

*TOWARD RECOVERY AND
SUSTAINABILITY OF THE
WORLD'S LARGE MARINE
ECOSYSTEMS DURING
CLIMATE CHANGE*



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Front and back cover image of Earth from space, courtesy of NASA from Apollo series.

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November 1, 2011

***TOWARD RECOVERY AND
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WORLD'S LARGE MARINE
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CLIMATE CHANGE***

*A global effort is underway to assess,
manage, and sustain Large Marine
Ecosystem (LME) goods and services.*

A Message from the Director of the Environment and Energy Group, United Nations Development Programme (UNDP)

Climate change is a critical global issue. Without action, climate change could negate decades of development progress and undermine efforts for advancing sustainable development.

As the UN's global development network, UNDP recognizes that climate change calls for a new development paradigm—a paradigm that mainstreams climate change into sustainable development planning at all levels, links development policies with the financing of solutions and helps countries move toward less carbon intensive sustainable economies.



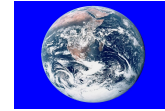
Dr. Veerle Vandeweerd

The integrity of all 64 of the World's Large Marine Ecosystems (LMEs) and the livelihoods of billions of people that depend upon them are under threat not only from climate change, but also from overfishing, toxic pollution, nutrient over-enrichment, invasive species, habitat degradation, and biodiversity loss. The large majority of these LMEs are shared by two or more countries, underscoring the need for regional cooperation to advance sustainable LME management. The UNDP Environment and Energy Group is pleased to partner with the Global Environment Facility, other UN agencies, intergovernmental organizations, and US-NOAA in providing capacity building and scientific and technical assistance in 75 developing countries executing ten Large Marine Ecosystem (LME) projects in Asia, Africa, Latin America, and Europe. Through these and other projects, UNDP also provides technical support to strengthen the capacities of developing coastal countries bordering LMEs to adapt to the effects of climate change on vital LME resources.

A firm scientific basis is essential in developing options for mitigating and adaptive actions during the present period of global warming. The LME approach recommends a baseline of information at the LME management scale of changing states of productivity, fish and fisheries, pollution and ecosystem health, and socioeconomic and governance conditions. This time-series information provides for assessment of the extent of overfishing, nutrient over-enrichment, habitat loss, and the progressive warming rates of surface water in LMEs around the globe, against which the success of climate change mitigation and adaptive actions to advance sustainable development of marine goods and services can be measured.

UNDP welcomes this approach as a key contribution toward meeting the Millennium Development Goals for reducing poverty, alleviating hunger and sustaining the environment. The world's LMEs contribute up to \$12.6 trillion annually to the global economy. LME goods and services provide employment and incomes to billions of people, many among the world's poorest, living in coastal population centers in Africa, Asia, Latin America, and eastern Europe. Through the continued cooperative efforts of UNDP and its partners, a growing number of countries have initiated joint LME management projects and gained support from the international community to develop and sustain vital economic assets of LMEs for present and future generations.

Sustainable Development of LMEs During Climate Change

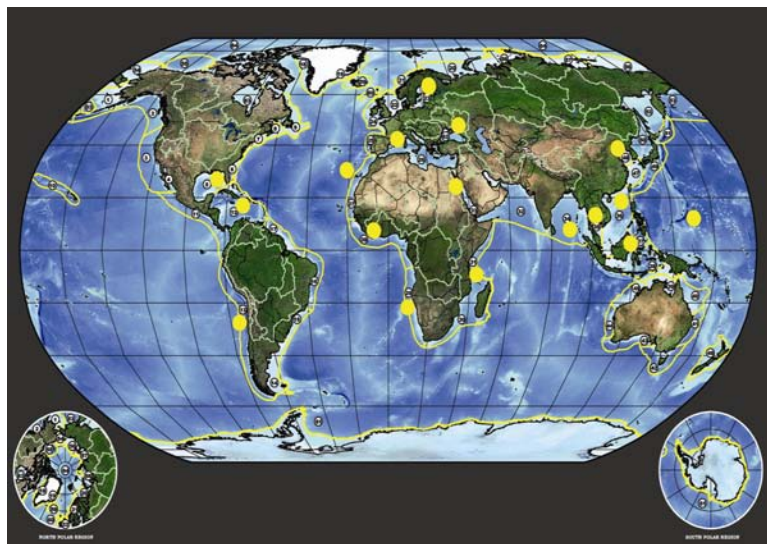


Large Marine Ecosystems (LMEs) are regions of ocean space encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margins of the world's major current systems. They are relatively large regions characterized by distinct bathymetry, hydrography, productivity, and trophically-dependent populations (1,2). On a global scale, the 64 LMEs support most of the world's marine fisheries. However, the LMEs are being degraded by coastal pollution, overfishing, invasive species, and habitat degradation.

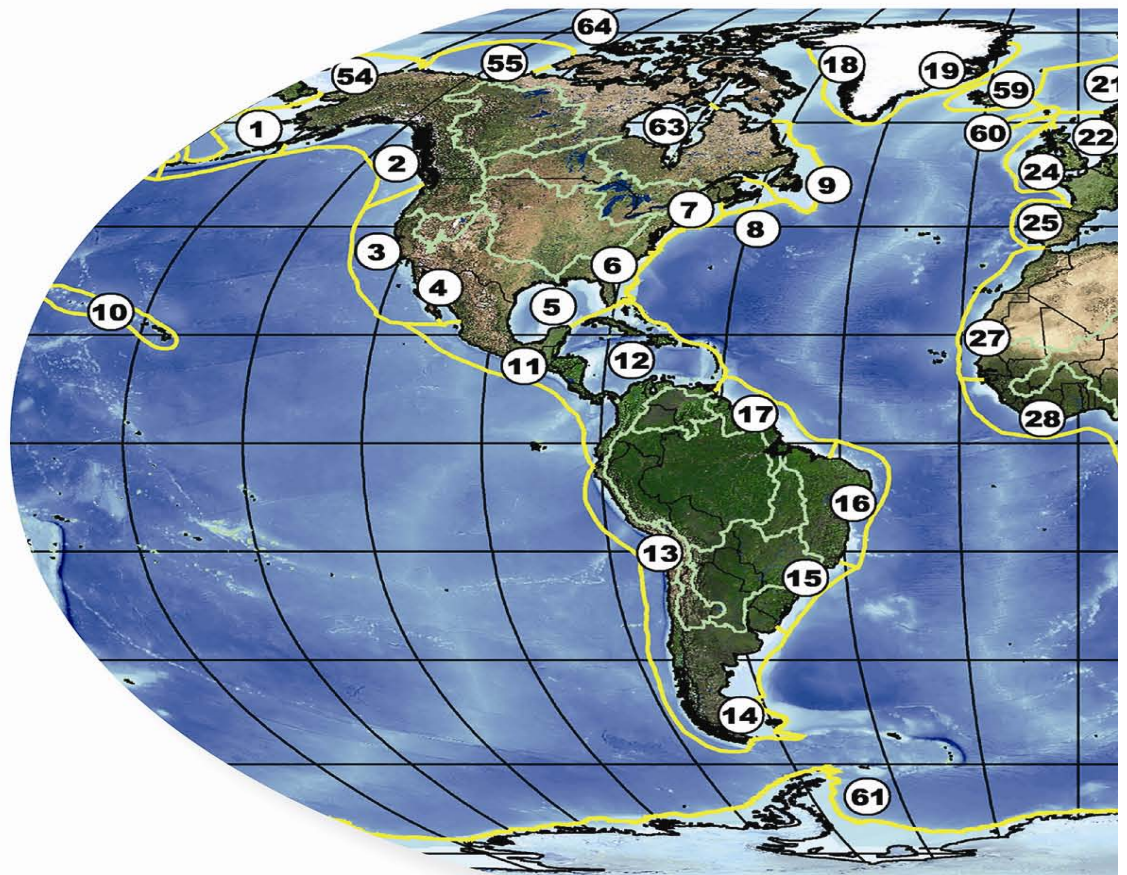
In a global effort to sustainably develop the world's LMEs, economically developing coastal countries in Africa, Asia, the Pacific, Latin America, and the Caribbean are working to restore and sustain coastal ocean goods and services. With assistance from two international financial institutions - the Global Environment Facility (GEF) and the World Bank, the United Nations system, and several industrialized countries, 110 coastal countries are implementing 17 trans-boundary, international LME projects to:

- *recover and sustain depleted fisheries*
- *reduce and control coastal pollution, and nutrient over-enrichment*
- *restore degraded habitats (e.g. seagrasses, corals, mangroves)*
- *mitigate and adapt to climate change.*

Location of 17 LME projects funded by the Global Environment Facility, UN agencies and the World Bank.

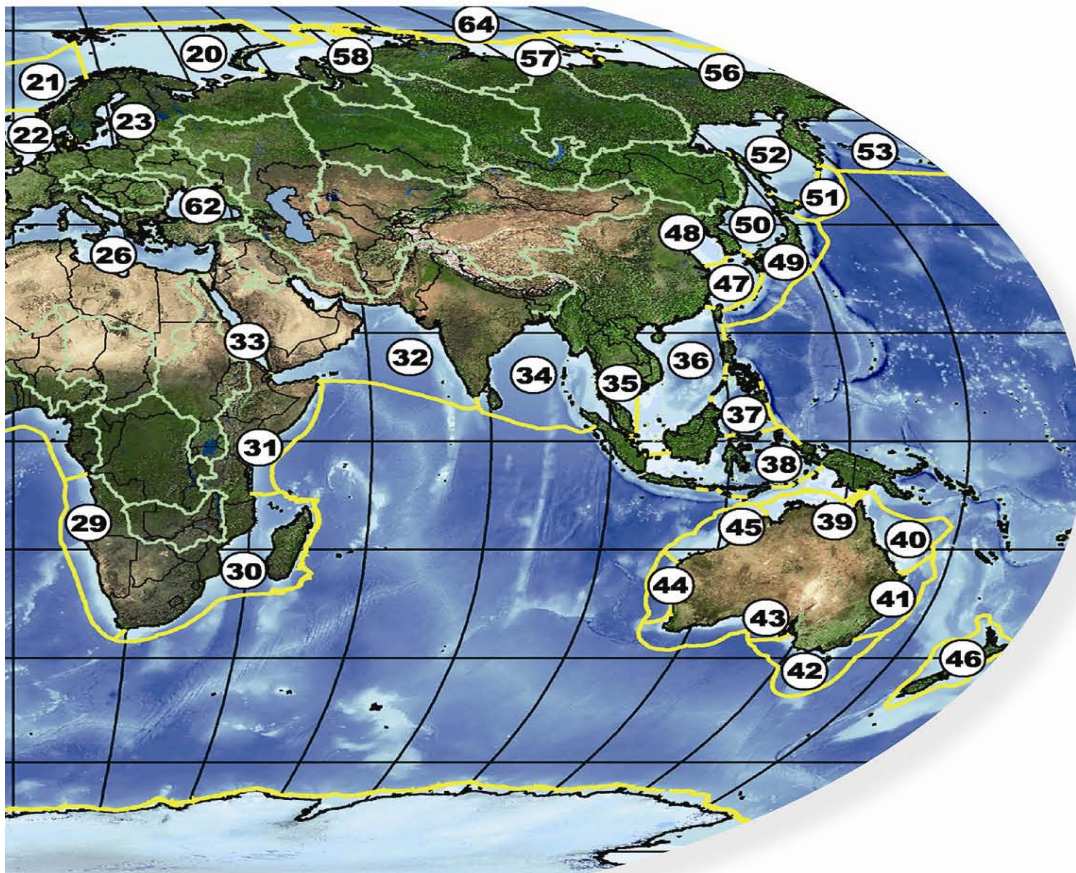


Large Marine Ecosystems of the

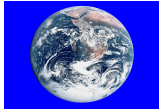


- | | | |
|-------------------------------------|-------------------------|---------------------------|
| 1 East Bering Sea | 13 Humboldt Current | 25 Iberian Coastal |
| 2 Gulf of Alaska | 14 Patagonian Shelf | 26 Mediterranean Sea |
| 3 California Current | 15 South Brazil Shelf | 27 Canary Current |
| 4 Gulf of California | 16 East Brazil Shelf | 28 Guinea Current |
| 5 Gulf of Mexico | 17 North Brazil Shelf | 29 Benguela Current |
| 6 Southeast U.S. Continental Shelf | 18 West Greenland Shelf | 30 Agulhas Current |
| 7 Northeast U.S. Continental Shelf | 19 East Greenland Shelf | 31 Somali Coastal Current |
| 8 Scotian Shelf | 20 Barents Sea | 32 Arabian Sea |
| 9 Newfoundland-Labrador Shelf | 21 Norwegian Sea | 33 Red Sea |
| 10 Insular Pacific-Hawaiian | 22 North Sea | 34 Bay of Bengal |
| 11 Pacific Central-American Coastal | 23 Baltic Sea | 35 Gulf of Thailand |
| 12 Caribbean Sea | 24 Celtic-Biscay Shelf | 36 South China Sea |

The World and Linked Watersheds

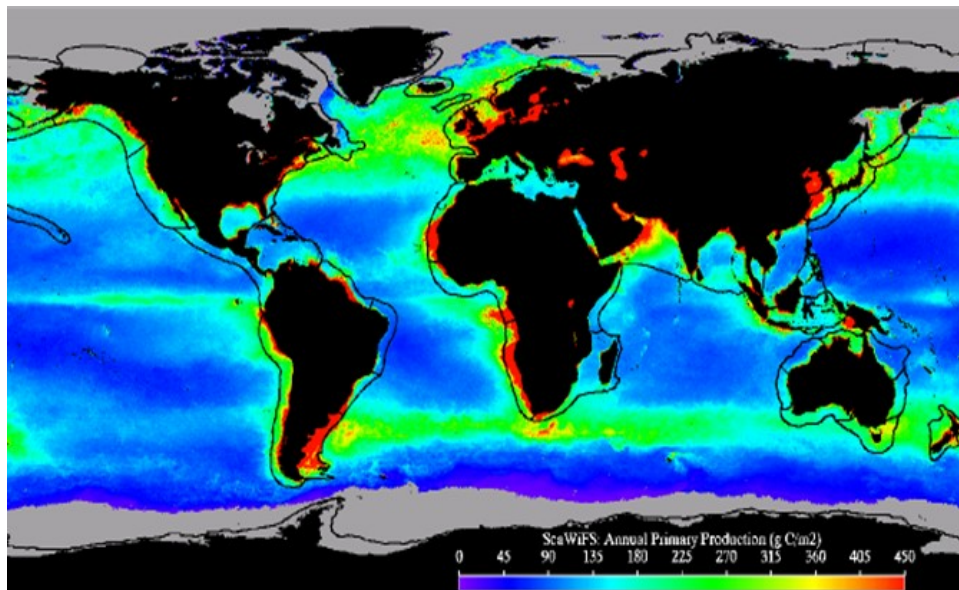
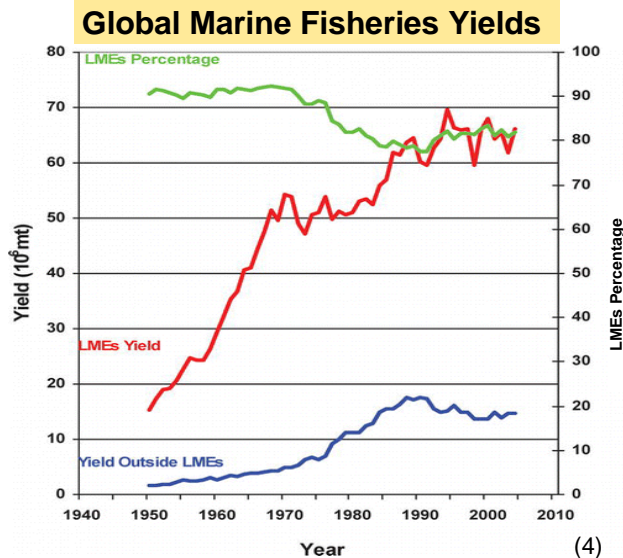


Sea	37 Sulu-Celebes Sea	48 Yellow Sea	60 Faroe Plateau
Current	38 Indonesian Sea	49 Kuroshio Current	61 Antarctic
Shelf	39 North Australian Shelf	50 Sea of Japan/East Sea	62 Black Sea
Shelf	40 Northeast Australian Shelf- Great Barrier Reef	51 Oyashio Current	63 Hudson Bay
Shelf	41 East-Central Australian Shelf	52 Okhotsk Sea	64 Arctic Ocean
Shelf	42 Southeast Australian Shelf	53 West Bering Sea	
Shelf	43 Southwest Australian Shelf	54 Chukchi Sea	
Shelf	44 West-Central Australian Shelf	55 Beaufort Sea	
Shelf	45 Northwest Australian Shelf	56 East Siberian Sea	
Shelf	46 New Zealand Shelf	57 Laptev Sea	
Shelf	47 East China Sea	58 Kara Sea	
		59 Iceland Shelf	



LMEs Are Highly Productive

The most highly productive areas of the ocean are located within the boundaries of the world's LMEs. Annual levels of primary productivity are measured in grams of carbon per square meter of ocean per year ($\text{gCm}^{-2}\text{yr}^{-1}$) as estimated from satellite data depicting light spectra of chlorophyll in ocean plankton, that supports the base of marine food webs. Areas of primary productivity, within LMEs, range from a high of $450 \text{ gCm}^{-2}\text{yr}^{-1}$ to less than $45 \text{ gCm}^{-2}\text{yr}^{-1}$ (3). The high primary productivity of LMEs supports 80 percent of the average annual catch of global marine fisheries yields (4).



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. The color-enhanced image depicts gradients of primary productivity from a high of $450 \text{ gCm}^{-2}\text{yr}^{-1}$ in red, to less than $45 \text{ gCm}^{-2}\text{yr}^{-1}$ in purple (3).

Ecosystem-Based Management

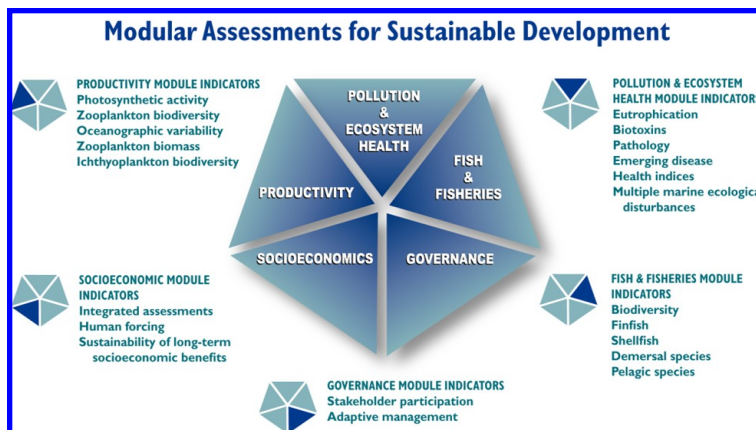


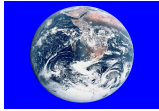
Managing the vital resources of LMEs from an ecosystem perspective requires a paradigm shift from small spatial scales to larger regional scales, from a short-term perspective to a long-term perspective, and from managing commodities to sustaining the production of coastal ocean goods and services.

ECOSYSTEM MANAGEMENT: A PARADIGM SHIFT	
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

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 (5)

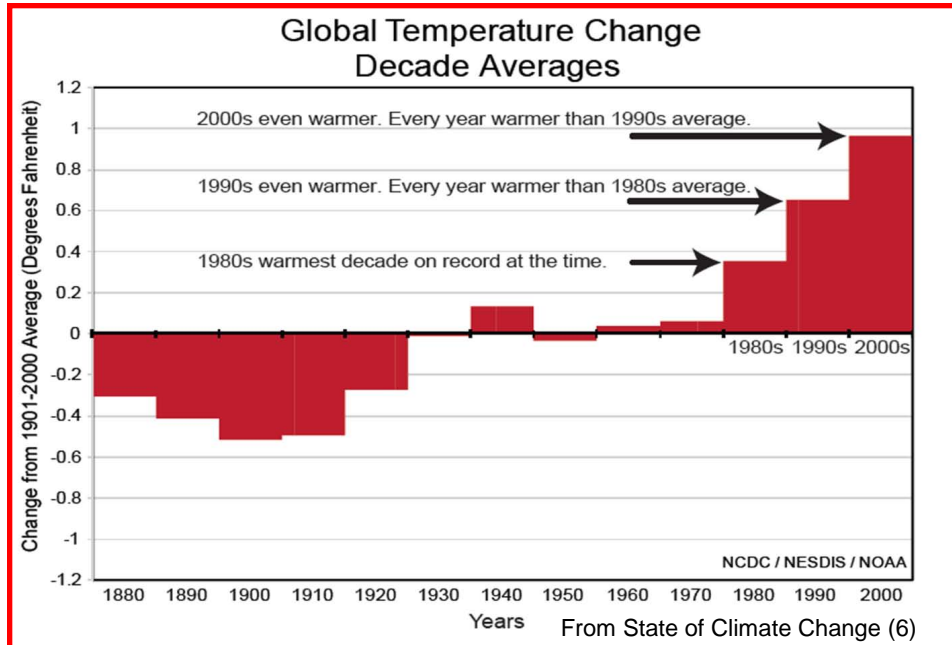
LME monitoring and assessment measurements focused on five modules (i) productivity, (ii) fish and fisheries, (iii) pollution and ecosystem health, (iv) socioeconomics, and (v) governance - support the paradigm shift to ecosystem-based management practices. Together the modules provide indicators and metrics used to assess the changing states of LMEs and support actions for recovery, sustainability, and management of goods and services. This approach is particularly important in adapting to climate change.





Global Temperatures On The Rise

Since the 1980s, global temperatures have been progressively warming.



From 1982 to 2006, the sea surface temperatures (SSTs) of LMEs warmed rapidly based on SST time series data (7).

SST changes in LMEs (1982 to 2006)

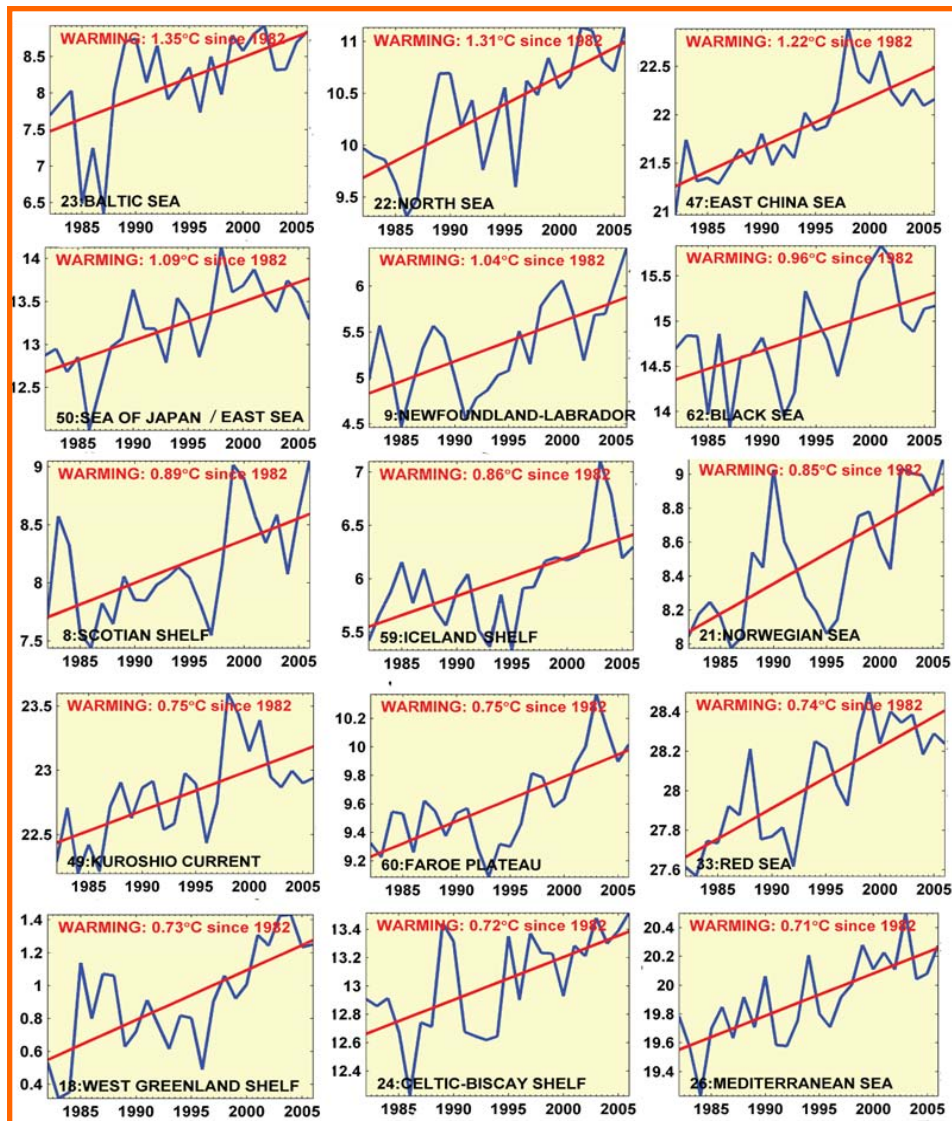
	(°C)
• Baltic Sea	1.35
• North Sea	1.31
• East China Sea	1.22
• Sea of Japan/East Sea	1.09
• Newfoundland/Labrador Shelf	1.04
• Black Sea	.96
• Scotian Shelf	.89
• Iceland Shelf	.86
• Norwegian Sea	.85
• Kuroshio Current	.75
• Faroe Plateau	.75
• Red Sea	.74
• West Greenland Shelf	.73
• Celtic-Biscay Shelf	.72
• Mediterranean Sea	.71

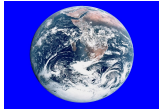
Warming Trends



For the period of 1982 through 2006, sea surface temperatures in 61 of the 64 LMEs followed an increasing warming trend, while 18 of the 64 warmed two to four times faster than the global average reported by the IPCC (8). Over this period, temperature increases in the 15 fastest warming LMEs ranged from 0.71°C in the Mediterranean Sea LME to 1.35°C in the Baltic Sea LME (7).

The 15 Fastest Warming LMEs (1982 to 2006)

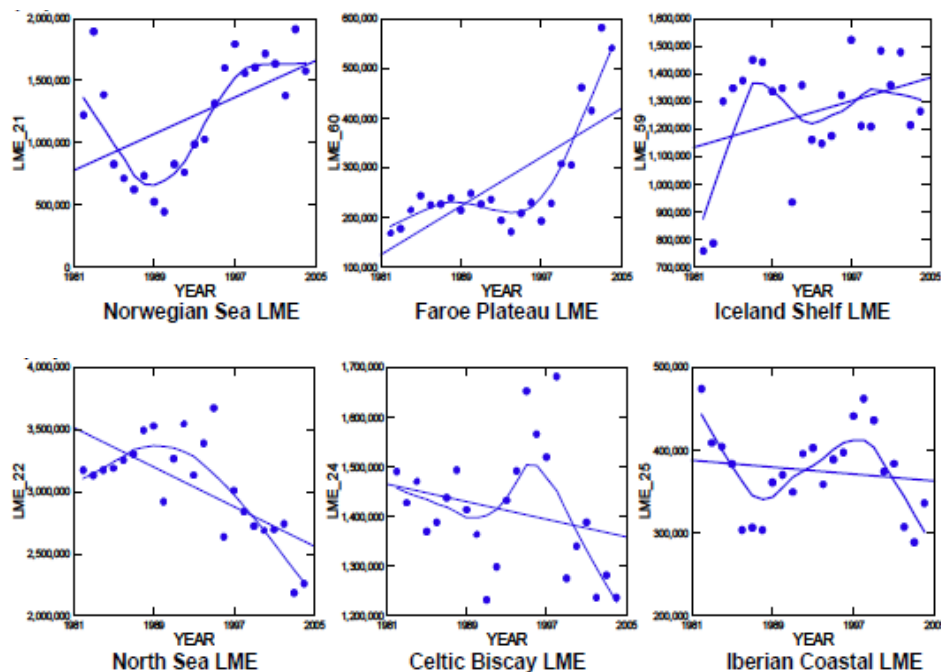




Fisheries' Biomass Yields Shift

Warming has been correlated with fisheries biomass yields (catches) in six of the warming LMEs. Yields increased from the mid-1980s to 2006 in the Norwegian Sea, Faroe Plateau, and Iceland Shelf LMEs and the rise in fisheries yield was most pronounced among zooplankton-feeding fish species including herring and blue whiting. In contrast, in warming LMEs further south in the Northeast Atlantic, the North Sea, Celtic Biscay Shelf and Iberian Coastal LMEs, fisheries biomass yields declined (9).

Fisheries biomass yields (in metric tons—mt): Of Six Warming Northeast Atlantic LMEs



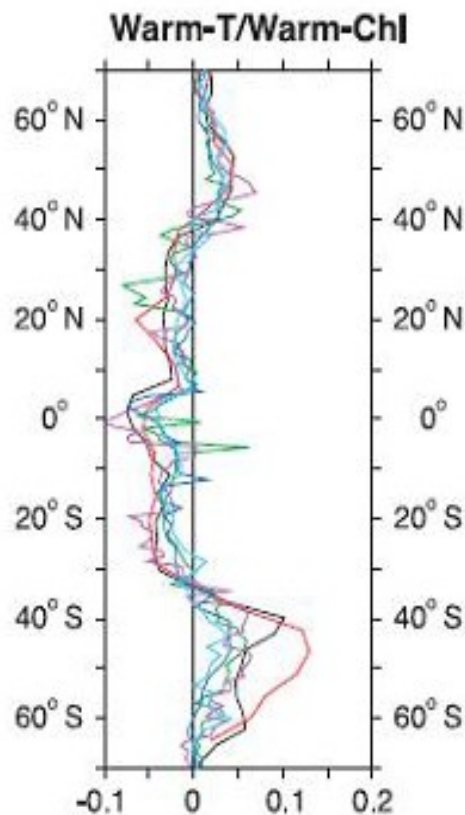
As the sea surface temperatures warmed in the North Sea, Celtic Biscay, and Iberian Coastal LMEs, the nutrient enrichment of the upper water layers was reduced from the effects of strong thermocline formation, less nutrient mixing from subsurface to the upper surface layers of the water column, reduced overall primary productivity and zooplankton production(10).

Primary Production Changes

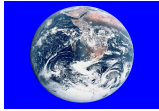


Six models extrapolating reductions in nutrient mixing (for years 2040 to 2060) in more densely stratified surface waters of the globe, predict a loss in primary productivity for the warmer latitudes. This may result in the decline of sustainable fishing yields in the LMEs off the coasts of developing countries in the tropics - with serious consequences for poor coastal populations dependent on these resources for both sustenance and livelihoods. At higher latitudes, productivity of the sub-Arctic waters is expected to increase with enhanced seasonal nutrient mixing, reductions in annual ice cover, and an extended period of the spring zooplankton bloom. As a result, fishing yields are expected to increase at these cooler latitudes.

Primary Production Change ($\text{Pg C deg}^{-1}\text{year}^{-1}$)



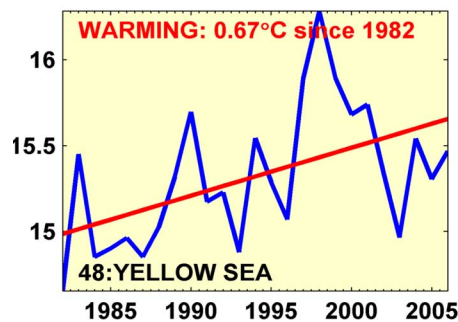
The global effects of climate warming on primary productivity are projected by latitude for the years 2040 through 2060. The primary productivity change ($\text{Pg C deg}^{-1}\text{year}^{-1}$), based on the effects of chlorophyll change and temperature increase, is shown above for six Atlantic Ocean Circulation models - as modified from Sarmiento et al. (11).



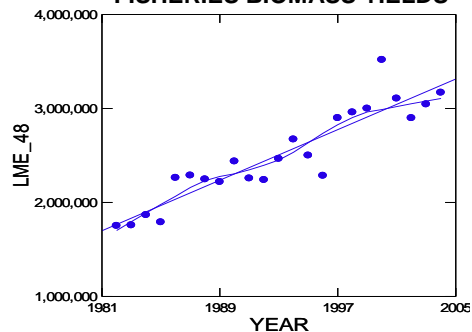
Sustaining Fisheries' Yields

In the warmer waters of LMEs in Africa and Asia, where temperatures are increasing, fisheries biomass yields are also increasing, and the average length of fish in the catches is decreasing (12) while the fish stocks are in an overexploited condition (13). In light of the modeling predictions of declining primary productivity over warmer latitudes of the globe, protection of fisheries is critical and catch limits should be considered as a precautionary action to sustain fisheries in LMEs located in warmer latitudes (9).

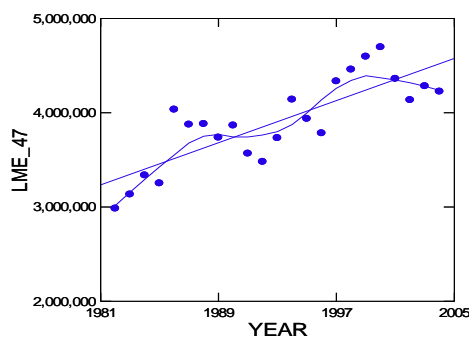
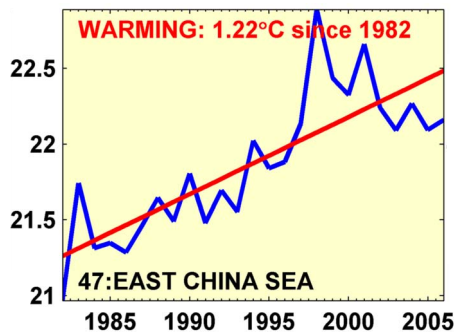
SEA SURFACE TEMPERATURE TRENDS



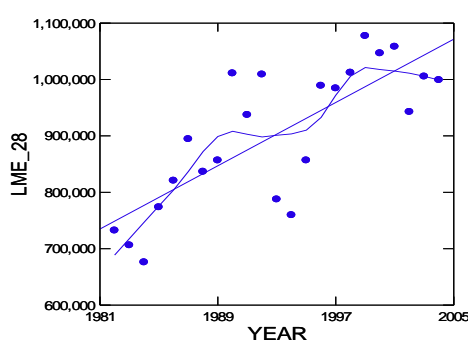
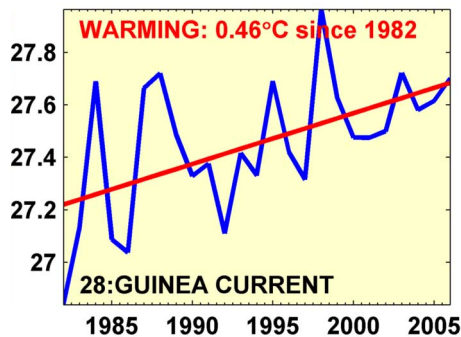
FISHERIES BIOMASS YIELDS



YELLOW SEA LME

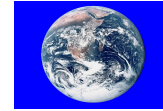


EAST CHINA SEA LME



GUINEA CURRENT LME

LME Governance



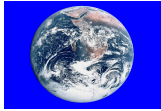
The objective of the UNDP/GEF Yellow Sea Large Marine Ecosystem (YSLME) project is to facilitate ecosystem-based management and sustainable use of the Yellow Sea goods and services. The GEF has pioneered a new methodology to systematically advance this process – a Transboundary Diagnostic Analysis (TDA) and Strategic Action Program (SAP). This method been applied in all 17 GEF LME projects and begins with a joint ‘fact finding’ exercise known as a TDA. The participating countries prioritize transboundary issues, environmental and socioeconomic concerns, and the immediate and root causes of these issues.

For the Yellow Sea, the People’s Republic of China and the Republic of Korea agreed to the following priority issues: overfishing, pollution (especially nutrients), habitat degradation, and climate change. These priorities were also officially supported by the Democratic People’s Republic of Korea. The TDA provides the technical basis for the subsequent preparation of the SAP, which delineates country commitments for regional and national legal, policy and institutional reforms, and investments. Countries agree to address the priority issues over a specific timeframe in the SAP.

The Yellow Sea SAP is notable for the high level of country commitment, including the agreement to reduce fishing effort by 33 percent, a vessel buy-back program and the retraining of fisherman for alternative livelihoods.



Mr. Zhanhai Zhang (left), Director-General, Department of International Cooperation, State Oceanic Administration, People’s Republic of China, and Mr. Sang-Pyo Suh, Director, Economic Organization & Environment Division, Ministry of Foreign Affairs and Trade, Republic of Korea, signed the statement of agreement approving the SAP at an endorsement ceremony in China in November 2009.



Managing the Yellow Sea LME

There is also a joint commitment to reduce nutrient discharges to the Yellow Sea by 10 per cent every five years through enhanced wastewater treatment and the reduction of fertilizer use and industrial discharges.

Another major outcome of the YSLME SAP was the agreement by the two countries to establish the YSLME

Commission, a first in the Asia-Pacific region. The Commission acts as a decision making body to expand efforts to implement management actions for recovering and sustaining YSLME goods and services.

In recognition of a lower fisheries yield, during the fish stock recovery period, both countries are ramping up newly developed mariculture technology (integrated multi-trophic aquaculture (IMTA) methodology) in the annual production of shellfish (mollusks) and marine benthic invertebrates (sea cucumbers). IMTA is adaptive and efficient. Buoys with strings of lantern nets are strategically placed over large coastal embayments. Fishermen travel to these fishing fields in a convoy of up to eight interconnected boats towed by a single, motorized boat.



Harvesting of *Laminaria* and other species.



Integrated Multi-trophic Aquaculture (IMTA) methodology buoy field at the production site in the Sanggou Bay, Shandong Peninsula, China.

New Multi-Trophic Mariculture



At the work site, fisherman move through the buoy field manually. In this way, the new IMTA methods reduce greenhouse gas emissions and conserve energy.

Immediately under each buoy, very small pieces of *Laminaria* (kelp) are affixed by hand where they grow and become long fronds. The kelp is used as food for the top tier of lantern nets seeded with juvenile abalone. The next tier is seeded with bay scallops. At the base of the string is a collection receptacle with juvenile sea cucumbers. The abalone grow rapidly on the *Laminaria* diet. Given the high levels of primary productivity, the bay scallops and the sea cucumbers grow rapidly and feed on the fecal pellets and organic detritus from above.

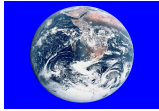
The juvenile stocks of abalone, scallops and sea cucumbers are raised in concrete tanks at shore-side facilities in strategic locations around the embayment and transported in the wooden work boats to the mariculture fields. In turn, the mature *Laminaria*, abalone and bay scallops are returned to the shore-side facility for processing and market destinations.



Lantern nets with separate platforms for abalone and bay scallops.



Loading *Laminaria* for processing at dockside.



Carrying Capacity of the YSLME

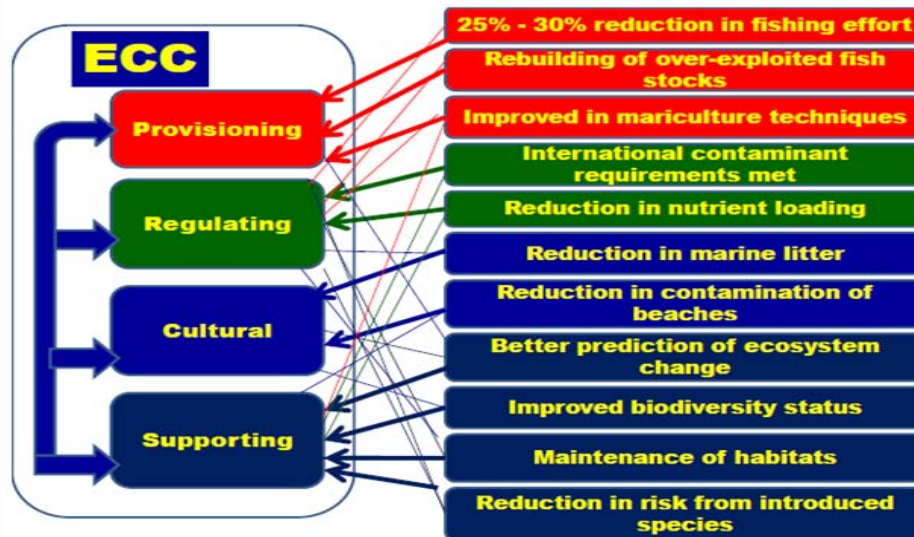
Within the framework of the UNDP/GEF YSLME project, **eco-system carrying capacity (ECC)** is defined as “the sum of the ecosystem services (provisioning, regulating, supporting and cultural) that benefit mankind (14).” The integrated multi-trophic aquaculture methodology is based on calibrated models of spatial carrying capacity using upper water column primary production data. It is estimated that 3.8 M mt Cy^{-1} is sequestered annually by China in shellfish and seaweed mariculture production in the Yellow Sea LME.

The harvesting of seaweeds in the YSLME removes an estimated 1.2 M mt Cy^{-1} . The combined photosynthesis of phytoplankton and ingestion of organic particulates by shellfish can utilize a significant

amount of carbon in the LMEs. The production of abalone and scallop shells also lock up carbon as calcium carbonate. As a result, the planned ramping up of IMTA methods in the YSLME will contribute significantly to improving the capacity of the YSLME to absorb atmospheric CO_2 (15).

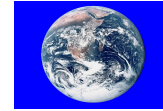
Transferring innovative IMTA methodology to GEF and other LME assessment and management projects around the globe could contribute toward the goals of the Cancun declaration and green energy initiatives aimed at reducing excess levels of atmospheric CO_2 .

The People’s Republic of China and the Republic of Korea are meeting ECC goals by reducing fishing effort, rebuilding capture fisheries, improving non-polluting mariculture technology, and conserving habitat.



Relationship between Ecosystem Carrying Capacity (ECC), services (left) and LME targets (right) that seek to maintain these services in the YSLME (16).

Sustainable Development of LMEs

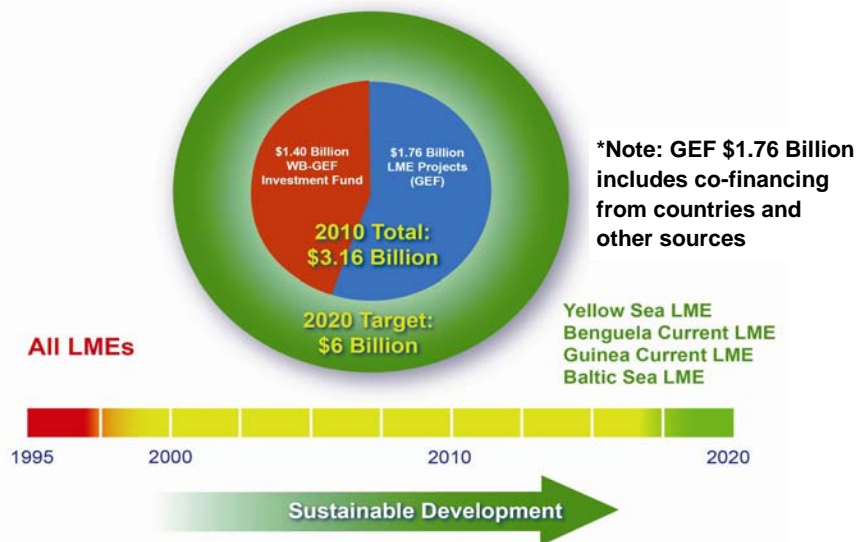


“Human activities are cumulatively driving the health of the world’s oceans down a rapid spiral, and only prompt and wholesale changes will slow or perhaps ultimately reverse the catastrophic problems they are facing.”

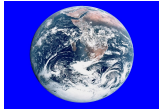
Dr. Jeremy Jackson, Scripps Institution of Oceanography / University of California, San Diego – Scripps News of 13 August 2008

The LME approach to sustainable development of coastal ocean goods and services has grown from a \$6 million GEF grant supporting six countries in the Gulf of Guinea demonstration project in 1995, to a global effort with

\$3.1 billion in cumulative financial support from GEF grants, World Bank investment funds, UN agencies, and participating countries, through 2010 (17). The downward spiral in the health of the world’s oceans was described by Jeremy Jackson (18). However, the influx of funding, innovative methodologies, and new partnerships between developing countries and UN agencies, non-governmental organizations (IUCN, WWF), and donor countries (e.g. Canada, Germany, Iceland, Norway, Sweden, U.S.), has supported sustainable development of LME resources since 1995 (14,19).

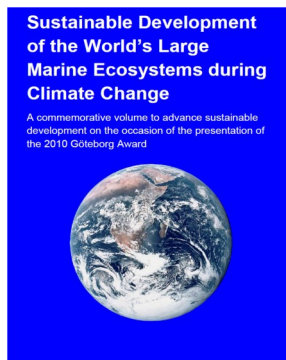


This helps support a substantial effort of 110 developing countries engaged in 17 GEF LME projects. The projects support ecosystem-based management actions focused on the recovery and sustainable use of LME goods and services that contribute an estimated \$12.6 trillion annually to the global economy (20).



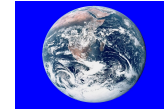
For readers interested in learning more about the LME approach for the sustainable development of coastal ocean resources during climate change, a commemorative LME volume has been published by the IUCN. The book includes chapters on sustainable development by former Prime Minister of Norway, Dr. Gro Harlem Brundtland, the need to control greenhouse gases by former U.S. Vice President Al Gore, and expert treatment of ocean tipping points by U.S. Commerce Under Secretary for Oceans and Atmosphere Dr. Jane Lubchenco.

Other chapters address LME assessment and governance methods, carbon sequestration processes, marine spatial planning, and actions being implemented by the Peoples Republic of China partnering with the Republic of Korea to protect and sustain the carrying capacity of the Yellow Sea LME. Copies of the volume can be obtained on request from the LME Program Office, NOAA-Fisheries, Narragansett Laboratory.



To order, send request to: Galen McGovern, Large Marine Ecosystem Program Office, Northeast Fisheries Science Center, National Oceanic and Atmospheric Administration, Narragansett, RI 02879, Galen.McGovern@noaa.gov, phone 401-782-3209.

For more information on Large Marine Ecosystems and specific GEF-supported International Waters projects visit the following websites: www.lme.noaa.gov, iwlearn.net/iw-projects, www.yslme.org, www.boblme.org, www.bclme.org, www.gclme.org, www.canarycurrent.org, www.asclme.org, gulfmexicoproject.org, www.clme.iwlearn.org, www.liaoning.iwlearn.org, www.pemsea.org, www.yt-gef.com, www.worldbank.org/blacksea, wqpp.iwlearn.org, www.unepmap.org, www.medpartnership.org, www.medsp.org, www.undp-dpr.org, www.icpdr.org, www.ices.dk/projects/BSRP.asp, www.unepscs.org, scfishproject.iw.learn.org, www.atsef.org, www.ffa.int/gef



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It is inevitable that the 6,972,184,086 people who inhabit the planet as of November 1, 2011 will leave their mark.



It is still possible to make individual and collective choices that will result in restoring and sustainably developing the ocean's full potential for present and future generations.