A global movement toward an ecosystem approach to management of marine resources

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The Large Marine Ecosystem Approach. Reports of problems with marine ecosystems are widespread in the scientific literature and the news media. Calls for an ecosystem approach to resource assessment and management are seldom accompanied by a practical strategy, particularly one with a payment plan for the approach in developing countries. However, a global movement that makes the ecosystem approach to management practical already exists. It is known as the Large Marine Ecosystem (LME) approach, and it is being endorsed and supported by governments worldwide, as well as 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 (Gislason & Sinclair 2000, Pitcher 2001, Stergiou 2002, Garcia et al. 2003, Sainsbury & Sumaila 2003, Browman et al. 2004, 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 and is presently under way, with the support of financial grants, donor and UN partnerships, in nations of Africa, Asia, Latin America and eastern Europe. It is within the boundaries of 64 LMEs that (1) 90% of the world's annual yield of marine fisheries is produced (Garibaldi & Limongelli 2003), (2) global levels of primary production are the highest, (3) the degradation of marine habitats is most severe, and (4) coastal pollution is concentrated and levels of eutrophication are increasing (GESAMP 2001). Large marine ecosystems (LMEs) are natural regions of coastal ocean space encompassing waters from river basins and estuaries to the seaward boundaries of continental shelves and outer margins of coastal currents and water masses (cf. Fig. 4). They are relatively large regions characterized by distinct bathymetry, hydrography, productivity, and trophically dependent populations (Alexander 1990, Levin 1990, Sherman 1994; see www.edc.uri.edu/lme).

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 LMEs located around the margins of the oceans. At present, 121 developing countries are engaged in the preparation and implementation of GEF-LME projects, totaling $650 million in start-up funding. A total of 10 projects including 70 countries has been approved by the GEF Council, and another 7 projects involving 51 countries have GEF international waters projects under preparation (see www.iwlearn.net).

A 5 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 productivity indicators include spatial and temporal measurements of temperature, salinity, oxygen, nutrients, primary productivity, chlorophyll, zooplankton biomass, and biodiversity. For fish and fisheries, indicators are catch and effort statistics, demersal and pelagic fish surveys, fish population demography, and stock assessments (NMFS 1999). Pollution and ecosystem health indicators include quality indices for water, sediment, benthos, habitats,

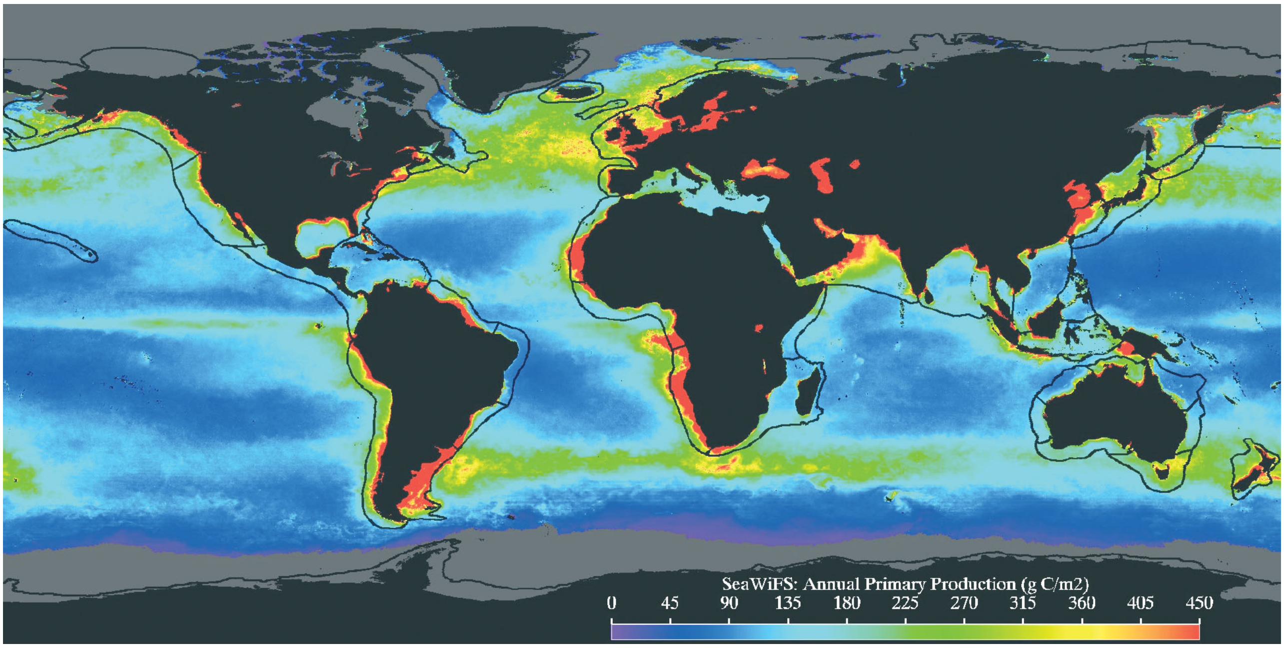

Fig. 4. Boundaries of the 64 Large Marine Ecosystems (LMEs) of the world and primary productivity (gC m^{-2} yr^{-1}). Annual productivity estimates are based on SeaWiFS satellite data collected between September 1998 and August 1999, and on the model developed by Behrenfeld & Falkowski (1997). Color-enhanced image provided by Rutgers University (available at: www.edc.uri.edu/lme, Introduction)

and fish tissue contaminants (EPA 2004). Socioeconomic and governance indicators are discussed in Sutinen et al. (2000) and Juda & Hennessey (2001). 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 (Wang 2004). These processes are critical for integrating science into management in a practical way, and for establishing appropriate governance regimes. Of the 5 modules, 3 modules apply science-based indicators that focus on productivity, fish/fisheries, and pollution/ecosystem health, and the other 2 modules, socioeconomics and governance, focus on economic benefits to be gained from a more sustainable resource base and from providing stakeholders and stewardship interests with legal and administrative support for ecosystem-based management practices. The first 4 modules support the TDA process, while the governance module is associated with periodic updating of the SAP development process. Adaptive management regimes are encouraged through periodic assessment processes (TDA updates) and through updating the action programs as gaps are filled.

The GEF-LME projects presently funded or in the pipeline for funding in Africa, Asia, Latin America and eastern Europe represent a growing network of marine scientists, marine managers, and ministerial leaders who are pursuing ecosystem and fishery recovery goals. The annual fisheries biomass yields from the ecosystems in the network are 44.8 % of the global total, and are a firm basis for movement by the participating countries toward the 2002 World Summit on Sustainable Development (WSSD) targets for introducing ecosystem-based assessment and management by 2010, and for recovering depleted stocks and achieving fishing at maximum sustainable yield levels by 2015. The FAO Code of Conduct for Responsible Fisheries (FAO 1995) is supported by most coastal nations and has immediate applicability to reaching the WSSD fishery goals. The code argues for moving forward with a precautionary approach to fisheries sustainability, using available information more conservatively to err on the side of lower total allowable catch levels than has been the general practice in past decades. Although fishing effort data are not available in FAO global catch reporting statistics and could bias catch data interpretations, it appears that the biomass and yields of 11 species groups in 6 LMEs have been relatively stable or have shown marginal increases over the period from 1990 to 1999. The yield for these 6 LMEs—the Arabian Sea, Bay of Bengal, Indonesian Sea, North Brazil Shelf, Mediterranean Sea and the Sulu-Celebes Sea—was 8.1 million t, or 9.5 % of the global marine fisheries yield in 1999 (Garibaldi & Limongelli 2003). The countries bordering these 6 LMEs are among the world's most populous, representing approximately one-quarter of the total human population. These LME border countries increasingly depend on marine fisheries for food security, and for national and international trade. Given the risks of fishing down the food web, it would appear opportune for the stewardship agencies responsible for the fisheries of the LME-bordering countries to limit increases in fishing effort during a period of relative biomass stability.

Evidence for species biomass recovery following significant reduction in fishing effort through mandated actions is encouraging. In the USA Northeast Shelf LME, management actions to reduce fishing effort contributed to a recovery of depleted herring and mackerel stocks and an initiation of the recovery of depleted yellowtail flounder and haddock stocks (Sherman et al. 2003); this was in combination with the robust condition of average annual primary productivity (350 g C m^{-2} yr^{-1}) for the past 3 decades, a relatively stable zooplankton biomass at or near 33 cm^3 per 100 m^3 for the past 30 yr (Sherman et al. 2002), and an oceanographic regime marked by a recurring pattern of interannual variability, but showing no evidence of temperature shift of the magnitude described for other North Atlantic LMEs, including the Scotian Shelf (Zwanenburg 2003), the Newfoundland-Labrador Shelf (Rice 2002), the Iceland Shelf (Astthorsson & Vilhjálmsson 2002) and the North Sea (Perry et al. 2005). On the other hand, 3 LMEs remain at high risk for fisheries biomass recovery—expressed as a pre-1960s ratio of demersal to pelagic species—the Gulf of Thailand, East China Sea, and Yellow Sea (Pauly & Chuenpagdee 2003, Chen & Shen 1999, Tang & Jin 1999). The People's Republic of China has initiated steps toward recovery by mandating 60–90 d closures to fishing in the Yellow Sea and East China Sea (Tang 2003). The country-driven planning and implementation documents supporting the ecosystem approach to LME assessment and management practices can be found at www.iwlearn.net.

Nitrogen loadings. Globally, LME projects, in addition to rebuilding depleted fish stocks and restoring degraded coastal habitats, are also concerned with the mitigation of the effects of nitrogen loadings. Nitrogen over-enrichment has been a coastal problem for 2 decades in the Baltic Sea LME (HELCOM 2001). More recent human-induced increases in nitrogen flux range from 4- to 8-fold in the USA from the Gulf of Mexico to the New England coast (Howarth et al. 2000). In European LMEs, recent nitrogen flux increases have ranged from 3-fold in Spain to11-fold in the Rhine River basin draining to the North Sea LME (Howarth et al. 2000). This disruption of the nitrogen cycle originated in the Green Revolution of the 1970s as the world community converted wetlands to agriculture, utilized more chemical fertilizer, and expanded irrigation to feed the world (Duda & El-Ashry 2000). For the estuaries of the southeastern USA (Duda 1982) and for the Gulf of Mexico (Rabalais et al. 1999), much of the increase in nitrogen export to LMEs is from agricultural inputs, from the increased delivery of nitrogen fertilizer as wetlands were converted to agriculture, and from livestock production (NRC 2000). Also, sewage from large cities is a significant contributor to eutrophication, as is increased nitrogen in atmospheric deposition resulting from combustion of fossil fuels by automobiles and industrial activities (GESAMP 2001).

Global forecast models of nitrogen export from freshwater basins to coastal waters indicate that there will be a 50 % increase world-wide in dissolved inorganic nitrogen (DIN) export by rivers to coastal systems from 1990 to 2050 (Seitzinger & Kroeze 1998, Kroeze & Seitzinger 1998). Such increases in nitrogen export are alarming for the future sustainability of LMEs. Given the expected future increases in population and in fertilizer use, without significant mitigation of nitrogen inputs, LMEs will be subjected to a future of increasing harmful algal bloom events, reduced fisheries, and hypoxia that further degrades marine biomass yields and biological diversity. Models of nitrogen loading from land-based sources and models of ecosystem structure and function are being applied to LMEs with financial assistance from the GEF. Estimates of carrying capacity using ECOPATH-ECOSIM food web approaches for the world's 64 LMEs are being prepared in a GEF-supported collaboration between scientists of the University of British Columbia and marine specialists from developing countries. Similarly, a 24 mo training project is being implemented by scientists from Rutgers University in collaboration with IOC/UNESCO to estimate expected nitrogen loadings for each LME over the next decade. Scientists from Princeton University and the University of California at Berkeley are examining particle spectra and pattern formation within LMEs. Additionally, the American Fisheries Society and the World Council of Fisheries Societies are collaborating in an electronic network to expedite information access and communication among marine specialists (for details on the GEF-LME project, see www.gefonline.org/projectDetails.cfm?projID=2474).

The growing number of country-driven commitments to move toward ecosystem-based assessment and management of marine resources and environments provides an unprecedented opportunity for accelerating the transition to sustainable use, conservation, and development of marine ecosystems. The social, economic, and environmental costs of inaction are simply too high for multilateral and bilateral institutions and international agencies not to support the initial efforts of 121 countries attempting to reach the WSSD marine ecosystem targets for restoration and sustainability. Both developed and developing nations have a stake in moving toward the use of sustainable ecosystem resources. Momentum should not be lost, as this could result in irreversible damage to coastal ecosystems, to the livelihoods and security of poor coastal communities, and to the economies of coastal nations.

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Differences in economic perspectives and implementation of ecosystem-based management of marine resources

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Ecosystem definition. What is an ecosystem, and what is ecosystem-based management? There are many answers to these questions (e.g. Sinclair & Valdimarson 2003). Here is my summary: an ecosystem is a geographically specified system of organisms, including humans, the environment, and the processes that control the system's dynamics. Similarly, an ecosystem-based approach to the management of marine resources (EAM) is geographically specified; it is also adaptive and takes account of ecosystem knowledge and uncertainties. It considers multiple external influences, and strives to balance diverse societal objectives. EAM requires that the connections between people and the marine ecosystem be recognized, including the short- and long-term implications of human activities along with the processes, components, functions, and carrying capacity of ecosystems.

The fact that ecosystems and the EAM are geographically specified implies that for ecosystems that are shared by 2 or more countries, policies that are transboundary in nature are required to manage them successfully. Many of the world's 64 large marine ecosystems are shared by 2 or more countries (Sherman & Duda 1999, see also www.seaaroundus.org). For instance, to effectively apply EAM to the management of the Benguela Current Large Marine Ecosystem (BCLME), policies need to be crafted and adopted by the 3 countries bordering the ecosystem, namely Angola, Namibia and South Africa. In terms of policy, getting countries with diverse societal objectives to agree on and implement joint EAMs is a challenge which must be met if EAM is to gain universal applicability.

I focus on 2 ways by which a country's societal objective regarding the use of marine ecosystem resources can be affected: (1) how the country weights market and non-market values from the ecosystem; (2) which discount rate is applied to flows of net benefits over time from the ecosystem.

Values and valuation. The economic theory of valuation is based on what people want — their preferences (Brown 1984, Arrow et al. 1993). People's preferences are expressed through the choices and tradeoffs they make given the resource and time constraints they face. It is therefore important that we capture a given population's preferences fully in the decision making process on the use and non-use of marine ecosystem resources. The economic theory of valuation of natural and environmental resources calls for a comprehensive compilation of all values into a *total economic value* (Goulder & Kennedy 1997). The theory stipulates that the total economic value should include market and non-market values, which consist of direct and indirect use values, option value, existence value (Krutilla 1967), and bequest value (Young 1992).

Market values are traded in the market, e.g. the value of fish caught and sold in the market. *Non-market values* are not traded in the market. *Direct use values* capture the value of ecosystem goods and services that are directly used for consumptive purposes, e.g. the value of commercial output such as fish harvest. *Indirect use values* are values of ecosystem goods and services that are used as intermediate inputs to production, e.g. services such as water cycling and waste assimilation. *Option value* is the potential that the ecosystem will provide currently unknown valuable goods and services in the future. *Existence value* (essentially described as *non-use value* in the literature) is the value conferred by humans on the ecosystem regardless of its use value — an environmental good may be valuable merely because one is happy that it exists, quite apart from any future option to consume it, visit it or otherwise use it; this value may arise from aesthetic, ethical, moral or religious considerations. Finally, *bequest value* captures the willingness to pay to preserve a resource for the benefit of one's descendants (future generations).

A country's perspective on market and non-market values depends on a number of variables, including, (1) net price per unit of market goods and services, and (2) unit non-market value derived from the ecosystem. In practice, different countries place different emphasis on market and non market values. Countries that put more emphasis on market values tend to maintain