Ocean & Coastal Management 90 (2014) 38–49

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Adaptive management institutions at the regional level: The case of Large Marine Ecosystems

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ARTICLE INFO

Article history:
Available online 3 August 2013

ABSTRACT

A global effort is underway by scientists, stakeholders, resource managers, and multisectoral ministerial representatives (e.g. fisheries, transportation, mining, energy, tourism, environment) from 110 economically developing countries to implement ecosystem-based management at the Large Marine Ecosystem scale. The effort is supported with $3.1 billion in financial assistance from the Global Environmental Facility and World Bank to assess and manage goods and services of Large Marine Ecosystems (LMEs) along the coasts of economically developing countries in Africa, Asia, Latin America and eastern Europe. Through a systematic spatial and temporal scaling across multiple jurisdictions (e.g. community, municipal, regional, national, and international) a generic suite of indicators is applied to monitor the annual changes in LME productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance. Ecosystem-based governance practices are being implemented by Commissions that serve as institutional frameworks for restoring and sustaining transboundary LME goods and services. Under activities guided by LME Commissions, the suites of indicators are analyzed in relation to drivers of change and the results are applied to adaptive management regimes to reduce coastal pollution, restore damaged habitats, recover depleted fisheries conserve biodiversity, control nutrient over-enrichment and ocean acidification, and mitigate and adapt to the effects of climate warming. Application of ecosystem-based adaptive management practices presently underway by the People's Republic of China and the Republic of Korea are discussed for the Yellow Sea LME.

1. The Large Marine Ecosystem approach

Large Marine Ecosystems (LMEs) are regions of ocean space of 200 000 km^2 or greater, encompassing coastal areas from river basins and estuaries out seaward to the break or slope of the continental shelf or out to the seaward extent of a well-defined current system along coasts lacking continental shelves. The World's LMEs are defined by ecological criteria including (1) bathymetry, (2) hydrography, (3) productivity, and (4) trophically linked populations (Sherman, 1993b; Duda and Sherman, 2002).

The LMEs continue to be degraded by unsustainable fishing practices, habitat degradation including loss of sea grasses, mangroves and corals; eutrophication, toxic pollution, aerosol contamination, ocean acidification; and emerging diseases. The scale and severity of risks to LME goods and services associated with depletion and degradation of near coastal oceans is well documented (Sherman et al., 2005; Lubchenco and Petes, 2010). The coastal waters of LMEs contribute an estimated $12.6 trillion annually to the global economy (Costanza et al., 1997). An estimated 80% of the world's annual marine fisheries catch is produced in 64 LMEs (Fig. 1).

The LME approach to the management of coastal and marine resources operates at multiple scales, within the boundaries of LMEs, and harnesses stakeholder support for integrated adaptive management in both Northern and Southern countries (Duda and Sherman, 2002; Duda, 2009). The LME approach to the assessment and management of coastal ocean goods and services includes a pragmatic application of natural and social sciences in support of adaptive management informed by time-series measurements of key ecosystem indicators of changing ecosystem conditions. The LME approach is based on five modules for measuring changing states in LMEs including (i) productivity, (ii) fish and fisheries, (iii) pollution and ecosystem health, (iv) socioeconomics, and (v) governance. Analyses of time-series measurements from the modular suites of indicators provide the basis for developing and implementing management actions to recover and sustain LME goods and services (Fig. 2).

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http://dx.doi.org/10.1016/j.ocecoaman.2013.06.008

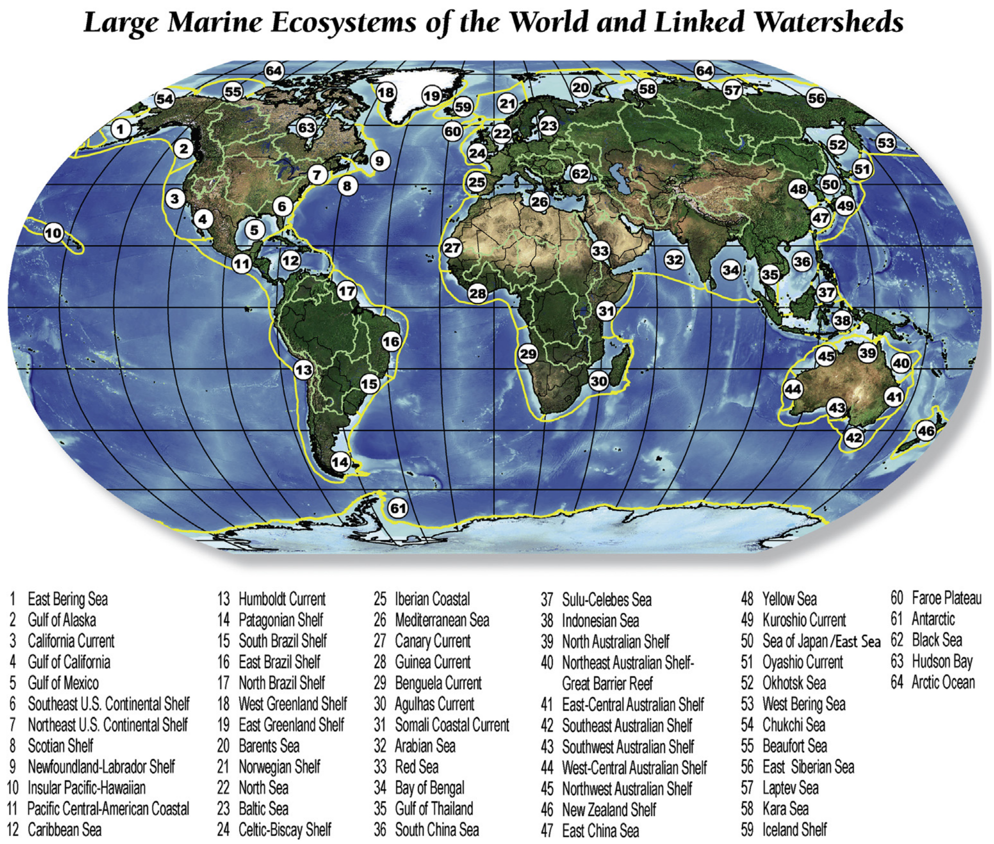


Fig. 1. Map of the 64 Large Marine Ecosystems of the world and their linked watersheds.

1.1. Productivity module indicators

Primary productivity can be related to the carrying capacity of an ecosystem for supporting fish resources (Pauly and Christensen, 1995; Christensen et al., 2009). Measurements of ecosystem productivity are also useful indicators of the growing problem of coastal eutrophication. In several LMEs, excessive nutrient loadings to 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; Sherman, 2000).

The ecosystem parameters used as indicators of changing conditions in the productivity module are: photosynthetically-active radiation, transparency, chlorophyll *a*, primary productivity, nitrogen, sea surface temperature, water column structure, and ocean fronts (Aiken et al., 1999; Berman and Sherman, 2001; Melrose et al., 2006; Belkin et al., 2009; Sherman et al., 2009a).

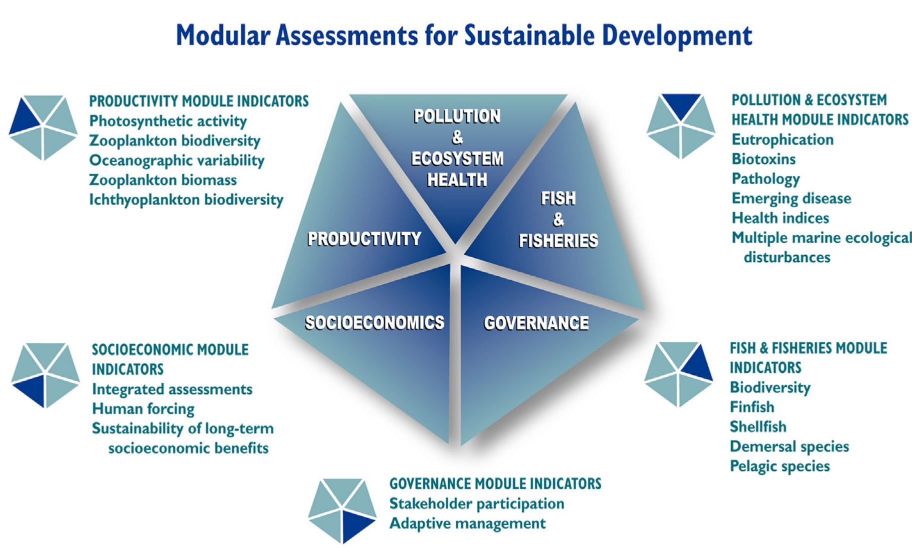


Fig. 2. LME modules as suites of ecosystem indicators.

1.2. Fish and fisheries module indicators

Changes in biodiversity and species dominance within fish communities of LMEs have resulted from excessive and selective exploitation, environmental shifts due to climate change and coastal pollution. Changes in biodiversity and species dominance in a fish community can rise up the food web to apex predators and cascade down the food web to plankton and benthos components of the ecosystem (Daskalov, 2003; Frank et al., 2005).

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. Standardized sampling procedures, when employed from small, calibrated trawlers, can provide important information on changes in fish species (Table 1). The fish catches on the surveys provide biological samples for stock identification, stomach content analyses, age-growth relationships, fecundity, and for coastal pollution monitoring, based on pathological examinations. Fish stock demographic data are used for preparing stock assessments and for clarifying and quantifying multispecies trophic relationships. NOAA Fisheries information is available at http://nft.nefsc.noaa.gov for development of a standard suite of methods for standardizing assessment tasks. The survey vessels can also be used as platforms for obtaining water, sediment, and benthic samples for monitoring harmful algal blooms, diseases, anoxia, and structure of benthic communities.

1.3. Pollution and ecosystem health module indicators

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

Pollution effects on the ecosystem are monitored systematically through the pathobiological examination of fish, and through the estuarine and near-shore monitoring of contaminant effects in the water column, the substrate, and selected groups of organisms. Where possible, bioaccumulation and trophic transfer of contaminants are assessed, and critical life history stages and selected food web organisms are examined for indicators of exposure to, and effects from, contaminants. Effects of impaired reproductive capacity, organ disease, and impaired growth from contaminants are measured. Assessments are made of contaminant impacts at both species and population levels. Implementation of protocols to assess the frequency and effect of harmful algal blooms, emergent diseases, and multiple marine ecological disturbances (Sherman, 2000) are included in the pollution and ecosystem health module. In the United States, the Environmental Protection Agency (EPA) has developed a suite of 5 coastal condition indicators: water quality index, sediment quality index, benthic index, coastal habitat index, and fish tissue contaminants index as part of an ongoing collaborative effort with the National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service (FWS), the U.S. Geological Survey (USGS), and other agencies representing states and tribes (USEPA, 2004).

Table 1
Fish and fisheries indicators.

Fish and fisheries indicators:
• Biodiversity indexes and assessments
• Demersal species surveys and assessments
• Pelagic species surveys and assessments
• Ichthyoplankton surveys and assessments
• Invertebrate surveys and assessments (clams, scallops, shrimp, lobster, squid)
• Changing sizes of essential fish habitat
• Size of/networks of marine protected areas

1.4. Socioeconomic module indicators

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

The new ecosystem accounting paradigm requires that resource managers of the different sectors of stakeholder interests incorporate the cumulative assessments of changing ecosystem productivity, fish and fisheries, pollution and ecosystem health and their effects on socioeconomic conditions and governance jurisdictions, as both additive and integrative effects on ecosystem conditions. These latter components of the LME approach to marine resources management have recently been described as the human dimensions of LMEs (Hennessey et al., 2005). A framework has been developed by the Department of Natural Resource Economics at the University of Rhode Island for monitoring and assessment of the human dimensions of LMEs and for incorporating socioeconomic considerations into an adaptive management approach for LMEs (Sutinen, 2000; Juda and Hennessey, 2001; Olsen et al., 2006). One of the more critical considerations, a method for economic valuations of LME goods and services, has been developed using framework matrices for indexing economic activity (Hoagland and Jin, 2006).

1.5. Governance module indicators

The legal basis for governance and management of the LMEs in relation to the United Nations Law of the Sea has been reviewed and validated in several studies (Belsky, 1986, 1989, 1992; Somers, 1998; Wang, 2004). The Governance Module is evolving, based on demonstration projects now underway in several LMEs that are being managed from an ecosystem perspective. In LME assessment and management projects supported by the Global Environment Facility (GEF) for the Yellow Sea, the Guinea Current, and the Benguela Current LMEs, agreements have been reached among the several ministries in each country bordering the LMEs (e.g., ministries responsible for ocean resources for the environment, fisheries, energy, tourism, finance and foreign affairs), to enter into joint resource assessment and management activities in support of ecosystem-based management practices. Elsewhere, the Great Barrier Reef LME and the Antarctic LME are also being managed from an ecosystem perspective, the latter under the Commission for the Conservation of Antarctic Marine Living Resources. Governance profiles of LMEs are being explored to determine their utility in promoting long-term sustainability of ecosystem resources (Juda and Hennessey, 2001). In each of the LMEs, governance jurisdiction can be scaled to ensure conformance with existing legislated mandates and authorities (Olsen et al., 2006). An example of multiple governance-related jurisdictions that includes areas designated for fisheries management, pollution control and marine protected areas, is described in *Sustaining the World's Large Marine Ecosystems* (Sherman et al., 2009b). Actions by several of the GEF-supported projects to establish governance bodies are moving forward. Experience in formalizing governance principles and practices is being developed within the framework of the LME Commission. Experience in formalizing governance principles and practices is being developed in the framework of the LME Commission for the Benguela Current LME (O'Toole, 2009) and recently for the Convention for the Benguela Current LME). The Convention document, signed on 18 March 2013, is downloadable from http://www.benguelacc.org/.

Some experience has been gained from the Interim Guinea Current Commission (www.gclme.iwlearn.org).

2. Sustaining LMEs

The increasing potential for negative effects on the sustainable development of LMEs has aroused international concern for the recovery and sustainability of depleted fish stocks, reduction and control of coastal pollution, nutrient over-enrichment and ocean acidification, restoration of degraded habitats, conservation of biodiversity, and for resilience to the effects of climate change. Through the mid-1980s and 1990s the scientific basis for moving toward ecosystem-based assessment and management of marine resources to reverse the downward spiral in LME goods and services was put forward at annual meetings of the American Association for the Advancement of Science (AAAS), the International Council for the Exploration of the Sea (ICES), and at international LME conferences. Changes in focus from single species assessments to multiple species assessments, and from local scales to the LME scale, are characteristic of the LME approach for measuring changing ecosystem states on an annual basis (Table 2). Sustainable use of ecosystem goods and services is an objective that is more effectively attainable in following the LME approach wherein the spatial and temporal scales of modular indicators of natural and social science changes conform with the natural boundaries of the LME. This perspective was affirmed by a group of 200 respected marine experts including scientists and policy professionals who compared the advantages of the LME ecosystem approach with a less effective sector-by-sector approach to adaptive management. This group defined ecosystem-based management (EBM) and recognized LMEs as appropriate areas of the globe for practicing EBM (McLeod et al., 2005). The LME approach to adaptive management of LME goods and services represents a paradigm shift from the individual species, small spatial scale, and short term perspective approach to marine resources assessment and management (e.g. fisheries, pollution, habitat) to the application of integrated cross-sectoral time-series assessments of changing LME conditions (Table 2).

3. The GEF supported LME Project development and implementation

With $3.1 billion in financial support from the Global Environment Facility (GEF) and the World Bank, partnerships have been forged among five UN agencies (UNDP, UNEP, UNIDO, FAO, IOC-UNESCO), the US-NOAA, Norway, Iceland, Germany, and two Non-Governmental Organizations (IUCN, WWF), to assist 110 countries in Africa, Asia, Latin America and eastern Europe in carrying forward LME Projects (Duda and Sherman, 2002; Sherman et al., 2010). The projects are introducing ecosystem-based assessment and management practices that consider multisectoral interests (e.g., fisheries, transportation, energy production, wind farms, recreation) to recover and sustain depleted fish stocks; restore damaged habitats (e.g. sea grasses, corals; mangroves); reduce and control pollution, nutrient over-enrichment, and acidification; and mitigate – and adapt to – climate change (Table 3).

Through GEF-supported LME projects, countries are moving towards joint governance arrangements to address the priority transboundary issues affecting LME fisheries, oil and gas production, transportation, tourism, and offshore energy production, identified in the LMEs they share. The processes used to make determinations on priority issues relating to governance include the joint preparation by participating countries of Transboundary Diagnostic Analyses (TDAs), to prioritize issues, and Strategic Action Programs (SAPs) focused on issues to be resolved within the framework of governance mechanisms to optimize socioeconomic benefits to be derived from healthy LMEs. The SAPs serve as agreed-upon international agreements guiding the implementation of actions identified and prioritized in the TDAs for advancing toward recovery and sustainability of LME goods and services (Duda and Sherman, 2002; Carlisle, 2013).

The overarching LME adaptive management strategy is derived from temporal analyses of the results from the system-wide measurements of changing states of productivity, fish and fisheries, pollution and ecosystem health, socioeconomic conditions and governance guidance, advice, and rulings. Management decisions are made with due consideration to the 5-module indicators of LME changing conditions at different spatial scales within the LME. These decisions are contingent on multiple sector impact assessments that consider integrated marine spatial planning results wherein, for example, fisheries sustainability may be placed at risk from developments in other sectors including marine transport,

Table 2
A paradigm shift to ecosystem-based management .

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

From Lubchenco, J. 1994. The scientific basis of ecosystem management. Ecosystem Management Status and Potential, 103rd Congress, 2d session, Committee Print. U.S. Government Printing Office, Superintendent of Documents 33-39.

Table 3
Marine spatial planning for multiple sectors, based on (Gold, 2010).

Marine spatial planning for: • Capture fish and fisheries • Aquaculture • Energy production (Gas and Oil) • Marine transport • Alternative sources of energy – wind, hydrokinetic (i.e. waves and tides), hydrothermal • Recreation/tourism • Coastal development

energy production, minerals extraction, recreation, mariculture (Table 2).

The ministerial approvals for GEF-supported LME Projects are obtained at the national levels with full knowledge that the ministries are entering into a five year agreement, with the option for a second five years, to address transnational and transboundary issues that have been prioritized through the GEF supported TDA and SAP processes, thereby integrating local, national and transboundary interests of the LME project for up to ten years.

Spatial scales to be considered range from the local community-based activity up through municipal, regional, national, and transboundary international scales (Fig. 3). Within the governance framework of the LME, management actions should consider multiple user issues relating to sustainable development. The GEF-supported LME projects are implementing integrated, adaptive management of oceans, coasts, and estuaries through an ecosystem-based approach that considers different time and space scales relevant to the ecosystem. GEF funding catalyzes integrated management from local to the regional LME scale through additive and integrative synthesis of information from the annual monitoring of changes in productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance. The bottom up TDA and SAP process assures that information from coastal communities gets to the national and supra-national planning levels. The GEF LME projects, globally, have activities underway to recover and sustain the goods and services identified in the TDA and SAP processes. These activities and policies affect food security and related marine industries, aquaculture, tourism, shipping, and energy for the people of Africa, Asia, Latin America and eastern Europe.

4. LME adaptive management: the Yellow Sea LME case study

The Transboundary Diagnostic Analysis (TDA) was updated in 2007 for the Yellow Sea LME. The TDA process involves consideration of activities related to the 5 modules including: (i) productivity, (ii) fish and fisheries, (iii) pollution and ecosystem health, (iv) socioeconomics, and (v) governance (UNDP/GEF, 2007). The first three modules are science-driven, while the other two modules address socio-economic and adaptive management processes (UNDP/GEF, 2007).

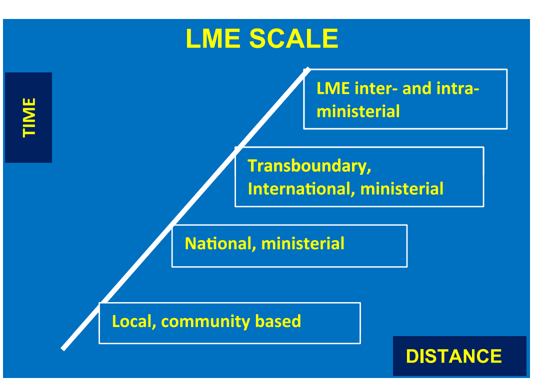


Fig. 3. Scaling from local to international activities in the LME approach.

The TDA for the YSLME Project identifies, quantifies, and sets priorities for the resource sustainability problems that are transboundary in nature. The TDA yields a list of priority issues and identifies transboundary effects and causes that make it desirable that the TDA process be conducted multilaterally. The evaluation of priorities is based on the severity of the problem in the context of its effects on those drawing their livelihood from the water area concerned. It is an examination of the reduction in economic gains from the area in relation to its sustainable potential. The TDA designates relative weightings to the causes at each level of hierarchy for each of the problems at the base of the causal chain analysis (UNDP/GEF, 2007).

The causal chain analysis is an analytical tool helping to identify the causes of a problem with its effects. A simple causal chain is one-dimensional. Most often there are inter-linkages between causes and effects, and sectoral dimensions that also need to be taken into account. Underlying causes are those that contribute to the immediate causes, and can broadly be defined as underlying resource uses and practices, and their related social and economic causes. The important social and economic causes influencing the goods and services of the YSLME include waste management procedures, demand and supply market patterns, demographic pressure on coastal areas, environmental values and gaps in information. Some of these causes are of national origin, and others are of transboundary origin. Transboundary causes "are not addressed by individual national actions alone" (UNDP/GEF, 2007).

4.1. YSLME (TDA) productivity

The Yellow Sea LME is a Class I, highly productive ecosystem (>300 g Cm^2 yr) that supports substantial populations of fish, invertebrates, marine mammals and seabirds (Sherman and Hempel, 2008). Ecosystem trends identified in the TDA show major changes over the past decades. There are signs of LME deterioration such as the decline of commercially important fish landings, increase of algal blooms and jellyfish blooms. The increase in the abundance of jellyfish in recent years is a "reflection of changes in primary and secondary productivity in the system and alterations to the food web of the Yellow Sea." While it might appear that increased primary production from nutrient over-enrichment "*would be beneficial to the Yellow Sea system it results in reduced diversity among algal and zooplankton species and some of the dominant algae may be harmful to higher organisms such as fish*" (UNDP/GEF, 2007). Excessive nutrient loading also reduces oxygen levels, leading to oxygen depletion events in the YSLME (Tang, 2009).

4.2. YSLME (TDA) fish and fisheries

"*The Yellow Sea overall remains a productive fisheries area yielding over* 2.3 *million t. of wild fish*". "*The commercial catches in the Yellow Sea are mainly of migratory species and this intrinsically makes the nature of the issue a transboundary one.*" The principal issue in fish and fisheries is the decline in landings of many traditional commercially important species such as the Pacific Herring, and increased landings of low value species (UNDP/GEF, 2007). Overfishing of pacific herring "has undoubtedly contributed to the decline of this fishery with climatic changes also playing a role". The TDA identifies a reduction of benthos from 170 species in the 1950s to some 70 species in the 1980s. Marine and coastal living resources are overexploited (Tang, 2009). In addition, climate change has contributed to an observed decline in landings of commercially important and vulnerable species that are important components of Yellow Sea biodiversity. The introduction of Spartina has altered the ecology of the YSLME system, further reducing biodiversity (UNDP/GEF, 2007).

The increase in the abundance of jellyfish in recent years has caused interference with fishing activities. Issues identified include the overcapacity of the fishing sector, the lack of alternative livelihoods to fisheries, the increasing demand for seafood, and unsustainable fishing practices. Overfishing can disrupt food webs by targeting specific, in-demand species (UNDP/GEF, 2007).

4.3. YSLME (TDA) pollution and ecosystem health

A summary of the types and nature of environmental problems relating to pollution is provided in the YSLME TDA. “The primary cause of increased eutrophication is an increased supply of dissolved nitrogen through riverine and wastewater discharge.” “The adverse effects associated with eutrophication are excessive algal blooms that decrease water transparency and give rise to high concentrations of organic matter in surface waters often referred to as ‘red tides’”. It will be important to introduce buffer zones between agricultural activities and freshwaters to reduce runoff of agricultural contaminants including pesticide and fertilizer residues and animal sewage (UNDP/GEF, 2007).

More than 30% of mud foreshores and lagoons have been lost over the past 30 years. The main effect of habitat loss is on the composition of communities and biodiversity in tidal mudflats. The loss of marshlands has caused a reduction in habitat for waterfowl and birds. The main cause of habitat loss, especially in estuaries and shallow bays, has been land reclamation for the purpose of mariculture, industrial development, salt pans, agriculture, and tourism facilities. Measures, however, have been taken to protect salt marshes (UNDP/GEF, 2007).

Alien species have been introduced, primarily for aquaculture and mariculture. Scallops are an important mariculture species, introduced from Japan and the United States. Alien species have also been introduced inadvertently through ballast water in ocean transportation (UNDP/GEF, 2007). A map prepared by the Korea Ocean Research and Development Institute (KORDI) and the World Wildlife Fund identifies priority areas for biodiversity conservation (Fig. 4).

Releases from industrial, agricultural and municipal sources along with sewage from surrounding urban centers contribute to eutrophication, fecal contamination and marine litter. The release of excessive nutrients, bacteria, viral and fecal matter, and food residues has caused adverse effects on e.g. the production of penaeid shrimps, and also on environmental and human health concerns. The presence of toxic substances constitutes a “hazard to human health that can result in reduced tourism opportunities and income as well as reduced value of seafood” (UNDP/GEF, 2007). So far, there have been incremental investments in infrastructure for waste management, especially in China, as both the People’s Republic of China and the Republic of Korea are experiencing rapid economic and social development.

YSLME/river watershed interface: changing river discharge is clearly relevant to the status of LME biodiversity as it alters both the

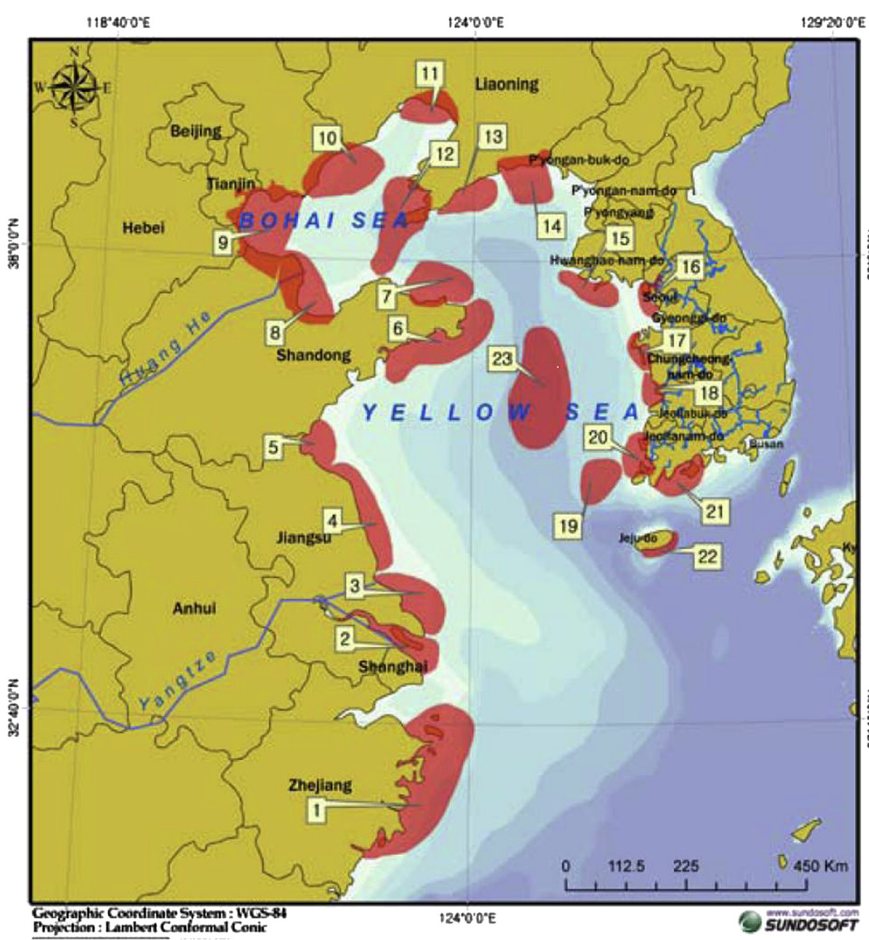


Fig. 4. Priority areas for biodiversity conservation in the YSLME. After WWF et al., 2006 (UNDP/GEF, 2007).

salinity and temperature regimes of estuaries and coastal areas directly influenced by freshwater discharge. This is especially true of freshwater discharge in summer and winter from the Yellow River. Other smaller rivers have seen their flow modified by engineering works in their drainage basins. An example of linkage between a river basin and the Yellow Sea LME is the GEF-supported Hai Basin Initiative led by China with assistance from the World Bank.

4.4. YSLME (TDA) socioeconomics

The areas draining into the Yellow Sea LME are inhabited by an estimated 600 million people. Large coastal cities depend on the LME as a source of food, economic development, recreation and tourism. The coastal areas are experiencing a growth in shipping and international trade. Fishing and mariculture constitute an important source of food, employment and foreign exchange to the states bordering the Yellow Sea LME (Sherman and Hempel, 2008). Over the past decades, increased pollution has had severe socio-economic impacts. The TDA identifies a need to take more account of environmental threats and achieve a balance in policies relating to economic expansion and environmental protection. Marine and coastal living resources are overexploited. Issues identified include the overcapacity of the fishing sector, the lack of alternative livelihoods to fisheries, the unchecked demand for seafood, and unsustainable fishing practices (UNDP/GEF, 2007).

An imperative put forward by the GEF in its support of LME projects is to secure livelihoods while reversing natural resource depletion and degradation (Duda, 2009) The economic evaluation of environmental goods and services is "not sufficiently advanced to be used for the purposes of including in the TDA the cost of adverse effects on the environment associated with contemporary problems in the Yellow Sea" (UNDP/GEF, 2007).

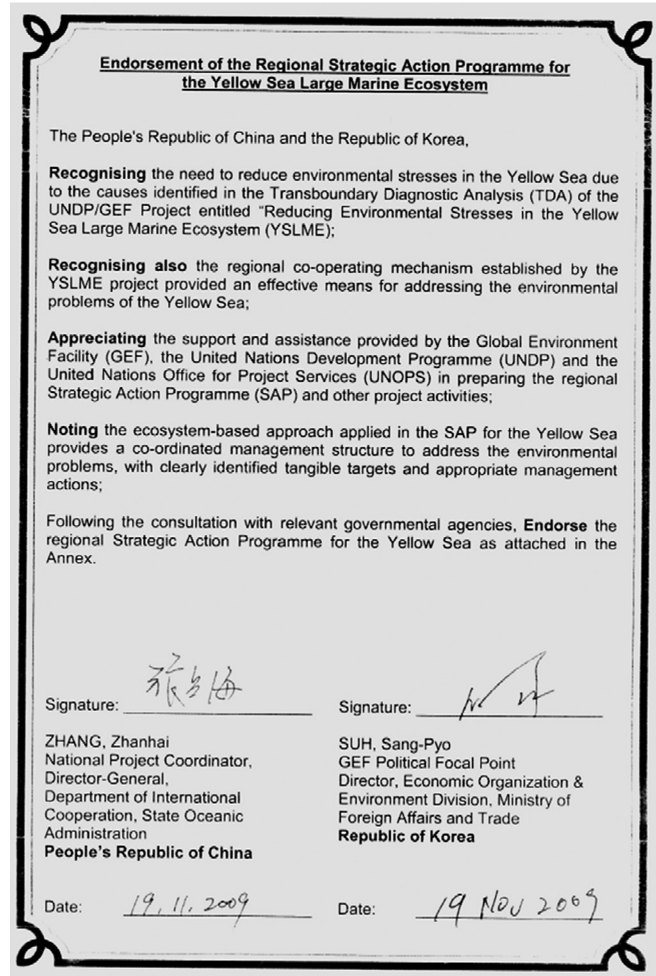
4.5. YSLME (TDA) governance

Governance of the YSLME is shared by the People's Republic of China, the Republic of Korea, and the Democratic People's Republic of Korea (DPRK). Presently, the DPRK is not participating in the YSLME project. The TDA identifies the lack of a comprehensive and coherent legislative framework to address transboundary problems in the Yellow Sea Large Marine Ecosystem, inadequate enforcement of legislation relating to coastal zone management and coastal protection, and illegal fishing activities (UNDP/GEF, 2007). The TDA document is serving as a basis for facilitating governance agreements between China and South Korea.

4.6. Application of the YSLME SAP process and five module methodology

The Project TDA provided a basis for the subsequent formulation of the Strategic Action Program (SAP). The aim of the SAP is "to restore and preserve the YSLME. It adopts a comprehensive approach and addresses land and sea-based sources of marine pollution, degradation of critical habitats and over-fishing". The SAP reiterates some of the environmental challenges identified in the Project TDA. Water is exchanged only every 7 years making the Yellow Sea LME vulnerable to pollution (UNDP/GEF, 2009). The LME is described as very productive as it supports substantial populations of fish, birds, mammals, invertebrates. A huge human population resides in the coastal areas adjacent to the LME.

The SAP was endorsed at a high governmental level on 19 November 2009 by the People's Republic of China and the Republic of Korea (Fig. 5).



Endorsement of the Regional Strategic Action Programme for the Yellow Sea Large Marine Ecosystem

The People's Republic of China and the Republic of Korea,

Recognising the need to reduce environmental stresses in the Yellow Sea due to the causes identified in the Transboundary Diagnostic Analysis (TDA) of the UNDP/GEF Project entitled "Reducing Environmental Stresses in the Yellow Sea Large Marine Ecosystem (YSLME);

Recognising also the regional co-operating mechanism established by the YSLME project provided an effective means for addressing the environmental problems of the Yellow Sea;

Appreciating the support and assistance provided by the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) and the United Nations Office for Project Services (UNOPS) in preparing the regional Strategic Action Programme (SAP) and other project activities;

Noting the ecosystem-based approach applied in the SAP for the Yellow Sea provides a co-ordinated management structure to address the environmental problems, with clearly identified tangible targets and appropriate management actions;

Following the consultation with relevant governmental agencies, **Endorse** the regional Strategic Action Programme for the Yellow Sea as attached in the Annex.

Signature:

ZHANG, Zhanhai
National Project Coordinator,
Director-General,
Department of International Cooperation, State Oceanic Administration
People's Republic of China

Date: 19, 11, 2009

Signature:

SUH, Sang-Pyo
GEF Political Focal Point
Director, Economic Organization & Environment Division, Ministry of Foreign Affairs and Trade
Republic of Korea

Date: 19 NOV 2009

Fig. 5. Endorsement of the Strategic Action Programme (SAP) for the Yellow Sea Large Marine Ecosystem by the People's Republic of China and the Republic of Korea on 19 November 2009.

The three main goals of the YSLME Project as outlined in the project SAP are:

1. to improve carrying capacity, sustain YSLME services, and provide food and genetic resources to meet the requirements of human wellbeing;
2. to improve sewage treatment and water quality regulation, and control disease;
3. to sustain YSLME cultural services for improved aesthetic values and attractiveness for recreation and ecotourism, by reducing marine litter and contaminants around bathing beaches and other recreational waters, and establishing nationally acceptable levels of pollution.

To achieve these goals, 12 selected targets are outlined in the Strategic Action Plan (SAP): (UNDP/GEF, 2009).

4.7. YSLME SAP—productivity

The project TDA had found evidence of changes in the composition of both phytoplankton and zooplankton communities in the Yellow Sea LME, resulting in changes in the food web and threats to food supplies for living marine resources at higher trophic levels (UNDP/GEF, 2007). Korea identified "change in dominant groups of zooplankton", while China observed a changed ratio of diatoms to dinoflagellates. Two project targets for LME productivity are: to monitor and assess ecosystem structure and productivity; and to better predict ecosystem change. "Monitoring is a continuous or periodic function that uses systematic collection of data, qualitative and quantitative, for the purposes of keeping activities on track". A goal is the establishment of a YSLME cross basin monitoring network and the implementation of regional monitoring activities, including scientific research. In the YSLME, the warming trend is significant and has been accelerating, leading to a northward movement of isothermals during that period. Climate change will affect marine ecosystems by altering large scale oceanic circulation patterns. Intensified stratification can reduce the productivity of the upper layer (UNDP/GEF, 2009). The increase in carbon dioxide emissions is also causing acidification of sea water. Measures will include the development of a monitoring and assessment strategy and an assessment of pollution. A regional workshop will be held every 5 years, focused on monitoring and assessment technology.

4.8. YSLME (SAP) fish and fisheries

Two targets for the fish and fisheries module are: to increase fisheries by reducing fishing pressures through a 25–30% reduction in fishing effort and a reduction in the number of fishing boats; and to rebuild over-exploited fish stocks. Presently, the level of fisheries exploitation is not sustainable. Fish catches are now dominated by short lived, smaller, lower trophic level and less valuable species such as anchovy and sandlance. The loss of key fish species through overfishing is thought to allow the blooms of flagellate and jellyfish. Rebuilding over-exploited fish stocks will need to be combined with reducing pollutant discharge. Other management measures will include an increase of mesh size to reduce the percentage of juveniles caught and the use of more selective fishing gear. Consideration is being given to the establishment of 10 protected areas for fishery resources in the YSLME (UNDP/GEF, 2009).

4.9. YSLME (SAP) pollution and ecosystem health

Six targets for this module are: to monitor the impacts of nutrient ratio change and climate change; reduce nutrient loading; reduce marine litter and the contamination of beaches; improve the biodiversity status; maintain habitats; and reduce the risk from introduced species. The Yellow Sea LME has two seasonal water circulation patterns, "but water circulation is weak, meaning that coastal areas are susceptible to localised pollution discharges" (UNDP/GEF, 2009).

The LME is also very vulnerable to eutrophication, which "promotes phytoplankton growth to such an extent that the bloom collapses, and the resulting bacterial decomposition causes oxygen depletion in the surrounding water causing fish kills and mass mortality of other less mobile organisms." A stated goal is to control total loading of pollutants, and to establish a regional conservation plan to protect endemic and vulnerable species. Another goal is to establish new Marine Protected Areas (MPAs) and improve the effectiveness of existing nature reserves to reduce stress, loss or modification of critical marine habitats. The project aims to update knowledge of current waste treatment facilities, improve treatment systems and capacities, and establish new facilities (UNDP/GEF, 2009).

4.10. YSLME (SAP) socioeconomics

The YSLME Strategic Action Programme set two targets for capture fisheries to be realized by 2020: (i) a 33% reduction of fishing effort for capture fisheries and (ii) rebuilding of fish stocks. Management actions have already been implemented to reduce fishing effort by reducing the size of the fishing fleet, limiting the places and seasons of fishing, and controlling mesh sizes (Walton and Jiang, 2009). The demand for fisheries products during the reduction in fishing effort will be met by scaling up advanced technological methods for increasing the carrying capacity of coastal mariculture through the application of integrated multi-trophic aquaculture (Fig. 6).

It is expected that scaling up of Integrated Multi-trophic Aquaculture IMTA methodology will result in improved water quality and greatly expanded production of shrimp, mollusks and other invertebrate species (e.g., abalone, bay scallops, sea cucumbers) to one million tons per year by 2020. Included in the SAP will be (1) demonstrated effectiveness of closed areas and seasons in the capture fisheries, (2) demonstrated effectiveness of stock enhancement practices and (3) demonstrated effectiveness of an accelerated vessel buy-back effort. In addition, the Republic of Korea will be significantly expanding sea sampling operations. The recovery actions, based on spatial oriented fisheries carrying capacity models will result in significant socioeconomic benefits to China and Korea from sustainable yields to be derived from both the capture fisheries recovery effort and the IMTA technology supporting large scale mariculture expansion (Walton and Jiang, 2009).

4.11. YSLME (SAP) governance

The governance target outlined in the SAP is to meet international contaminant requirements. The countries bordering the LME have chosen a combination of improvements in environmental legislation and enforcement, and aim to improve regional coordination and cooperation within national government agencies. The YSLME Commission is being planned as an institutional vehicle, serving to coordinate national efforts and to enhance the effectiveness of regional efforts. It is to be a soft, non legally binding, cooperation-based institution. It will be based on a joint declaration or MOU. Efforts will be made to ensure the DPRK's full participation in the YSLME Commission. The SAP, endorsed at a high governmental level by the People's Republic of China and the Republic of Korea, identifies the need for process indicators to characterize this institutional process (UNDP/GEF, 2009). The YSLME Commission will focus effort on the recovery and sustainability of the present degraded state of transboundary goods and services.

5. YSLME adaptive management best practices and carrying capacity

Project best practices for the YSLME can be identified at all planning phases. The YSLME Project has well defined goals and a time line that were agreed upon in the project TDA and SAP. The rationale for the LME project along with a summary of project goals are described in project newsletters and book chapters (UNDP/GEF, 2009; Walton and Jiang, 2009). The project manager is in charge of

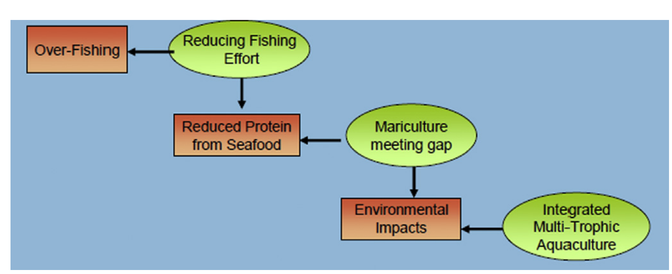


Fig. 6. Logical considerations of management implementation (after Walton and Jiang, 2009).

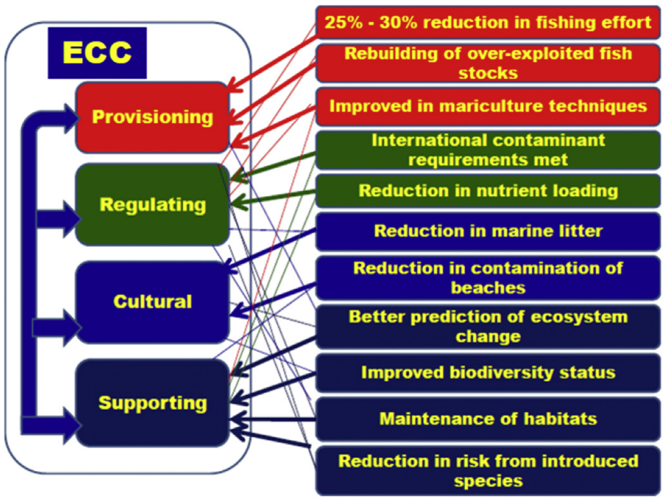


Fig. 7. The relationship between Ecosystem Carrying Capacity (ECC), ecosystem services (left) and the YSLME targets (right) that seek to maintain these services (UNDP/GEF, 2009).

financial aspects and constraints, the definition of project tasks, their sequence and duration, and problem solving. The project manager also understands how the existing governance system works. Good communication skills are critical. While each LME is unique, the YSLME project outcome can be replicated in other LME projects with similar conditions along with some of its best practices.

The SAP defines "ecosystem carrying capacity" as the capacity of the ecosystem to provide its services or the sum of all the ecosystem services it can provide (UNDP/GEF, 2009). The SAP provides a road map for improving the carrying capacity of the YSLME. Over the past decades there have been signs of ecosystem deterioration, such as the decline of commercially important fish landings, increase of algal blooms and jellyfish blooms. The problem can be summarized in five broad categories: unsustainable fisheries, pollution, habitat modification, climate change, and unsustainable mariculture.

The goal of ecosystem management is to maximize and sustain ecosystem services. Because there are linkages and tradeoffs among services, if aquaculture production, for instance, is unsustainably maximized, then other services will be diminished in addition to reduction of wild fish catch (UNDP/GEF, 2009). This is why sectoral approaches to assessment and management have not been very successful. Another issue is that not all the drivers of ecosystem change are controllable (e.g. climate change).

The YSLME SAP states the need for a holistic and comprehensive approach based on carrying capacity, determined by the various ecological processes that are interdependent, "which in turn are determined by ecosystem configuration and state". While environmental conditions change, management efforts can focus on an adaptive, learning based process that applies the principles of scientific methods to the process of management. It may be possible to estimate pollution conservatively as the capacity of the marine environment to assimilate waste materials based on current knowledge of physical, chemical, and biological conditions in the YSLME. Such assimilative capacities would be calculated to also define the density of acceptable coastal development (TDA p. 75). It should be possible to calculate the assimilative capacity of coastal embayments and the YSLME as a whole, and determine acceptable limits (TDA p. 94). Actions to be undertaken, based on ecosystem carrying capacity, are listed in the YSLME SAP action plan and summarized in Fig. 7. The full text of the Strategic Action Programme for the YSLME (ISBN: 978-89-964543-0-4 93530) is available online from the YSLME website at www.yslme.org/pub/SAP.pdf.

The ecological carrying capacity assessments are to be reviewed periodically through the activities of YSLME Working Groups arranged under the umbrella of the 5 modules. Contingent on the

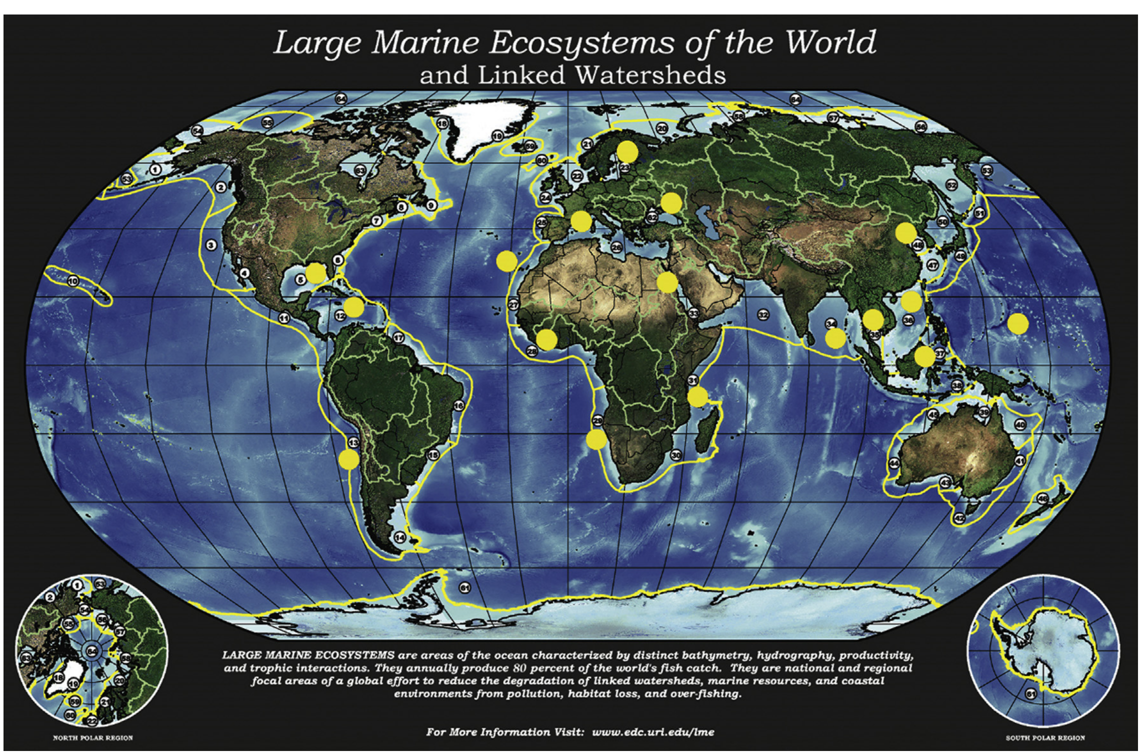


Fig. 8. The locations of 17 of the GEF-supported LME projects around the globe.

results of analyses of ECC, adaptive management practices will be implemented to the recovery and sustainable development of the YSLME goods and services. The recommendation for actions will be considered by both participating countries through a joint Commission for the YSLME, and based on the stated objectives of the agreed-upon YSLME SAP (available for download at www.YSLME.org).

6. The YSLME commission

The long-term objective of the YSLME 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. An important planned action, founded on fish and fisheries carrying capacity modeling, is the agreement to reduce fishing effort by 33% by 2020 in the Yellow Sea LME. The carrying capacity modeling effort has been applied to development and implementation of integrated multi-trophic aquaculture methods (IMTA). Initial successes suggest that the ramping up of pilot projects in waters adjacent to the Shandong peninsula could sustain annual harvests of abalone, seaweed, and sea cucumbers to 500 000 tons (Tang, 2009; Walton and Jiang, 2009).

A joint LME Commission for the Yellow Sea is under consideration to assess and manage the shared resources of the Yellow Sea LME (www.yslme.org/doc/rstp4/reg%20gov.pdf). Both China and Korea are moving forward within the framework of a GEF-supported joint SAP to recover and sustain the critically important shared goods and services of the YSLME.

7. Summary and conclusions

The Large Marine Ecosystem movement towards adaptive management of coastal ocean goods and services is being supported by a growing number of developing countries in Africa, Asia, Latin America, and eastern Europe. Financial support in grants, investment funds and donor country contributions reached a total of $3.1 billion in 2010. One hundred and ten countries are carrying forward 17 LME projects in coastal areas around the globe (Fig. 8).

The generic LME approach to adaptive ecosystem management is being successfully practiced. The approach based on a five-module assessment strategy requiring time-series measurements of LME productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance has been applied to efforts by the Peoples' Republic of China and the Republic of Korea for the recovery and sustainability of the degraded Yellow Sea LME (YSLME).

The carrying capacity of the YSLME is defined as the capacity of the ecosystem to provide essential services. Efforts to recover degraded ecosystem services include overcoming declines in landings of capture fisheries, unusual jellyfish blooms, nutrient over enrichment, habitat degradation and unsustainable mariculture.

Assessments of time-series monitoring data of YSLME productivity, fish and fisheries, pollution and ecosystem health, socioeconomics and governance, have supported actions to improve the degraded state of the YSLME with regard to ecosystem carrying capacity for provisioning and regulating YSLME goods and services. Agreement was reached to improve provisioning services through reduction of capture fisheries by 25–30 percent by the year 2020. In addition, the demand for fisheries products during the reduction in fishing effort is to be met by scaling up advanced mariculture technology and methods through the application of integrated multitrophic aquaculture.

From an ecosystem regulating services perspective, improved controls are to be implemented for reducing nutrient over-enrichment levels through improved aquacultural practices, improved and new sewerage treatment facilities, and more comprehensive water quality regulation.

The YSLME project demonstrates the compatibility of the ecosystem-based modular approach to the recovery, assessment, and management of LME goods and services and the GEF TDA and SAP processes supporting a bottom-up country-driven framework for integrating natural science and social science goals with time-series data and observations in support of ecosystem-based adaptive management practices.

The provision of financial, scientific, and technical assistance to the growing numbers of developing countries undertaking country-driven LME projects is in keeping with the stated goal of world leaders at the Rio plus 20 Conference of 2012 wherein agreement was reached to "…protect and restore the health, productivity, and resilience of oceans and marine ecosystems and to maintain their biodiversity, enabling their conservation and sustainable use for present and future generations…."

There is a growing application of national and global ecosystem-based assessments of LMEs. The seminal studies can be found in 14 LME volumes published between 1986 and 2006 by the American Association for the Advancement of Science (5 vols.), Blackwell Science (4 vols.), and Elsevier Science (5 vols.). A complete list of books, chapters and authors is available on our website at www.lme.noaa.gov. More recently, in keeping with the ecosystem-based approach to adaptive coastal ocean management, the United States designated eleven LMEs for integrated coastal and marine spatial planning, including the Northeast Continental Shelf LME, Southeast Continental Shelf LME, Gulf of Mexico LME, Caribbean Sea LME, California Current LME, Gulf of Alaska LME, East Bering Sea LME, West Bering Sea LME, Chuckchi Sea LME, Beaufort Sea LME and the Insular Pacific-Hawaiian Islands LME (Council on Environmental Quality, 2010; Executive Order, 2010).

As the application of ecosystem-based management progresses toward the UNCED sustainable development goals, support for LME studies by OECD-country scientists is advancing the understanding of LME primary productivity and fisheries yields (Chassot et al., 2010; Conti and Scardi, 2010; Conti et al., 2012); LME energy flow and fisheries yields (Coll et al., 2008; Christensen et al., 2009; Blanchard et al., 2012; Friedland et al., 2012); LME fish and fisheries (Worm et al., 2006; Pauly et al., 2008; Worm et al., 2009); LME fisheries catch shares (Costello et al., 2008); fish length comparisons among LMEs (Fisher et al., 2010); fisheries and food webs in LMEs (Essington et al., 2006); nutrient over-enrichment of LMEs (Seitzinger et al., 2008); and global warming effects on LMEs (Belkin, 2009; Sherman et al., 2009a; Cheung et al., 2013; Payne, 2013).

As both OECD countries and economically developing countries advance towards ecosystem-based, adaptive management, innovative linkages for moving forward are being forged including an ICES Working Group on LME Best Practices (http://ices-usa.noaa.gov), providing an organized forum for members of the WG to meet and exchange LME project plans and results. The GEF is also cognizant of the need to support the flow of information between OECD countries and the countries participating in GEF-supported LME projects relevant to promoting ecosystem-based governance regimes. To further development of ecosystem-based governance practices, funds have been made available for IOC-UNESCO, ICES, and other institutions to strengthen networks of scientists and policy experts and resource managers engaged in LME assessment and management practice (www.theGEF.org, GEF Project ID #5278).

In conclusion, the prospects for continuing movement toward adaptive management of LME goods and services at the regional level is being significantly advanced through the catalytic actions of the GEF in supporting LME Project partnerships with United

Nations agencies, OECD countries, and over 100 developing countries around the globe.

In keeping with their commitment to Rio +20, the GEF plans to allocate financial support from its sixth 4-year funding replenishment from 2014 through 2018 to continue assisting developing countries in the recovery and sustainability of LME goods and services (www.thegef.org/gef/search/node/LME%20Conference). The level of financial support through 2020 is projected at several billions of dollars based on catalytic ocean financing successes reported by the UNDP and the GEF (Hudson, 2012). Progress toward future self-financing and continuity of LME projects initiated with GEF grants is encouraging. In the case of the Yellow Sea LME project, the Republic of Korea, which no longer is eligible for GEF financial support due to its present robust economy, agreed to maintain its partnership with the Republic of China in moving toward agreed-upon objectives for the recovery and sustainability of YSLME goods and services (Sherman and McGovern, 2011). Given the prospect of continuing financial support by the GEF, and the expressed political will of countries with growing economies investing in LME projects the outlook for advancing LME project activity around the globe appears rather positive.

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