish (mollusc) culture is often associated with environmental impacts due to organic enrichment of the sediments associated with the increased sedimentation rates from the production of pseudofaeces and faeces produced by the molluscs (oysters, clams, scallops, etc). This enrichment can result in anoxic conditions causing changes in the benthic community toward domination by opportunistic polychaetes. However a recent study in Sanggou Bay, suggested that despite 20 years of mariculture, it had avoided the environmental impacts associated with shellfish culture in other parts of the world as a result of the low culture density, the current regime and the co-culture of oxygen-producing seaweed that prevent anoxia in the sediments (Fang et al. 2009).

   As farmers switch to the more profitable shellfish and fish culture, demands on the environment will increase. To counteract this, the YSLME project is promoting the use of IMTA and the concept of carrying capacity. Carrying capacity models together with adaptive management can be used to optimize the culture density of various species so that nutrient flows are balanced and the environmental condition is maintained (Figure 4).

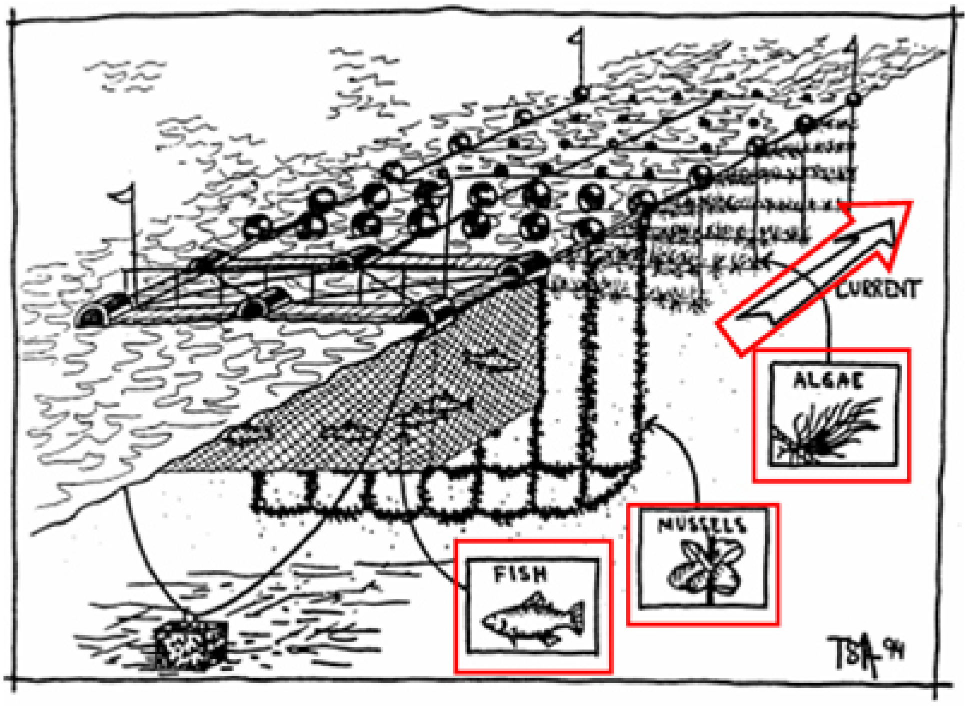

Figure 3. Diagrammatic representation of IMTA from Troell and Norberg (1998)

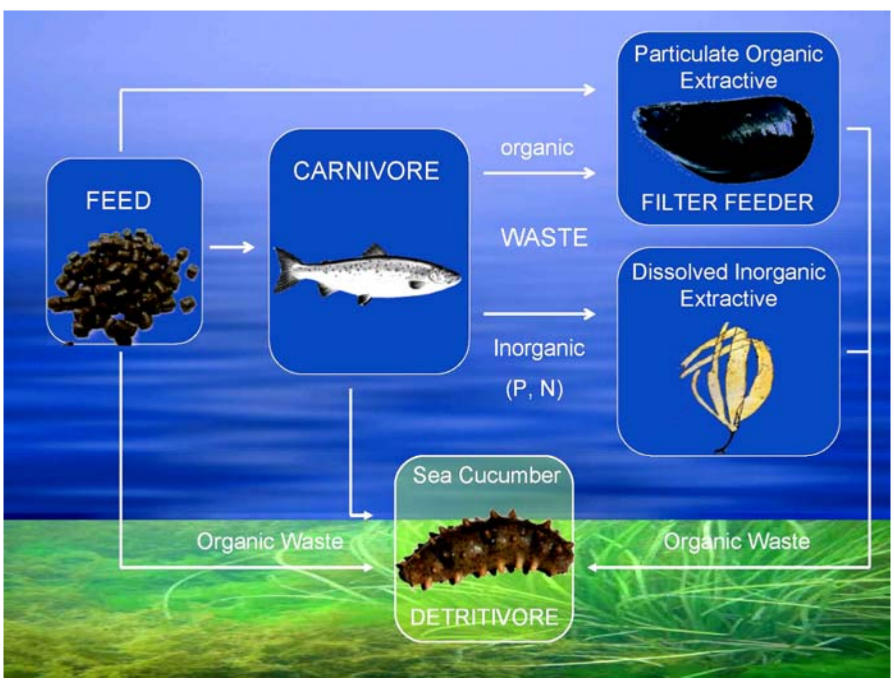

Figure 4. IMTA concept: The particulate waste in the water column is removed by filter feeding bivalves, while the portion that ends on the seafloor is utilised by sea cucumbers. The dissolved inorganic nutrients (N, P & CO_2) are absorbed by the seaweed that also produces oxygen, which in turn is used by the other cultured organisms. Modified from (Fang et al. 2009)

(i) IMTA of abalone and kelp

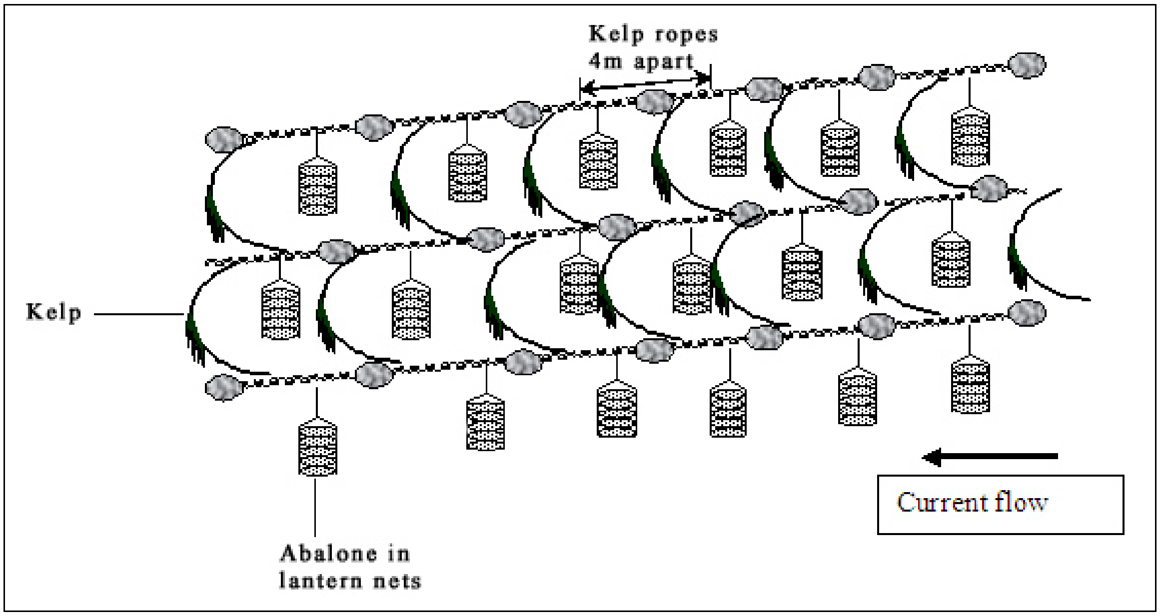

Figure 5. Diagrammatic representation of IMTA of long-line culture abalone and kelp

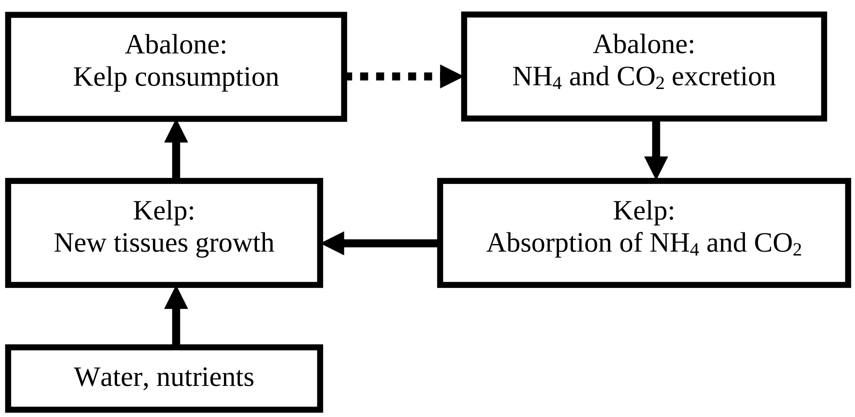

Figure 6. Diagrammatic representation of nutrient flows in IMTA of long-line culture abalone and kelp

The excretory products of the abalone are absorbed by the kelp, a small proportion of which is then used for feeding the abalone (Figures 5 and 6).

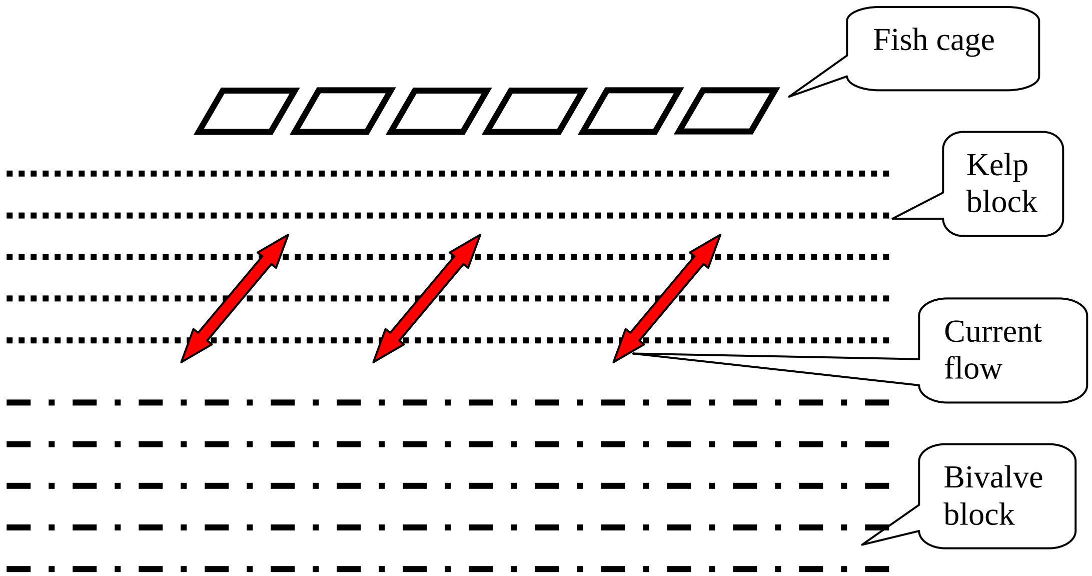

Figure 7. Diagrammatic representation of IMTA of long-line bivalve and kelp culture with cage culture of finfish

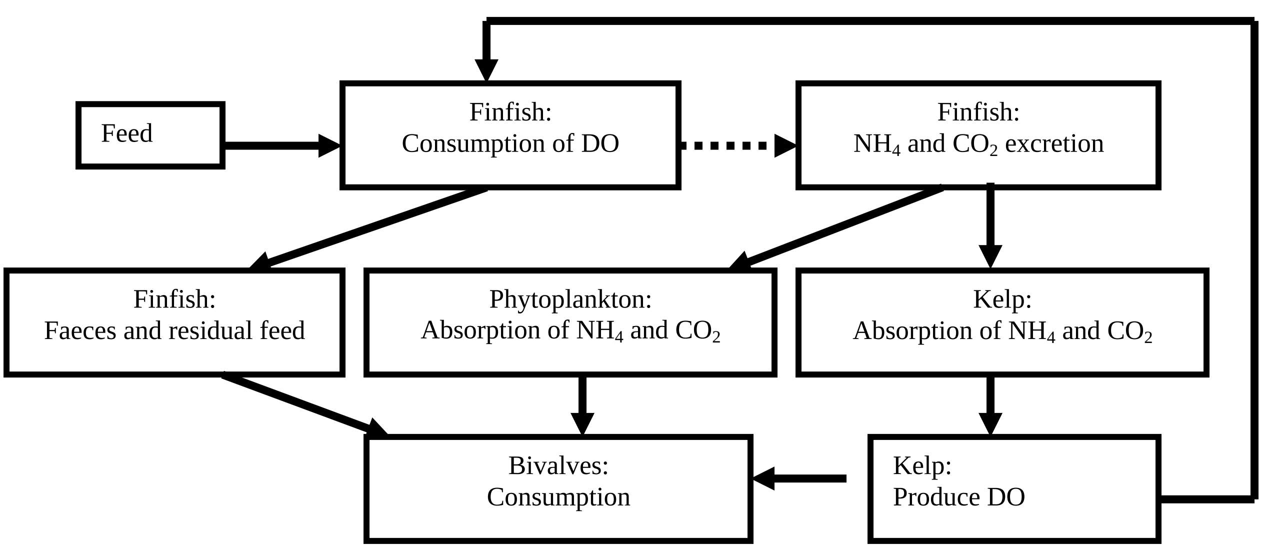

Figure 8. Diagrammatic representation of nutrient flows in IMTA of long-line culture finfish, bivalve and kelp

The purpose of this activity is to demonstrate:

- How nutrient flows can be balanced so there is no detrimental effect of eutrophication (Figures 7 and 8).
- How far productivity can be increased as a result of optimizing the densities of the various culture species, without over-stretching the carrying capacity of the bay and through utilizing the 3 dimensional culture space.
- How the profitability of these systems can be increased as a result of integration.

Heterotrophic shrimp culture

Shrimp culture is one of the most important mariculture industries in both China and R. Korea, but traditional methods using intensive or semi-intensive technology have a number of associated environmental impacts that have tainted the industry such as:

- The release of nutrients and particulates from the pond during water exchange can cause coastal eutrophication and smother benthic organisms.
- Outflows can also contain disease causing pathogens or parasites that may affect wild stocks.
- Large amounts of fish protein are used in production of cultured shrimp, competing with the local population for fish catches.
- Large areas are required for shrimp cultivation often competing with other users such as farmers or with natural coastal habitats. The conversion of these habitats can have unforeseen consequences due to the loss of ecosystem services.

Recently the industry in both China and R. Korea has suffered from decreased productivity due to disease and water quality problems.

Heterotrophic shrimp culture is a more stable method of shrimp culture that encourages the growth of bacterial flocs through the addition of a carbohydrate source and intensive aeration that keeps particulates in suspension. These bacterial flocs use the eaten food and shrimp wastes as a nitrogen source to increase biomass and hence recycle the food as they are consumed by the shrimp. This in turn reduces the percentage of fish protein required in diet hence reducing the amount of fish protein used in the production of shrimp as the food is used more effectively and food conversion ratios (FCRs) become closer to 1 (i.e. 1 kg shrimp produced using 1 kg feed).

This recycling of nutrients means that the water quality remains stable and no water exchange is needed, except some freshwater to allow for evaporation, which reduces the outflow of nutrients, pathogens and chemicals to the environment. It also means that there are no incoming diseases, therefore survival is much higher. The stability of the water quality means that much higher culture densities can be obtained, reducing the need for the huge pond areas, and the competition for space with other users.

Progress: Initial trials are very promising, stocking densities of 300 *Litopenaeus vannamei* juveniles per m^2 (traditional stocking densities are 15-30 shrimp/m^2) in outdoor lined ponds resulted in a production of almost 2.72 kg/m^2/crop and food conversion ratios (FCRs) of 1.39 over 3 month's culture achieving an average body weight of 12.5 g with survival rates in excess of 70%. Indoor raceways have achieved a production of >20 kg/m^2/year with 2.5 crops per year, this more than 70 times higher than traditional pond culture (Jang 2009). Nursery culture has also been very successful resulting in even lower FCRs at densities of up to 5000 post larvae /m^2.

Recently two new indoor commercial scale culture tanks were constructed offering even better bio-security and enhanced water quality control and, at the tanks' inauguration, a number of aquaculture farmers expressed interest in this new technology; one commercial farm is currently in operation.

Integrated Multi-trophic Aquaculture summary

Both these methods offer the opportunity of enhancing mariculture productivity to compensate for the shortfall in capture fisheries production following cuts in fisheries effort. These methods offer a way to increase production without also increasing negative impacts on both ecosystem health and fisheries production.

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The IUCN Support of Marine Protected Area Sites within Large Marine Ecosystems

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Professor Dan Laffoley, Vice Chair, WCPA Thematic Team Leader for the Marine Biome

Photo: Nancy Sefton

Figure 1. The Caribbean Sea LME.

Why Marine Protected Areas?

The International Union for Conservation of Nature (IUCN) and the IUCN World Commission on Protected Areas (WCPA) have long advocated the need to step up and scale up efforts to protect the world's vast and increasingly vulnerable marine environment from climate change, pollution, resource depletion and other threats. We are faced not only with small scale impacts but now with a vast footprint from human innovation and industry that is spreading across our wide oceans to their greatest depths. Unchecked, such impacts will continue to deplete our seas; if impacts are halted, then sustainability may be achieved for ocean resources.

In recent decades, growing awareness of the continuing decline in the quality of our oceans and seas has stimulated the nations of the world to recognize the challenges that face us, provide effective stewardship, and agree on a number of targets that relate fully or in part to the implementation of Marine Protected Areas (MPAs). Globally these include:

- halting the decline of biodiversity by 2010;
- introducing an ecosystems approach to marine resource management by 2010;
- designating a network of representative marine protected areas by 2012; and
- restoring depleted fish stocks to maximum sustainable yield levels by 2015.

The measures we take to protect marine wildlife and the environment need to keep pace with human impacts. They need to be meaningful for large scale physical ocean processes and also address future impacts from climate change and ocean acidification.

Effective area-based protection through MPAs helps maintain ecosystem health and productivity, while safeguarding social and economic development. MPAs also help maintain the full range of genetic variation essential for securing viable populations of key species, sustaining evolutionary processes and ensuring resilience in the face of natural disturbances and human use (Agardy and Staub 2006).

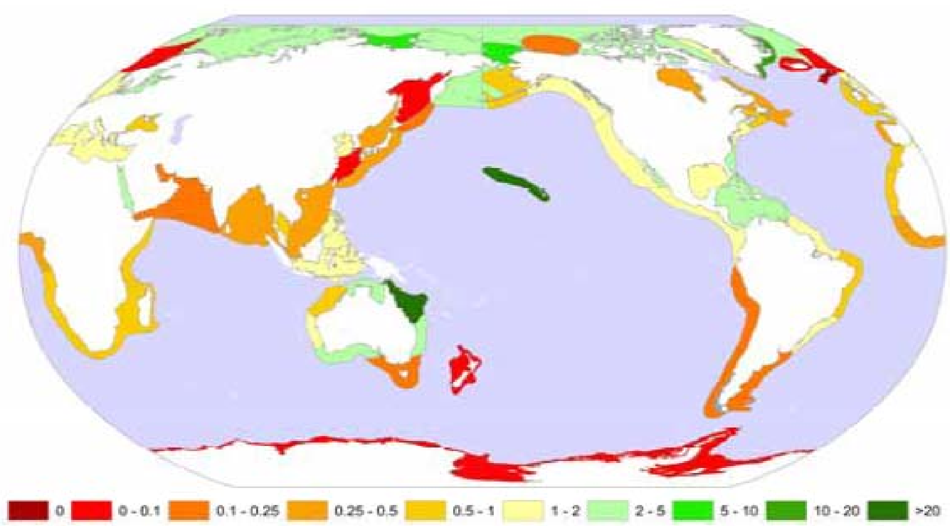

Figure 2. Percentage of Large Marine Ecosystems covered by marine protected areas. Courtesy of Louisa Wood / IUCN

If designed correctly and managed well, MPAs have an important role to play in protecting ecosystems and, in some cases, enhancing or restoring the productive potential of coastal and marine fisheries. When MPAs are used in conjunction with other management tools, such as integrated coastal management (ICM), marine spatial planning, and broad area fisheries management, they offer a cornerstone for strategizing marine conservation (Christie et al. 2002; Cicin-Sain and Belfiore 2005).

IUCN-WCPA Response

Building on years of preparatory work and ground-level implementation of marine protected areas, the IUCN and WCPA have, in the last few years, ramped up marine protected area network activity. A Plan of Action is in place to achieve the global MPA agenda. The key objectives are to develop and share solutions for creating and managing MPAs and MPA networks. Another important aim is to increase public visibility, understanding and awareness of MPAs and MPA networks using existing and new IT technologies to engage people with oceans and MPAs.

Regional Case Studies – a history of IUCN's work on MPAs

Canary Current LME and Guinea Current LME

PROMOTING INTERNATIONAL COOPERATION THROUGH A NETWORK OF MPAS

Photo: Jim Thorsell

Figure 3. Artisanal fishing in West Africa.

The Regional Marine and Coastal Conservation Programme (PRCM) for West Africa was set up on the initiative of IUCN, WWF, Wetlands International and the International Foundation for the Banc d'Arguin (FIBA), in partnership with the Sub-regional Fisheries Commission (CSRP). It now represents a coalition of nearly 50 partner institutions which aim to coordinate conservation efforts directed at the coastal zone of Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, Sierra Leone and Cape Verde.

For all West African seaboard countries, the coastal zone is an area of strategic importance for economic development. All large urban centres are located there, and nearly 60% of the inhabitants of these countries live on the coast. Over 600,000 jobs stem directly or indirectly from fisheries and related activities. Marine and coastal resources have, however, considerably declined due to human-induced pressures which are often too intense or poorly controlled (e.g. pollution, overuse of resources, unsustainable fishing practices). In view of the vulnerability of fisheries resources and the lack of effective management, marine protected areas are set to play an important role in the recovery of marine resources.

An aim of the IUCN and PRCM in the region is building the capacity of institutional and nongovernmental stakeholders and local communities so they can fully participate in the design, implementation, decision-making process, and management of their MPAs. The network of 24 MPAs in this part of West Africa covers 6 countries and has been regrouped under the umbrella of RAMPAO (Regional Network of Marine Protected Areas in West Africa) to maximise the exchange of lessons learned, training opportunities, research and international cooperation.

The main long-term threats to biological diversity in the region are the erosion of marine habitats, estuaries and waterways; overfishing of already depleted fisheries; and the ecological effects of accidental bycatch. Managing these threats, whilst taking account of the needs of local populations dependent on marine ecosystems, remains a major challenge. MPAs are an effective means of conserving biological diversity and species and helping fisheries become ecologically and economically sustainable. On the coastline between Cape Verde and Guinea, more marine protected areas are being planned and implemented.

South China Sea LME

NHA TRANG BAY MARINE PROTECTED AREA: A MODEL FOR PROTECTING VIETNAM'S SEAS

The Hon Mun MPA Pilot Project in Nha Trang Bay is an Integrated Conservation and Development Project and the first MPA to be established in the Socialist Republic of Vietnam. The project, initiated in 2001, lays out plans for the sustainable management of the Bay and will carry out community development activities to support local uses of the Bay's resources. The MPA project aims to protect the marine environment and assist local island communities in improving their livelihood. The MPA project partners with stakeholders to restore marine biodiversity in Nha Trang Bay and it will serve as a model for collaborative MPA management in Vietnam.

Photo: James Oliver/ IUCN

Figure 4. Nha Trang Bay, Vietnam – model Marine Protected Area

The Nha Trang Bay MPA covers about 160km^2 and has many important habitats including coral reefs, seagrass beds, and mangrove areas. Nha Trang Bay has the highest coral reef diversity of any surveyed location in Vietnam. Its biodiversity makes Nha Trang Bay an "area of highest national priority" for marine conservation and coastal tourism.

A cornerstone of the project is to improve the livelihood of local villagers through the ecological sustainability of aquaculture and fisheries. This will reduce overexploitation and depletion of traditional wild-caught fisheries. Since the MPA was established, access to some traditional fishing grounds has been restricted to replenish stocks.

To date, village aquaculture has focused on cage culture for reef lobster and marine fish. To address the increased demand for wild-caught 'seed' and food to supply aquaculture facilities, the Project has planned and implemented a series of aquaculture trials to demonstrate the feasibility of species diversification, the use of hatchery-produced seeds, and species that feed successfully from natural food sources or formulated pellets. To date, most trials have shown that there is a wide variety of species other than marine fish that can be cultured successfully to help improve the livelihood of local fishers (Hoang Tung, 2002).

It is anticipated that the Nha Trang Bay MPA can be used as a model for the development of the other 14 MPAs planned for the coast of Vietnam over the next decade. Financed by the Global Environment Facility through the World Bank, DANIDA (Government of Denmark), and the Government of Vietnam, the Hon Mun MPA Pilot Project in Nha Trang Bay was implemented by IUCN in partnership with the Vietnamese Ministry of Fisheries and Khanh Hoa Province.

The Mediterranean Sea Large Marine Ecosystem

MAPPING MPAS TO HELP PROMOTE A COHERENT INTERNATIONAL NETWORK

In collaboration with WWF and MedPAN, the network of managers of Mediterranean MPAs, the IUCN has built an inventory and assessed the status of Marine Protected Areas in the Mediterranean Sea LME. It is the first survey of Mediterranean MPAs that includes a data collection of management characteristics and is based on questionnaire responses. Eighteen countries bordering the Mediterranean Sea LME participated in MPA management agencies.

The database contains accurate data and useful information for all known MPAs. Users can search sites by country, and find information on:

- *General characteristics of the MPA* (contacts, map, size, geographical coordinates, zonation, IUCN management category, legal references);
- *MPA Management* (management plan, surveillance and enforcement, equipment, staff, monitoring programme, and illegal activities);
- *Habitats and species* currently under protection, and health status of key habitats and species; and
- *Main threats* affecting Mediterranean MPAs.

The main aim of this initiative is to provide an updated baseline to assess the progress being made in the development of an ecologically representative and coherent network of MPAs in the Mediterranean Sea LME. It is offered as a resource to MPA managers, institutions, scientists, decision-makers, and the general public, to be better informed on the marine conservation work being accomplished in the region. Mediterranean MPAs do not yet fully represent all the diverse habitats of the region. Sixty nine of them (or 73.4%) are located along the LME's northern shore, highlighting the lack of MPAs along the southern and eastern coasts. These under-represented regions and habitats are ecologically distinctive in terms of their oceanography and biogeography. Many MPAs are ecologically isolated, with 75% of the MPAs separated by more than 30 km.

The percentage of protection is still a long way from the Convention on Biological Diversity (CBD) target (10% by 2012). Marine protected and managed areas represent 3.8% of the Mediterranean Sea LME. If the Pelagos Sanctuary is not taken into account, the area is only 0.4% of the total surface area. MPAs should be implemented in the southern and eastern Mediterranean as these areas present major needs and challenges related to management and surveillance capacity.

Figure 5. Marine Protected Areas of the Mediterranean.

Agulhas and Somali Current LMEs, East Coast of Africa

TANGA FISHERIES RESERVE

The Western Indian Ocean is home to over 11,000 plants and animals, of which nearly 15% are endemic to the region. Marine Protected Areas are key to the survival of marine biodiversity. Establishing and managing such areas must be carried out to ensure that the needs of all those who use and depend on the ocean are taken into account. The IUCN approach is to involve all stakeholders in the management of these areas, for the equitable sharing of their benefits.

Figure 6. Artisanal fishing off the East Coast of Africa

In 1994, the Tanga Coastal Zone Conservation and Development Programme (TCZCDP) was a response to the Tanga Regional government's concern for the decline of marine resources and degradation of reefs. The project was implemented through IUCN's Eastern Africa Regional Office (EARO), with funding from Irish Aid.

TCZCDP was one of the first coastal management programmes in the Western Indian Ocean to make socioeconomic considerations a central objective. It was one of the first to take a community-based approach to planning and implementation right from the start. A broad and ambitious strategy incorporated the development of new socioeconomic activities, developed and implemented fisheries and mangrove management plans, established and mainstreamed new institutional arrangements for coastal management, and built capacity through a major training and environmental education program (Wells et al. 2007).

Collaborative management areas (CMAs) for fisheries were formally adopted in village by-laws and approved at the national level (Wells et al. 2007). These areas include reefs closed to fishing to serve as fishery reserves. Destructive and illegal beach seines (juya) and dynamite fishing were dramatically reduced through surveillance patrols and gear exchange for beach seines (Horrill et. al. 2001). Regular monitoring of coral reef health and artisanal fisheries, and the implementation of alternative livelihood strategies such as seaweed farming by women, were further key aspects of the program. The Tanga Coastal Zone Conservation and Development Programme (TCZCDP) has led to a major improvement of the reef's health. However, in 2003-2005 dynamite fishing returned and the recovery of fish stocks was reversed, which coincided with the removal of a navy boat from the area and also the end of donor funding to the project (Samoilys et al. 2007).

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Links and further reading

Websites

IUCN GMP website: www.iucn.org/marine
Protect Planet Ocean website: http://www.protectplanetocean.org/
Mediterranean MPA database: http://www.medpan.org/
WCPA Marine website:
http://www.iucn.org/about/union/commissions/wcpa/wcpa_work/wcpa_biomes/wcpa_marine/index.cfm
PRCM : http://www.prcmarine.org
Hon Mun MPA: http://www.nhatrangbaympa.vnn.vn/

Publications:

IUCN WCPA MPA Plan of Action:
http://cmsdata.iucn.org/downloads/mpa_planofaction.pdf
Establishing Resilient Marine Protected Area Networks - Making it Happen:
http://cmsdata.iucn.org/downloads/mpanetworksmakingithappen_en.pdf
Status of Marine Protected Areas in the Mediterranean Sea:
http://cmsdata.iucn.org/downloads/status_lr.pdf

Future Needs of the LME Approach Worldwide

Gotthilf Hempel

Kiel, Germany

For the conservation of nature and natural resources in the World's oceans and in coastal waters, some approaches target individual species or groups of species, others aim to protect certain habitats and their biodiversity. The holistic concept of Large Marine Ecosystems goes one step further by encompassing large areas reaching from the sea shore into the open sea above the shelf and continental slope. In the course of three decades, the LME concept of an ecosystem-based approach to resource management has been adopted worldwide. The LME criteria, modules and indicators have shown to be sufficiently robust and flexible to be applicable in all climate zones and in regions differing greatly in their socio-economic and political condition.

The LME concept became the framework for national and international programmes of LME wide research and monitoring and for the development of management strategies and governance. In the United States, the Northeast Shelf was the starting point for the development of LME oriented projects. The LME approach has been followed in other parts of the world, particularly in developing countries eligible for funding by the Global Environment Facility (GEF). There are presently 16 GEF-funded LME projects, in Africa, Asia, Latin America, the Caribbean and eastern Europe (Sherman et al., this publication).

The LME programmes serve various stakeholder groups: for the environmentalists, LME projects are striving towards the recovery of depleted fish stocks, restoration of degraded habitats, reduction of nutrient enrichment, coping with the invasion of alien species, conservation of biodiversity, and adaptation to climate change. For society, LME projects strive for the sustainable development of marine resources and services for growing populations of coastal communities, coastal states and the global market. Marine scientists – both pure and applied – learn much about complex biological interaction in the ecosystem and the different roles of natural driving forces and of man in altering the system in the past and at present.

My relations to the LME movement date back to its very early days in the 1970´s and I returned to it in the 1990´s when Angola, Namibia and South Africa with the support of advisors from Northern Europe joined in a marine programme. The Benguela Environment Fisheries Interaction and Training Program (BENEFIT) aimed at the surveillance and management of the living resources of the Benguela Current system and at the formation of scientific and technical staff, particularly in Angola and Namibia. The Benguela Current LME Programme (BCLME) became the operational arm of BENEFIT. LME projects such as the BCLME offer research vessels and other technical facilities and opportunities for many kinds of basic research. Already in the founding documents of BENEFIT and of the BCLME Programme this was stressed and has materialized in the meantime in terms of close cooperation with leading marine scientists of the University of Cape Town and other universities in the region. The links of the BCLME Programme with the governments and administration of the three participating countries have been fairly strong and have resulted in the creation of the Benguela Current Commission covering both environment and fisheries, and addressing natural and societal concerns. The dialogue between natural and social scientists has been implemented rather recently, but there is still room for improvement.

The following examples are mostly taken from a recently published book on the Benguela Current and its LME project ("Benguela, Current of Plenty" edited by Gotthilf Hempel, Michael O´Toole and Neville Sweijd, 2008).

The need for better interaction

Within all LMEs more interaction is required between LME science and academia, natural and social scientists, science and industry, science and administration, science and public. LME projects should strive for more cooperation with universities. LME projects need academia as the nursery ground for the next generation of marine scientists, advisors and administrators and as the main source of new scientific concepts.

In turn, the marine science community should realize that LME projects have much to offer to the mainstream of marine research and to universities: LME projects consist of a cadre of marine scientists who speak worldwide the same scientific language and who provide great, coherent data sets on many of the highly exploited and productive shelf seas and adjacent oceanic waters. Those time series are badly needed for the understanding of biological variability on different scales of space and time.

We also need more communication, cooperation and coordination, both on a continent-wide (mega-regional) and global scale, among the various LME projects. Such interaction will improve links to the outside world and address global and continent-wide concerns. Common strategies are needed to enhance human capacity and science, particularly social sciences within the LMEs. With those goals in mind, BCLME became a strong driver for the establishment of a Pan-African LME Alliance (see below).

Human capacity

Within any LME, sustainable management of fisheries and other kinds of uses of the goods and services of the sea, including biodiversity, requires a sound scientific basis in natural *and* social and economic sciences, strong assessment methods, indicators comparable across LMEs, effective monitoring routines and good governance based on full stakeholder participation.

In each LME project good science is needed, often to be done by many more marine scientists and social and economic experts very competent in their own field but also willing to enter fruitful discussions with experts in other fields in order to develop overarching concepts and solutions. In Africa alone several thousand professionals of different levels of training and experience are now engaged in the LME projects. They have been trained by the concerted efforts of the countries of the region with substantial and continued outside support. The greatest need for further capacity building is in countries bordering the tropical and subtropical parts of the world's oceans. Here the need for food security is most pressing and the loss of biodiversity is greatest.

Enhancement of scientific and technical capacity means primarily investing in people and institutions. The BCLME Programme and other LME projects have done much in terms of augmenting the scientific, technical and administrative capacity for marine activities in many countries. Human capacity was created by overseas fellowships, training courses in the region and particularly by training on the job. Any programme for advanced capacity building should be based on close relations to the universities of the region.

Much of the capacity built over the years was quickly lost through brain drain. The LME projects together with the local research institutes and universities lost many of their best people moving into more lucrative jobs within the region or overseas. Therefore, any new capacity enhancement programme has to include measures for combating the brain drain. This is mostly a matter of governmental policies providing adequate incentives in terms of higher salaries, career assurance and better working conditions particularly for women, who constitute a major or even the major part of the scientific and technical staff in marine science in developing countries.

The need for a new generation of experts

The complexity of the ecosystem approach to fisheries and other marine activities calls for a new generation of professionals, addressing the sustainability issue in a much broader sense than before. The preservation of fish stocks and other goods and services of the ecosystem including the protection of marine biodiversity has to be taken care of, as must 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.

In order to address all five modules of the LME concept, specialists are needed like ichthyologists and plankton experts, gear designers, sociologists, economists and experts in international law. On the other hand experienced generalists and modelers are required to put the facts and findings together and to create management scenarios. Those generalists are rather rare and not easy to recruit.

To a certain extent, a fair division of research work between the developed and developing countries might be envisaged. Developed countries have the capacity and hence the responsibility of advancing science in the broadest possible way - including the theory and analysis of interactions in the sustainability triangle of environment, economy and society. Working in collaboration with colleagues and institutions in other parts of the world, including developing countries, is a win-win situation. Such division has been implemented in the Benguela Large Marine Ecosystem, when e.g. the German *R/V Meteor* oceanographic cruise carried out basic research in marine biogeochemistry of the anoxic zones, while the *R/V Africana* cruise of South Africa and the cruise on the Norwegian *R/V Dr. Fridtjof Nansen* studied the distribution of zooplankton and fish.

Continent-wide alliances of LMEs and global LME structure

Everyone agrees that LME programmes will benefit from a better exchange of experiences, tools, platforms and people. So far, connections between the projects are mainly through informal personal contacts at the top level, particularly during the annual LME consultations at the IOC-Unesco in Paris (see LME consultation reports at: www.lme.noaa.gov/ and also at http://unesdoc. unesco.org/ulis/.

Interaction can be established through global and mega-regional workshops on specific topics and in general symposia involving natural and social scientists, administrators and civil society to further develop common scientific and organisational concepts and strategies, as well as tools, and methods.

Up to now, the LME approach and strategy has largely been steered by a handful of senior scientists. Meanwhile, however, within the LME projects a good number of junior scientists are active with new knowledge and new ideas. Ways and means have to be found to engage them in those meetings and in the decision making process on the mega-regional and global level. The involvement of those younger scientists in the BCLME symposia and in the Pan-African LME Forum in

2007 was a step in that direction. Based on the positive experiences of the BCLME Programme and of the Guinea Current LME Programme, the Forum focused on:

- The transfer of experience from established LMEs to new ones.
- The exchange of scientists and technicians among LMEs, e.g. in cruises and workshops.
- The sharing of technical infrastructure, as on the *R/V Dr. Fridtjof Nansen*.
- Joint participation in mega-regional projects, e.g. by building up a network of observation stations for GOOS-Africa.
- Making scientific meetings and training programmes more attractive to participants from abroad.

Those activities require – on the global scale - some formal structure to ensure the continuous flow of communication and cooperation between LMEs.

In terms of the future of the LME movement, an organizational structure has to be found, which takes care of the interests of the individual LME projects and their mega-regional alliances, helps to promote the global obligations of the LME movement under the agenda and targets of the World Summit for Sustainable Development (WSSD).

In a nutshell

The LME approach remains a good way forward in the direction of the sustainable use of marine ecosystems. In the future, the interaction should be strengthened amongst the various science sectors and among scientists and stakeholders, the general public, and national and international governance structures. Partnership is needed on all levels and on all geographical scales – from village communities to the globe. What is lacking is not so much the money but rather the political will and the vision of enthusiastic and competent experts. LME partners should become members of a global network requiring a minimum organizational structure for which the key elements have been discussed in the past year.

Outreach and Education for Ecosystem-based Management in the World's Large Marine Ecosystems

Marie-Christine Aquarone
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The LME approach and its five modules (productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance) provide a practical way to integrate marine science, ocean management, and the improvement of economic conditions at the ecosystem scale in each of the world's 64 Large Marine Ecosystems (LMEs) (**Figure 1**).

Figure 1. Map of the 64 Large Marine Ecosystems of the world and their linked watersheds.

The 5-module methodology is applicable in all climate zones and in all regions. It provides a framework for assessing the variability of Large Marine Ecosystems and offers a solid framework for effective management action by the countries adjacent to an LME to recover and sustain the use of marine goods and services. The approach has developed suites of indicators for each of the 5 modules (**Figure 2**).

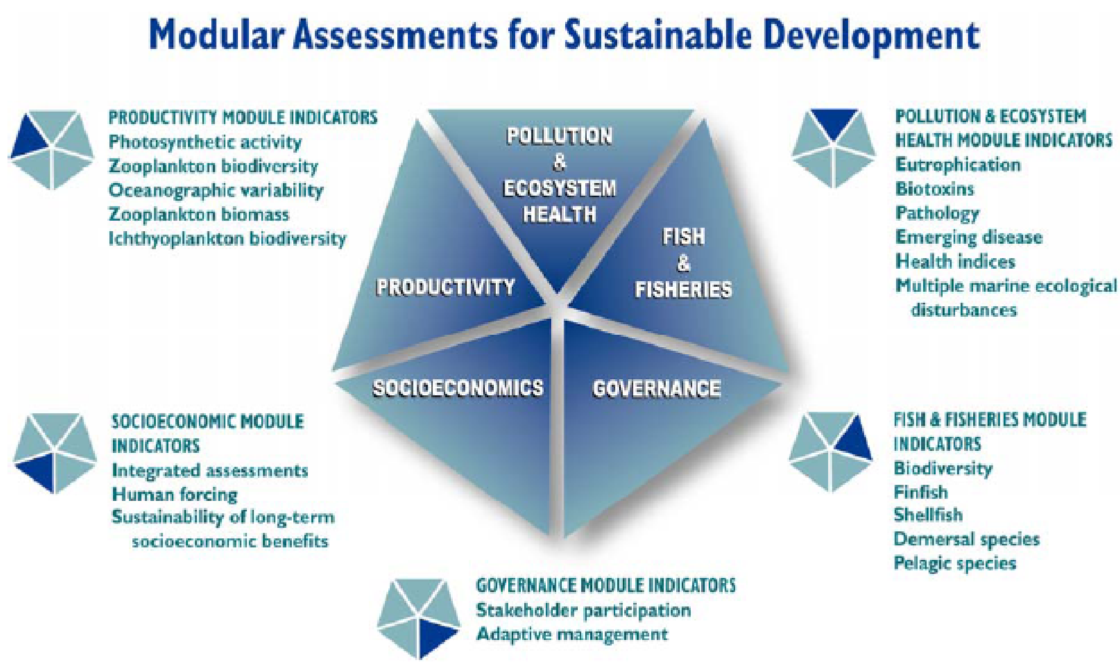


Figure 2. LME modules as suites of ecosystem indicators (Sherman et al. 2005)

Outreach Focus for LME-based Assessment and Management Practices

The LME movement (Duda, this volume; Sherman et al. 2005) can be described as having three phases. The early phase in the decade of the mid 1980s to the mid 1990s was focused on framing the LME approach through a series of symposia and published reports and volumes. The symposia were based on the scientific, economic, and legal dimensions of LMEs and were convened at four annual meetings of the American Association for the Advancement of Science (AAAS) beginning in 1984, and an international LME symposium held in Monaco in 1990. The symposia were followed by four peer-reviewed LME volumes published by the AAAS in 1986, 1989, 1990 and 1993. Other peer reviewed publications followed later, published by Blackwell Science and Elsevier Science. A complete listing of 14 published LME volumes, along with chapter headings and authors, is given in the Annex.

A second phase, from the mid 1990s to the present, was a period of steady growth in the application of the LME approach to the assessment and management of ocean goods and services. Beginning in 1995 NOAA, in collaboration with the Global Environment Facility (GEF) and in partnership with five United Nations agencies (UNDP, UNEP, UNIDO, IOC-UNESCO, FAO), the IUCN and the World Wildlife Fund, has been providing scientific and technical assistance on the LME approach to 110 developing countries engaged in the planning and operationalization of the 16 GEF supported LME projects in Africa, Asia, Latin America, and eastern Europe (Figure 3).

During the present third phase, LME Program international activities are focused on the extension of new GEF-supported LME projects in Asia and Latin America. In a parallel effort, an estimated 2,500 LME project practitioners are developing a global community of best practices for operationalizing the 5-module LME assessment and management approach. It is expected that the LME community of practice (LME-CoP) will establish an electronic network for the selection and dissemination of “best-practices” methodologies. The methodologies are to be used in the training and education of up to 10,000 LME project practitioners by 2015 and will be reproduced and distributed in electronic and print reports, volumes, and visualizations.

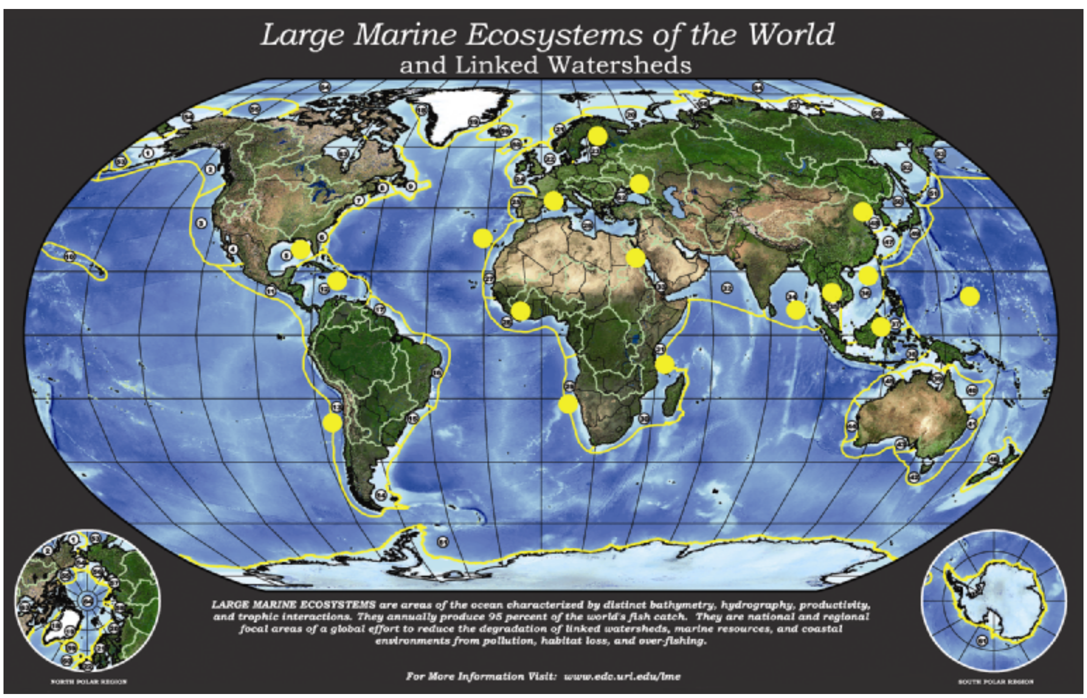


Figure 3. Global Distribution of Large Marine Ecosystem Projects Funded by the GEF. The yellow dots on the map represent the location of the 16 operational GEF-LME projects. These are: the Caribbean, Gulf of Mexico, Humboldt Current, Baltic Sea, Black Sea, Mediterranean Sea, Canary Current, Guinea Current, Benguela Current, Agulhas and Somali Current, Red Sea, Bay of Bengal, Gulf of Thailand, Yellow Sea, South China Sea, and Sulu Celebes LMEs. Also represented with a yellow dot is a 17th project in the Pacific Ocean, the Pacific Warm-Water Pool LME Equivalent.

Paradigm Shift

The five module LME approach has provided an effective way forward in developing countries for guiding scientists, managers and policy makers in introducing ecosystem based management practices. While ecologists have long studied the structure and function of marine ecosystems (Lubchenco 1994, Levin and Lubchenco 2008), the applied and pragmatic LME approach is directed to assessing and managing large ocean areas for recovering and sustaining marine goods and services. Previous management approaches have often failed to look beyond the individual sectors. Those with regulatory authority over one sector often make decisions on that sector's uses in isolation from the decisions involving other sectors. Fish harvest decisions are often made on a species-by-species basis, without accounting for the numerous interactions such as predator-prey or competitive relationships among the species.

Ecosystem-based management represents a paradigm shift away from a sector by sector approach and requires a better overall understanding of marine ecosystems and of the transboundary nature of water governance, fisheries, climate change, and water pollution (Figure 4).

FROM →	TO
Individual species	Ecosystems
Small spatial scale	Multiple scales
Short-term perspective	Long-term perspective
Humans: independent of ecosystems	Humans: integral part of ecosystems
Management divorced from research	Adaptive management
Managing commodities	Sustaining production potential for goods and services

Figure 4. Ecosystem management requires a paradigm shift. From Jane Lubchenco, 1994.

Education and outreach activities supporting ecosystem-based management within LMEs are focused on:

(1) Continued investment in sound science and data on LME (i) productivity; (ii) fish and fisheries; (iii) pollution and ecosystem health; (iv) socioeconomics; and (v) governance modules, with an emphasis on transboundary assessments for sound decision-making.

(2) Improved understanding of the synergistic role of the five modules, and the combined effects of natural variability and human activities driving habitat destruction, degraded benthos, overfishing, ocean warming, increased

acidification and nutrient over-enrichment in relation to the changing states of marine ecosystems.

(3) *Engendering a willingness on the part of scientists* to communicate scientific findings more widely and develop strategies for *becoming true collaborators in the policy process* (Sponberg 2008).

(4) Expanding LME practitioners membership and an improved communications network. The GEF-funded LME projects have now reached a point where it is beneficial and useful to share experiences, information, technological improvements, measurable benefits, and lessons learned, and make the information available on the LME portal, www.lme.noaa.gov.

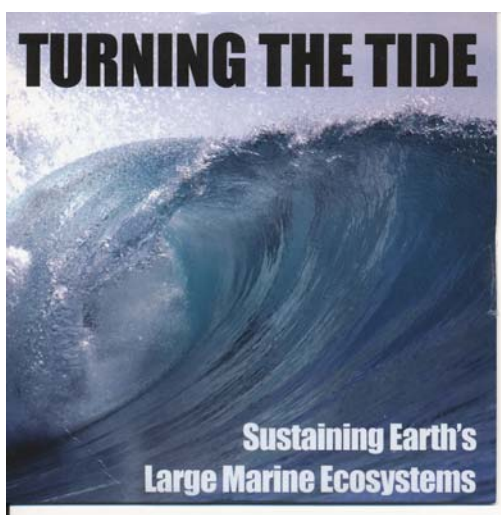
(5) Production of public education materials and curricula geared towards an ecosystem-based approach are being prepared to inform and educate broad audiences as well as school children and students. Materials are being developed that are suited to specific LME settings.

(6) Continued capacity building efforts for ecosystem-based assessment and management to support the recovery and sustainability of coastal oceans at a time of climate change, biodiversity loss, and loss of sustainable livelihoods from oceans. To face this challenge it is important to continue training marine experts through LME methodology workshops.

Outreach through DVDs

Two DVDs have been produced to demonstrate current stress on the oceans of the world, and the utility of the LME approach to initiate ecosystem recovery:

(1) Turning the Tide – Sustaining the Earth's Large Marine Ecosystems



(26 minutes)

In 2007, the LME Program Office and the GEF supported UNDP International Waters Learn project produced a DVD, **"**Turning the Tide—Sustaining Earth's Large Marine Ecosystems**,"** which describes the uncontrolled use of the oceans and counters this message by describing the GEF-LME global movement supporting an upward spiral of actions aimed at recovery and sustainability of ocean resources.

The DVD delivers a description of the LME approach. The narration states that, around the world, Large Marine Ecosystems provide over 80% of the marine fish that humans consume. The uncontrolled use of large-scale industrialized vessels has put nine of the World's seventeen major fishing grounds in serious decline. The demand for marine protein has devastated marine resources. Nitrogen overenrichment of LMEs is increasing. Marine mammals are in trouble, and coral reefs are threatened. However, there is hope for a common global understanding of how to address the world wide crisis of marine life degradation. Pioneering work by lead scientists has identified 64 Large Marine Ecosystems (LMEs) determined by ecological functionality and physical parameters rather than political boundaries. The Large Marine Ecosystem approach blends science and stewardship to reduce coastal pollution, restore damaged habitats, and recover depleted fisheries.

The Global Environment Facility (GEF) assists developing countries working together in planning and implementing LME projects. The DVD includes comments by Dr. Alfred Duda, Senior Advisor for the International Waters focal area of the GEF, Dr. Kenneth Sherman on Large Marine Ecosystems, and Dr. Biliana Cicin-Sain, Director of the Global Forum on Oceans, Coasts and Islands, and footage of the Benguela Current, Antarctic, Agulhas and Somali Currents, Humboldt Current, and Baltic Sea LMEs.

The DVD has been screened in elementary, middle and high school classrooms on the American continent and in Africa. The following quotes are taken from student comments.

"I already knew that the oceans were in trouble, but the movie still taught me a lot. I learned about different types of pollution. I didn't know about the GEF. I think it's a great program, because thanks to your movie, I saw how the group is saving the world. "In the movie 'Turning the Tide', I liked how the videography started out very peacefully, and beautifully, gets to the less beautiful clips toward the middle, and by the end, the videography became peaceful and beautiful. I liked how the videography went in that order because: since it didn't begin with the less beautiful, pollution parts, it didn't lead the watchers to thinking the entire video would show only those clips. If you ended with the pollution parts, it would lead the reader to remembering those parts most. The order was brilliant. "All in all, I loved the movie. It was the best science movie I have ever seen." (school student, Wakefield, Rhode Island, USA).

"This movie taught me a lot and that's quite a bit to say because my dad is a fisherman and one of my two brothers adores everything that's alive and protecting those things. He knows very much about them. One thing I learned from "Turning the

Tide" that surprised me is that illegal fishing is as big of a problem as it is. I knew it was a problem, but not one that large. I also learned that the population of jackass penguins is small. I've heard of those birds before, but I thought they were pretty common.

"Turning the tide" was a very inspirational movie. The whole "working together to save marine ecosystems" is especially inspiring. Also, the movie was very interesting. Even the parts about government were interesting, and government is a subject that can easily bore many kids. Not one person in my class seemed bored. Another good thing about the movie is that it has great pictures and clips—the color quality is great and the photographer(s) is/are great at their job(s)! I did notice one thing that could be changed: the words at the very beginning of "Turning the Tides" are a bit small and hard to read if you aren't very close up. Thank you very much for giving us a sample of the movie. It was great and I hope it will be very successful—I know it was in my class!" (school student, Wakefield, Rhode Island, USA).

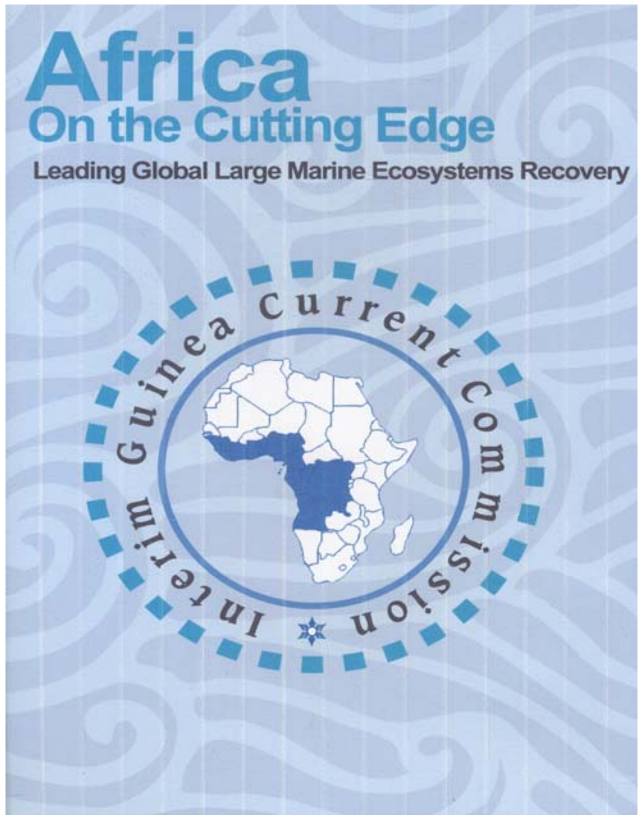
*"After watching this film, I want to do something to help the marine life that has helped us" (Emily, age 11). "It has really been brought to my attention that I should be a part of protecting Large Marine Ecosystems" (Namita, age 11) (*students, Accra, Ghana, Africa).

To obtain a copy of the DVD, please contact The NOAA Large Marine Ecosystem Program, 28 Tarzwell Drive, Narragansett, RI 02882, USA. Tel: +1 401 782-3211. FAX: +1 401 782-3201. Emails: Kenneth.Sherman@noaa.gov, MC.Aquarone@noaa.gov.

A booklet accompanies the DVD, reproducing its images and elaborating on the narration. The DVDs, the booklet, and supporting materials available for downloading at www.lme.noaa.gov can reach and inform young people, perhaps encouraging them to pursue careers in marine science. More stock assessment scientists and other marine specialists are needed to evaluate management measures and prepare recovery plans vital for the future of our marine ecosystems, for the environment, and for our global economy.

(2) Africa on the Cutting Edge – Leading Global Marine Ecosystem Recovery

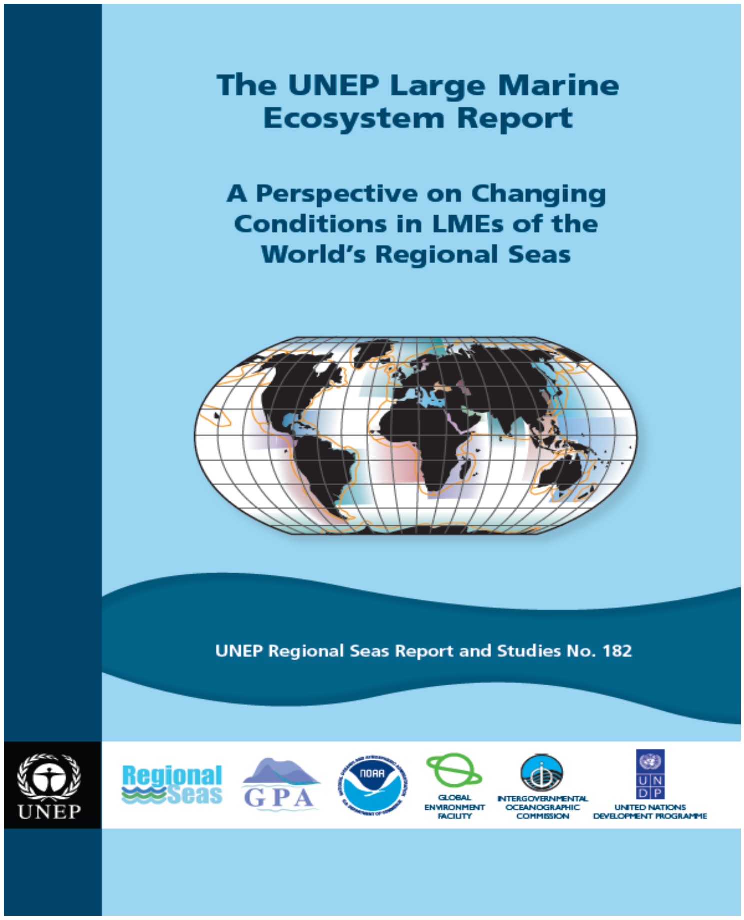
A second DVD "Africa on the Cutting Edge—Leading Global Marine Ecosystem Recovery" describes the activities underway to operationalize the LME 5-module assessment and management approach by the 16 countries participating in the Guinea Current (GCLME) project. The DVD brings the viewer into direct contact with the importance of fish as a critical food source for the people of West Africa; the threats to the environment from urban pollution, coastal erosion; and the chronic negative biological impacts of oil pipeline leaks from ongoing marine oil production, especially in the Niger delta area of Nigeria. Among the professionals recorded for this DVD and committed to introducing an upward spiral of fisheries recovery, habitat restoration, and pollution reduction and control are Dr. Chidi Ibe, GCLME project coordinator; His Excellency Stephen Asamoah-Boateng, the Environmental Minister of Ghana, and Kandeh Yumkella, Director General of UNIDO, the United Nations agency responsible for assisting the participating countries in executing the GCLME project. A description is given of the five module LME approach (productivity, fish and fisheries, pollution and ecosystem health, socioeconomics and governance) adopted in the Guinea Current LME (GCLME) Program that brings together 16 countries extending from Guinea Bissau southward to Angola on the West African coast.



(18 minutes)

The GCLME is ranked among the most productive coastal and offshore waters in the world with rich fishery resources, an important reservoir of marine biological diversity of global significance, oil and gas reserves, precious minerals and a potential for tourism. Approximately 20% of Africa's total population lives in the coastal areas of the GCLME, close to lagoons, estuaries, creeks and inshore waters. Their wellbeing and food security depends on the sustainable use of the goods and services of the ecosystem. Through the efforts of the Guinea Current Large Marine Ecosystem Program and the newly established Interim Guinea Current LME Commission, scientists, industry leaders and policy makers are working side by side to recover and sustain the Guinea Current LME. To obtain a copy of the DVD and supporting materials, please contact: NOAA Large Marine Ecosystem Program, 28 Tarzwell Drive, Narragansett, RI 02882, USA. Tel: +1 401 782-3211. FAX: +1 401 782-3201. Emails: Kenneth.Sherman@noaa.gov, MC.Aquarone@noaa.gov.

The UNEP LME Report (2008): Global Trends



The 852 page UNEP Large Marine Ecosystem Report is the result of a collaborative effort with NOAA's Large Marine Ecosystems Program and the United Nations Environment Program (UNEP) to provide a global view of baseline ecological conditions of the World's LMEs. Each of the briefs is based on the five module LME assessment framework of i) productivity, ii) fish and fisheries, iii) pollution and ecosystem health, iv) socioeconomics, and v) governance. Time series trends are projected for LME: productivity ($gCm^{-2}yr^{-1}$), ocean fronts, sea surface temperatures (SSTs), SST anomalies, annual fisheries biomass yields, values of catches, mean trophic levels, fisheries conditions relative to stock conditions, and the amount of primary productivity required to support the mean annual catch levels.

In the opening chapter, the complementarity between UNEP's Regional Seas activities and the GEF-supported Large Marine Ecosystem projects is described. The next three chapters provide a global perspective based on comparative LME trend analyses—for fish and fisheries by D. Pauly et al. (2008); for effects of global warming on fisheries biomass yields by Sherman et al. (2008); and for the growing problem of nutrient overenrichment from land-based sources by

Seitzinger and Lee (2008) who, based on a business as usual (BAU) modeling scenario, estimate a potential doubling of nutrient loading into LMEs around the globe by 2050. The LME briefs demonstrate the utility of a generic ecosystem-based approach that uses comparable time series indicators for each of the 5 modules to serve as the basis for assessing changing conditions among the world's LMEs.

Outreach and educational uses of the UNEP LME Report: By identifying the impacts of ecosystem drivers of alteration such as nutrient over-enrichment, pollution, over-fishing, and global warming, the UNEP LME report serves as a useful scientific reference as well as an educational and outreach document. The information is both quantitative and comparative, with lessons to be learned from comparing the marine geography, LME productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance conditions between and amongst the 64 LMEs. The briefs pertaining to the 16 LMEs for which the GEF has funded projects provide further detail on their progress in turning the corner to recover depleted fisheries, reduce coastal pollution, and restore damaged habitats.

The report is intended for use by educators, scientists, resource managers and the general public. The entire report can be downloaded from the LME website at: www.lme.noaa.gov/. To obtain a hard copy of the UNEP LME Report, please contact: NOAA Large Marine Ecosystem Program, Tarzwell Drive, Narragansett, RI 02882, USA. Tel: +1 401 782-3211; FAX: +1 401 782-3201. Emails: Kenneth.Sherman@noaa.gov, MC.Aquarone@ noaa.gov.

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ANNEX

Published Volumes in the Large Marine Ecosystem Series

Titles, Chapters and Authors of 14 published Volumes of the Large Marine Ecosystem Series 1986 – 2007

1986 Vol. 1	Sherman, K. and L. M. Alexander, eds. **Variability and Management of Large Marine Ecosystems.** American Association for the Advancement of Science (AAAS) Selected Symposium 99. Westview Press, Colorado. 319p	Authors
	Part I – Impact of perturbations on productivity of renewable resources in LMEs	
	1. Introduction to parts one and two: Large marine ecosystems as tractable entities for meaasurement and management	K. Sherman
	2. Shifts in resource populations in large marine ecosystems	J. R. Beddington
	3. Long-term changes in the Baltic ecosystem	G. Kullenberg
	4. Changes in the biomass of the California Current ecosystem	A. D. MacCall
	5. Perturbation of a predator-controlled continental shelf	M. P. Sissenwine
	Part II – Measuring variability in LMEs	
	6. Definitions of environmental variability affecting biological processes in large marine ecosystems	A. Bakun
	7. Variability of the environment and selected fisheries resources of the eastern Bering Sea. ecosystem	L. Incze and J. D. Schumacher
	8. Results of recent time-series observations for monitoring trends in large marine ecosystems with a focus on the North Sea	N. Daan
	9. Comparison of continuous measurements and point sampling strategies for measuring changes in large marine ecosystems	A.W. Herman
	10. Measurement strategies for monitoring and forecasting variability in large marine ecosystems	K. Sherman
	Part III – Institutional framework for managing large marine ecosystems	
	11. Introduction to part three: Large marine ecosystems as regional phenomena	L. M. Alexander
	12. Legal constraints and options for total ecosystem management of large marine ecosystems	M. H. Belsky
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	Accompanying CD containing relevant explanatory information about the WS as well as texts of selected contributed and invited papers presented during the Specialist Sessions and at the Closing Ceremony, plus relevant model outputs/ animations and color diagrams are included .	