Sustainable Development of the World's Large Marine Ecosystems during Climate Change

A commemorative volume to advance sustainable development on the occasion of the presentation of the 2010 Göteborg Award

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Preface

The people of Sweden have an abiding commitment for advancing toward sustainable development and promoting actions to reduce and control global warming. This commitment has long tradition. In 1972 the UN's first major conference on international environmental issues was held in Stockholm, Sweden. As a nation we have adopted in our Parliament forward-looking environmental policies to advance sustainable development. Our overall goal in Sweden is to solve major environmental problems within one generation. To attain this goal requires the sincere commitment of a wide range of bodies and organizations such as county administrative boards and local authorities.

In Göteborg (Gothenburg), the city also has a long tradition to work proactively with sustainable development together with academia and business. The city of Gothenburg recognizes that the challenges of sustainable development require new and unconventional solutions. To encourage new solutions we have established the Göteborg Award for Sustainable Development.

The Göteborg Award is the city's international prize that recognizes and supports work to achieve sustainable development. In the Göteborg region and from a global perspective, the Award, one million Swedish crowns, is administrated and funded by a coalition of the city of Göteborg and twelve companies. The Göteborg Award is considered the "environment equivalent of the Nobel Prize."

This year, the Göteborg Award is recognizing the serious degradation of our oceans, and the outstanding contributions being made for sustainable development of ocean goods and services. The oceans are essential to all life on Earth, and yet mankind's most ruthless exploitation is taking place in the seas through overfishing, pollution and other environmental impacts that damage biological diversity and the very basis for life both underwater and for humans on land. For this reason, the Göteborg Award for Sustainable Development in 2010 goes to two prominent persons who have in different ways strongly contributed to solutions for sustainable development of our oceans. The Göteborg award will be divided equally between Kenneth Sherman from the United States and Randall Arauz from Costa Rica.

Recognizing the importance of promoting global efforts underway for sustainable development of the oceans, the Göteborg Award Selection Jury is pleased to distribute a special volume, *Sustainable Development of the World's Large Marine Ecosystems during Climate Change* on the occasion of the presentation of the 2010 Göteborg Award.

In keeping with the sustainable development theme of the Göteborg Award, contributors to the commemorative volume are focused on actions proposed and underway by high profile public figures, scientists, and policy experts for reducing climate warming and advancing sustainable development of marine goods and services.

Prof. John Holmberg
Chair of The Göteborg Award for Sustainable Development Selection Jury
UNESCO Chair
Vice-president
Chalmers University of Technology
Göteborg, SWEDEN

A Message from the Director of the Environment & 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.

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 an estimated $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.*

UNDP welcomes this volume on the sustainability of the world's Large Marine Ecosystems as a key contribution to advancing the needed paradigm shift in LME management in a changing climate. The papers featured cover a range of key issues, from the impacts of climate change on LMEs to new policy and institutional tools for LME governance. UNDP wishes to express its sincere thanks to the distinguished group of contributors to this volume for their leadership and commitment to sustainable human development.

Dr. Veerle Vandeweerd, Environment & Energy Group, UNDP

Foreword

The book's opening three chapters by world renown leaders argue for coalitions of industries, governments, and citizens to lead actions for promoting sustainable development of world resources and implementing reductions in greenhouse gases. Dr. Gro Harlem Brundtland, former Prime Minister of Norway, former Chairman of the United Nations Conference on Environment and Development, and Göteborg Laureate (2002) puts forward the cogent argument that, "The responsibility for solving the greatest challenge of all, the climate crisis, rests not only with political leaders, but with each one of us as representatives of businesses, as consumers, and as voters." Former Vice President, Nobel Laureate, and Göteborg Laureate (2007), Al Gore, in his call for action to reduce greenhouse gas emissions, provides convincing evidence of the harmful effects on the planet of GHGs, indicating that, "the solution to global warming is as easy to describe as it is difficult to put it into practice. Emissions of six pollutants—CO_2, methane, black carbon, halocarbons, nitrous oxide, and carbon monoxide (and volatile organic compounds)—cause the problem and must be reduced dramatically. Simultaneously, we must increase the rate at which they are removed from the air and reabsorbed by the earth's oceans and biosphere." The third call to action by the US Under Secretary of Commerce for Oceans and Atmosphere, Jane Lubchenco, in a chapter with Laura Petes of NOAA, argues convincingly that, "degraded marine ecosystems cannot provide key ecosystem services, such as production of seafood, protection of coastal areas from severe storms and tsunamis, capture of carbon, and provision of places for recreation. The accelerating pace of change presents daunting challenges for communities, businesses, nations, and the global community to make the transition to more sustainable practices and policies."

The chapters that follow describe actions underway in a global movement to restore and sustain the world's Large Marine Ecosystems (LMEs) and their multi-trillion dollar annual contribution to the world economy. Substantial financial support to the global effort by the Global Environment Facility is described in Chapter four by Alfred Duda of the GEF.

Examples of the effects of accelerated global warming on the fisheries biomass yields of LMEs is given in Chapter five by 2010 Göteborg Laureate Kenneth Sherman and co-authors. In Chapter six, the scientific assessments of carrying capacity of LMEs for marine fisheries around the globe by Villy Christensen of the University of British Columbia, and associates, indicates that an astounding one billion metric tons of fish biomass is produced annually in the LMEs of the world. The contribution in Chapter seven by Sybil Seitzinger, Director General of the International Geosphere and Biosphere Program at the Swedish Academy of Science in Stockholm, with Rosalynn Lee of Rutgers University, cautions that without mitigation actions, the level of nutrient over-enrichment from continental drainage basins of dissolved inorganic nitrogen (DIN) into LMEs is likely to double by the year 2050, leading to increases in oxygen depleted areas and dead zones in LMEs around the globe.

Jan Thulin, ICES Senior Advisor, writes in Chapter eight about the successful application of ecosystem-based assessment and management practices leading to a large investment by the European Union of approximately 100 million Euros to support continued assessment and management of the goods and services of the Baltic Sea LME. In the case of the Benguela Current LME, Dr. Michael O'Toole of the Marine Institute in Galway, Ireland, describes in Chapter nine the establishment of the world's first LME Commission for the transboundary management by three countries (Angola, Namibia and South Africa) of the goods and services of the Benguela Current LME, based on integrated ecosystem-based assessment and management practices.

Chapter ten describes the extraordinary actions underway by the People's Republic of China and the Republic of Korea in a joint effort supported in part by the GEF to reduce environmental stress in the Yellow Sea LME. Both countries have agreed to reach ecosystem recovery and sustainability objectives stated in their Strategic Action Programme (SAP). The historic document, signed by representatives of the People's Republic of China and the Republic of Korea, supporting the actions described in the SAP is reproduced in the Annex to the chapter.

Processes contributing to the sequestration of carbon within the boundaries of the world's LMEs, and the importance of taking actions to implement planning to ensure augmentation of carbon sequestration, are described by Jerker Tamelander, Dorothée Herr and Dan Laffoley of IUCN in Chapter eleven.

In Chapter twelve, Barry Gold of the Gordon and Betty Moore Foundation, stresses the importance of marine spatial planning as a framework for systematic restoration and sustainable development of LME goods and services.

The importance of the work by Randall Arauz, Director of PRETOMA in Costa Rica and 2010 Göteborg Laureate, in taking actions to eliminate shark finning and reduce and control the catch of marine sharks is described in a Commemorative Commentary entitled, *Sustaining Shark Populations*, to complete the volume.

The Editors
Narragansett, RI
October 2010

Acknowledgements

The Göteborg Commemorative volume was made possible by the willingness of world political leaders, renowned scientists, and prescient marine policy experts to lend their names and share their messages for pursuing actions supporting sustainable development, reduction of greenhouse gases, and mitigating climate change. We are indebted to the chapter authors and their gracious willingness to allow the inclusion of their works in this volume. We thank the Göteborg Awards Committee for the many courtesies extended that allowed the volume to be produced in a near record time. Special thanks are extended to the Gordon and Betty Moore Foundation, the United Nations Development Program, the International Union for Conservation of Nature and to the National Oceanic and Atmospheric Administration of the US Department of Commerce, for financial and other contributions made to support the volume's production. We are especially indebted to Yihang Jiang of the UNDP for his exceptional effort in expediting the final printing and shipping of the Commemorative volume in time for distribution during the Göteborg Sustainable Development Commemoration Day.

The Editors

CONTENTS

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Chapter 1

Our Common Future in Sustainable Development and Climate Change[*]

Gro Harlem Brundtland, UN Special Envoy on Climate Change [1]

There are many who complain that the global effort against climate change is characterized by "too little too late." I sympathize with all those who are impatient. At the same time, the fact that we have been able to act before gives reason to believe that we will be able to act again. One of the most stimulating tasks I have had was to lead the World Commission on Environment and Development. The Commission's report, "Our Common Future," published in 1987, based its recommendations on broad and solid scientific evidence.

Five years later, in 1992, world leaders came together in Rio. Here we agreed on a climate convention, as well as a convention on biodiversity and desertification. Five years later we had the Kyoto Protocol, where most developed countries committed to limit their emissions of green house gases. In an historical perspective, this was quite remarkable.

Twelve years later we find that both green house gas emissions and temperatures are increasing faster than expected. The result is that sea levels are rising, glaciers melting, weather is becoming more extreme, and that people are suffering. This has potentially dramatic repercussions for the global economy, as it triggers a perilous chain of uncertainties, along supply chains, in the financial markets, and for consumers. Again, it is time to act. This was recognized in Bali three years ago. Leaders agreed on a plan of action to end up with the conclusion of a new climate deal. The Copenhagen Accord was not the deal we were looking for. But negotiations are continuing.

Only by making concrete commitments can leaders prove that they are serious about curbing global warming. Leaders are also expected to agree on a process that results in legally binding protocols. Only in this way will they be able to provide business with the stable and predictable framework it needs: one that is a solid basis for long term investment decisions which are

[*] From her speeches in Tällberg and in Copenhagen 2009, and approved for presentation here by G. H. Brundtland.

[1] Environmental Minister of Norway (1974-1979), Prime Minister of Norway (1981; 1986-1989; 1990-1996), Chairperson of the World Commission on Environment and Development (WCED)(1983-1987), Director General World Health Organization (1998-2003),and Göteborg Laureate (2002).

good both for business and for climate. Let us be clear. We are not just looking for any deal. We are looking for a good deal.

A good deal is science-based, involves all countries, consistent with their capabilities covers all major emissions, is long term and provides predictability, is fair and just, and offers today's developing countries as good opportunities for economic growth as today's developed countries had.

Developed countries must take on ambitious mid-term targets in the 25-40 % reduction range identified by the Intergovernmental Panel on Climate Change. Developing countries must limit the growth in their emissions, not continue with business as usual. The most important means to succeed in getting such a deal is the provision of sufficient new funding for mitigation, adaptation, capacity building, and technology development and transfer to developing countries. There is no doubt about it: A significant financing package is a make-or-break element for a climate deal. A package should include both fast track funding as well as long term mechanisms.

We must expect a direct relationship between the cost-effectiveness of a mechanism and how much finance will be made available. A deal must also unlock private investment, including through carbon markets. In particular, I would like to see agreement on a mechanism that could secure new, additional, and predictable financial resources that go beyond annual budget allocations from developed countries. While there are real costs involved in taking action against climate change, I can assure you, the cost of inaction will be much greater.

The world's attention has for some time now been on the financial crisis. Not surprising, as it has immediate and very concrete adverse effects on so many. Governments, businesses, researchers and society at large are all focused on finding the best way out of the crisis. We live in times when it is particularly important to avoid bad investment decisions. My best advice is: whatever you do, make sure it contributes to the sustainable, low-carbon economy we will need in order to survive and thrive on planet earth in the future. Otherwise you risk wasting your money.

The fact of the matter is that the world needs both to stimulate the economy and to secure sustainable development. By designing a policy which stimulates green growth, we can reach both goals at the same time. I challenge you all to communicate effectively to Heads of State and Government your need for a global, long term policy framework.

I can see that some businesses are naturally more progressive on the climate issue than others, just as some countries are more progressive than others. But I think most businesses share an interest in as much long term predictability as they can get. My advice is: create as broad an alliance as possible. Politicians listen when large corporations speak. Their message is effectively reinforced if it is repeated by business associations. And when labour unions turn up with the same message; that is when governments really start to listen.

A climate agreement is a vitally important means in the fight against climate change. While an international agreement is important, there are also other elements which determine business behaviour. National standards and regulations is one factor, consumer preferences another.

I have great expectations when it comes to how businesses can contribute; through effective communication with governments, through board room decisions and through innovations resulting from investments in research and development. Hiccups from time to time in the broad political process of climate change negotiations should not deter us from forging ahead and contribute to progress. We all know where we have to go. We need to strive towards a scenario where science, industry, consumers and civil society combine and work together in fighting climate change.

While governments have an important role in setting targets for emissions from cars, it is the research done by Ford, Volkswagen, Toyota and other manufacturers, and the demand from discerning consumers, which will make the difference in practice. I am convinced that the threat of climate change also means immense opportunities for business and industry. The world needs to improve significantly on energy efficiency. It needs to expand the supply of renewable energy. And we need to eliminate emissions from the use of fossil fuels. Already, the private sector provides more than two-thirds of the world's investments in lean technology innovation.

Those businesses which have adaptable products ready to go to the market as new regulations come into effect will reap considerable benefits from their foresight. The effort to counter global warming has been described as the biggest investment trend of all times. Estimates project the market potential of green technology to reach 2000 billion Euros by 2020. Who doesn't want to be part of this?

Energy technology is emerging as one of the biggest growth trends. For example, in Denmark, energy technology has recently passed food as the most important export-category. The growth in the industry was 19% from 2007 to 2008, with a market value of 64 billion Danish Kroner. Similar developments are observed in other European countries. The same trends can be observed in the financial markets. The investment bank HSBC has compiled an index of 100 companies working with climate-related technologies. The average growth in these companies has been 48% since 2004. Energy efficiency requirements for new buildings entail both investments and potentially large savings. The latest EU directive prescribes zero emissions from new buildings by 2018. This paves the way for investments in technology development and the creation and rapid expansion of new markets.

Just as Corporate Social Responsibility has created new business practices and new markets, it is now time to include Corporate Climate Responsibility as a guideline for development of future business practices. The key ingredient must be commitments to reduce emissions of green house gases. The world is heading towards low carbon growth. Those businesses which will survive in the long run have already acknowledged that this is the case. They have seen that we have to cut emissions dramatically without limiting growth in countries where development is desperately needed. They have seen that we have to stimulate innovation and make the best technologies available where they need it most. They have seen the need to protect those already affected by climate change. They have seen the need for a global climate deal. And they are acting on what they see.

We must now help our leaders make the right political decisions and commitments.

In my professional and political life, I have always wanted to build on the principle learned first from my father, who had a profound influence on me. He was a medical doctor who imprinted on me the importance of having a scientific and rational basis for opinions and actions. As I became a medical doctor myself, my resolve to base my opinions and actions on the best available evidence grew even stronger. We need to build evidence, strengthening the knowledge base on which we depend when making decisions.

It is always cheaper to prevent than to cure, whether we focus on people or societies. Certainly, we must never overlook how important it is to couple state of the art scientific knowledge with strong political commitment. Science must be translated into political action to be of relevance to society. This is true for gender equality, health policies, environmental policies and climate policy. Ideology and values dominate when we set our goals. But when it comes to deciding on what we should do to reach them, they have to be inspired by sound scientific knowledge.

From 1984-87, I headed the United Nations' World Commission on Environment and Development. First of all, I was blessed with a number of excellent people on the Commission. Secondly, we were determined to draw on the best available expertise at the time in our work. The Commission's report, "Our Common Future" was the outcome of a collective effort, which I had the privilege to lead.

More than 20 years ago, we had the findings of scientists from 30 countries. Already then, back in the 80's, these scientists had reached the conclusion that man-made climate change was plausible and probable. The World Commission coined the concept of sustainable development. It warned about the mounting evidence on global warming and led the world to Rio, where we adopted the Framework Convention on Climate Change in 1992.

The World Commission was able to establish a new and convincing analysis of the global situation. We were able to identify the trends that, with hindsight, we now know are the most important in determining the human environment. I think we also prescribed the right medicine.

Hardly anything that has happened in the field of environment and development since our report was published in 1987 has come as a surprise. The problem of climate change is not new. We have seen this coming for more than 20 years. It has become increasingly clear that the climate is changing, but at an even faster pace than anticipated.

The work of the Commission was like no other assignment focused on the task ahead of us. The report designed a way of thinking which, as I see it, is still valid. Only through adhering to the principles of sustainable development will we be able to survive on planet earth.

As we move towards sustainable patterns of production and consumption, it is imperative that we do not lose sight of the fact that poverty, lack of opportunity and human dignity remains one of the most fundamental challenges to humanity. Developing countries have the right to development. Their economic growth must go hand in hand with reductions in global emissions of green house gases.
So, what are the tasks ahead of us today?
I venture to say that the task ahead for mankind is to safeguard the human environment so that our species can survive on this planet.

Climate change is essentially a global threat, one that pays no attention to borders drawn by humans. No issue better demonstrates the need for global cooperation. No issue is more important for our survival. And no issue is more fundamental to long-term security.

Almost two thirds of cities with populations of more than 5 million are situated in low-lying flood-prone areas. Nine out of ten disasters recorded are now climate related. We need to succeed in reaching a post Kyoto deal on climate change. Countries now start to realize that it is in their national interest to take action.

While political leaders clearly have a central role to play, we do not need to choose between state control and market forces to address climate change, but seek the optimum mix between the two. Governments need to give business clear and coherent signals, provide them with level playing fields and long-term predictability. Markets have a major role to play.

Energy is key. Sixty per cent of the relevant emissions are related to either production or use of energy.

Increased energy consumption has been both a precondition for economic growth and a consequence of economic growth. This will have to change. In the future, we must be able to combine economic growth with reduction of emissions. Here I must complement Sweden. Sweden has managed to reduce emissions significantly over the past ten years while, until recently, maintaining economic growth.

How can other countries follow suit? Most importantly, we must increase energy efficiency. The International Energy Agency (IEA) estimates that more than half of the energy related emission cuts that will have to be carried out must come from energy efficiency measures.

This has implications in many walks of life. We must find new ways of heating and cooling our houses, cutting the loss of energy in electricity distribution systems, improvements in steel mills, in the manufacturing of cement and other products. Cars, trains, airplanes, boats, all means of transportation must become more energy efficient.

We must redouble the production of energy from renewable sources, such as hydro, wind and sun. Growth in renewable energy may account for as much as 20% of the global reductions of emissions we need to achieve by 2050. Many countries today also plan on increasing nuclear power supply.

Whether we like it or not however, for many decades, a substantial part of the world's energy supply will still come from fossil fuels, mainly coal. It is essential that we also reduce emissions from the use of fossil fuels. As a major supplier of oil and gas, Norway has embarked on an ambitious project with the aim of making carbon capture and storage economically viable.

A global price on carbon and a global market for trading in carbon emission permits, will introduce the right incentives to the market, and guide the behavior of businesses around the world.

An outdated market thinking, with no price being paid for the use of the atmosphere, a global public good, will destroy the planet. By introducing the right price on carbon, the market will help us save the planet.

We need nothing less than a technological revolution. Human resources and ingenuity is once again what will lift humanity towards new levels of civilization. To facilitate such a revolution, we must be willing to agree to set a price on emissions. The demand for new technologies will also create millions of new jobs. Businesses which have products ready to go to the market when a global price on carbon comes into effect will reap considerable benefits from their foresight. However, we do need financing mechanisms to help secure the timely dissemination of state of the art technology, whether for mitigation or adaptation. Financing must be made available so that developing countries may secure cleaner economic growth. We should not forget that 17 per cent of emissions stem from deforestation and forest degradation in developing countries. Deforestation needs to be included if we are to effectively limit the dangerous rise in global temperatures.

Financing is of the essence, a cross cutting issue, vitally important for mitigation, adaptation, technology development and transfer. To secure sufficient levels of stable and predictable financing, we will have to create innovative mechanisms, and avoid becoming dependent only on direct allocations from states. Several suggestions are out there. What leaders can agree on will decide.

It may be challenging to translate scientific results into practical policies on the domestic scene. It is even more challenging to reach an evidence-based agreement among nearly 200 countries. Especially when the measures to be taken come with a price tag, and the distribution of initial costs has to be decided upon to reach an agreement. Distributing costs is difficult, even if we know they will continue to spiral if we do not agree. But this is precisely what we must and will do!

Much has been done since 1987 to tackle the threat of climate change. Much remains to be done. We know what we have to do. Our challenge is to agree on the necessary measures before it is too late. The responsibility for solving the greatest challenge of all, the climate crisis, rests not only with political leaders, but with each one of us, as representatives of businesses, as consumers and as voters. We can do it.

Chapter 2

WHAT GOES UP MUST COME DOWN*

Al Gore, Vice President of the United States (1993-2001)[1]

Human civilization and the earth's ecological system are colliding, and the climate-crisis is the most prominent, destructive, and threatening manifestation of this collision. It is often lumped together with other ecological crises, such as the destruction of ocean fisheries and coral reefs; the growing shortages of freshwater; the depletion of topsoil in many prime agricultural areas; the cutting and burning of ancient forests, including tropical and subtropical rain forests rich in species diversity; the extinction crisis; the introduction of long-lived toxic pollutants into the biosphere and the accumulation of toxic waste from chemical processing, mining, and other industrial activities; air pollution; and water pollution.

These manifestations of the violent impact human civilization has on the earth's ecosystem add up to a worldwide ecological crisis that affects and threatens the habitability of the earth. But the deterioration of our atmosphere is by far the most serious manifestation of this crisis. It is inherently global and affects every part of the earth; it is a contributing and causative factor in most of the other crises, and if it is not quickly addressed, it has the potential to end human civilization as we know it. For all its complexity, however, its causes are breathtakingly simple and easy to understand.

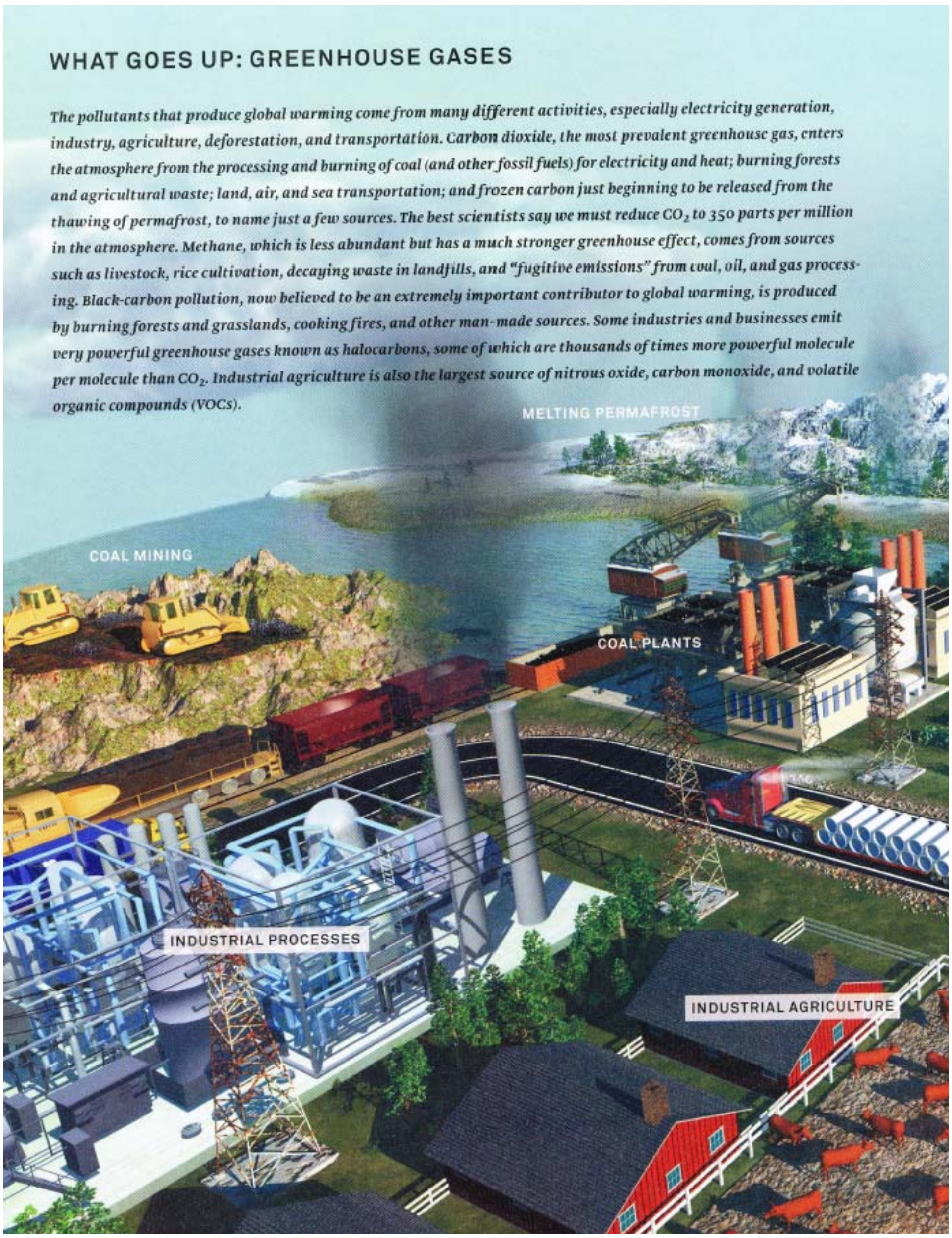
All around the world, we humans are putting into the atmosphere extraordinary amounts of six different kinds of air pollution that trap heat and raise the temperature of the air, the oceans, and the surface of the earth. These six pollutants, once emitted, travel up into the sky quickly. But all six of them eventually come back down to earth, some quickly, others very slowly. And as a result, the oft-cited aphorism, "What goes up must come down," will work in our favor when we finally decide to solve the climate crisis. Indeed, the simplicity of global warming causation points toward a solution that is equally simple, even if difficult to execute: we must sharply reduce what goes up and sharply increase what comes down.

The biggest global warming cause by far—carbon dioxide—comes primarily from the burning of coal for heat and electricity, from the burning of oil-based products (gasoline, diesel, and jet fuel) in transportation, and from the burning of coal, oil, and natural gas in industrial activity. Carbon dioxide produced in

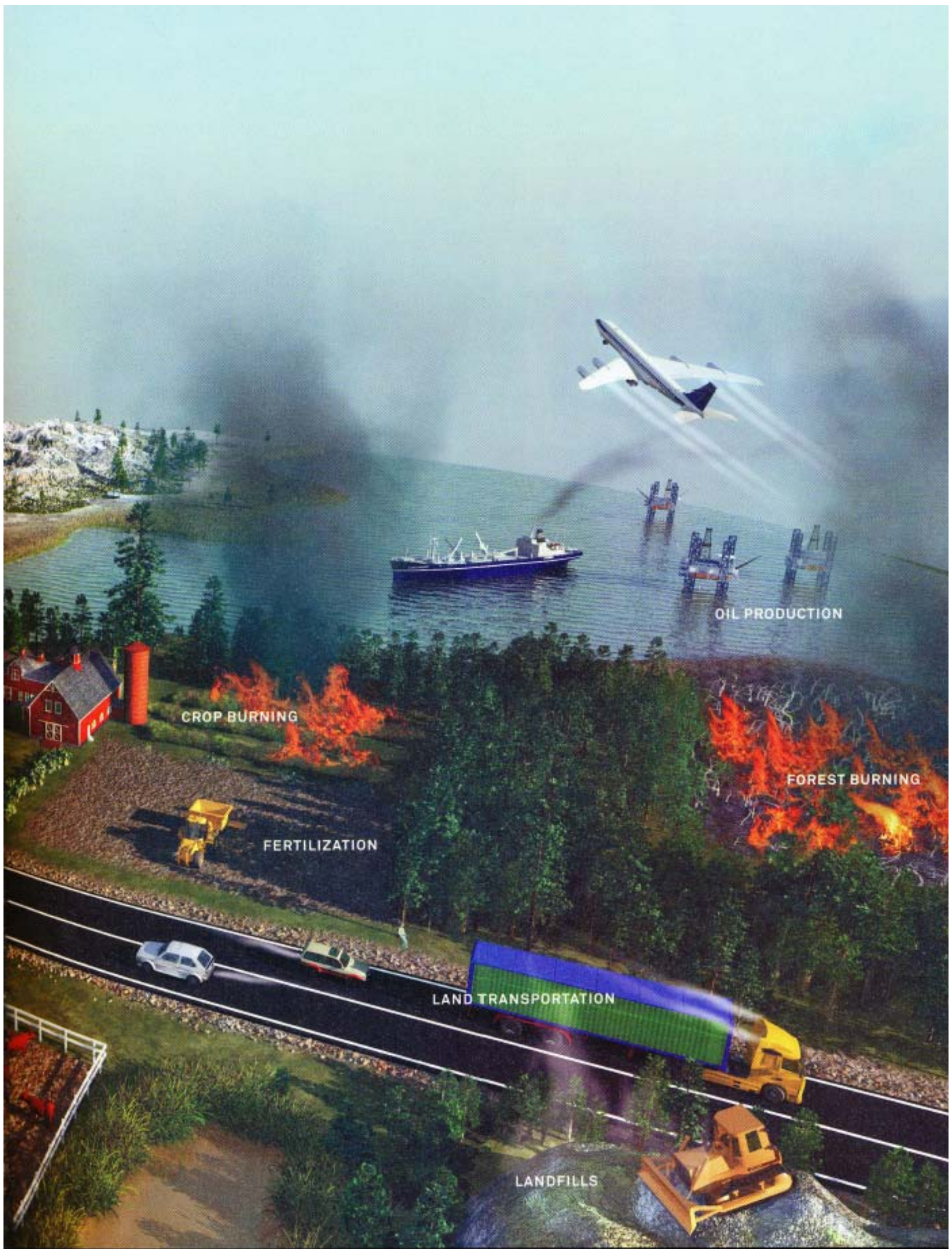
* From A. Gore (2009) *Our Choice*, Chapter 1. What Goes Up Must Come Down; included here with permission.

[1] Nobel Peace Prize Laureate 2007; Göteborg Laureate 2007; Chairman, Alliance for Climate Protection; Director Generation Investment Management; Representative, US House of Representatives 1976-1984; Served as US Senator 1984-1993.

the burning of these fossil fuels accounts for the single largest amount of the air pollution responsible for the climate crisis. That is why most discussions of how to solve the climate crisis tend to focus on producing energy in ways that do not at the same time produce dangerous emissions of CO_2.



At this point, however, the burning of coal, oil, and natural gas is not only the largest source of CO_2 but also far and away the most rapidly increasing source of global warming pollution. After fossil fuels, the next largest source of human-caused CO_2 pollution—almost a quarter of the total—comes from land use changes—predominantly deforestation, the burning of trees and vegetation. Since the majority of forest burning is in relatively poorer developing countries and the majority of industrial activity is in relatively wealthier developed countries, the negotiations of proposed global agree-



ments to solve the climate crisis generally try to strike a balance between measures that sharply reduce the burning of fossil fuels on the one hand and sharply reduce deforestation on the other.

There's good news and bad news about CO_2. Here is the good news: if we stopped producing excess CO_2 tomorrow, about half of the man-made CO_2 would fall out of the atmosphere to be absorbed by the ocean and by plants and trees within 30 years.

Here is the bad news: the remainder would fall out much more slowly, and as much as 20 percent of what we put into the atmosphere this year will remain there 1,000 years from now. And we're putting 90 million tons of CO_2 into the atmosphere every single day!

The good news should encourage us to take action now, so that our children and grandchildren will have reason to thank us. Although some harmful consequences of the climate crisis are already underway, the most horrific consequences can still be avoided. The bad news should embolden us to a sense of urgency, because—to paraphrase the old Chinese proverb—a journey of a thousand years begins with a single step.

The second most powerful cause of the climate crisis is methane. Even though the volume of methane released is much smaller than the volume of CO_2, over a century-long period, methane is more than 20 times as potent as CO_2 in its ability to trap heat in the atmosphere—and over a 20-year period, it is about 75 times as potent.

Methane is different from CO_2 in one other key respect: it is chemically active in the atmosphere. CO_2, for the most part, does not interact with other molecules in the atmosphere, but methane does—and it plays a big role in its interactions with ozone, particulates, and other components of the atmosphere. Methane interacts with other chemicals in the atmosphere that break it down over a 10-12-year period into CO_2 and water vapor, both of which trap heat, though less powerfully molecule for molecule than methane before it is broken into its component parts. The global warming effect of methane is also magnified by these interactions in ways that make it a somewhat larger cause of the problem than scientists used to believe. Overall, it is now considered to have contributed about two thirds as much to global warming as CO_2.

More than half of human-caused methane releases occur in agriculture. Most of the methane from agricultural operations comes from livestock, livestock waste, and rice cultivation. And most of the remaining methane emissions come from oil and gas production, coal-mining operations, landfills, waste treatment, and fossil fuel combustion.

There is some good news about methane: since it has inherent economic value, there are powerful incentives driving efforts to capture it and prevent it from being released into the atmosphere wherever that is possible. For example, the "natural gas" that heats many homes is primarily methane, so captured methane can be put to good use. In addition, almost a quarter of the methane releases come from leaks and evaporation during the processing, transportation, handling, and use of the gas. And as a result, some of these releases may prove easier to stop.

However, there is also bad news about methane: continued warming of the frozen permafrost in the land surrounding the Arctic Ocean (and from warming seabed sediments) is beginning to release large amounts of methane into the atmosphere as the frozen structures containing it melt, and as microbes digest the thawing carbon buried in the tundra. The only practical way to prevent these releases is to slow and then halt global warming itself—while there is still time.

The third largest source of the climate crisis is black carbon, also called soot. Black carbon is different from the other air pollutants that cause global warming. First, unlike the others, it is technically not a gas but is made up of tiny carbon particles like those you can see in dirty smoke, only smaller. That is one reason it only recently became a major focus for scientists, who discovered the surprisingly large role it was playing in warming the planet. Second, unlike the other five causes of global warming, which absorb infrared heat radiated by the earth back toward space, black carbon absorbs heat from incoming sunlight. It is also the shortest lived of the six global warming culprits.

The largest source of black carbon is the burning of biomass, especially the burning of forests and grasslands, mostly to clear land for agriculture. This problem is disproportionately concentrated in three areas: Brazil, Indonesia, and Central Africa. Forest fires and seasonal burning of ground cover in Siberia and eastern Europe also produce soot that is carried by the prevailing winds into the Arctic, where it settles on the snow and ice and has contributed greatly to the progressive disappearance of the Arctic's sea ice cover. Indeed, one estimate is that black carbon is responsible for an estimated 1°C (1.8°F) of warming that has already occurred in the Arctic. Large amounts of black carbon are also produced by forest fires in North America, Australia, Southern Africa, and elsewhere. In addition to biomass burning, as much as 20 percent of the black carbon comes from the burning of wood, cow dung, and crop residues in South Asia for cooking and heating homes, and from China, where the burning of coal for home heating is also a major source.

Black carbon also poses a particular threat to India and China, partly because of the unusual seasonal weather pattern over the Indian subcontinent, which typically goes without much rain for six months of the year between monsoon seasons. The temperature inversion that forms over much of South Asia during the period traps the black carbon above the glaciers and snow, causing air pollution high in the Himalayas and on the Tibetan Plateau. In some of these areas, air pollution levels are now comparable to those of Los Angeles. So much thick carbon settles on the ice and snow that the melting already triggered by atmospheric warming has accelerated.

Since half of the drinking water and agricultural water in India and much of China and Indo-china comes from the seasonal melting of these same glaciers, the human consequences could soon become catastrophic. For example, 70 percent of the water flowing in the Ganges River comes from the melting of ice and snow in the Himalayas.

Black carbon is also produced by the burning of agricultural waste, such as residue from sugar cane (bagasse) and residue from corn (stover), and from burning firewood throughout the world.

More than a third of the black carbon in the atmosphere comes from the burning of fossil fuels, primarily from diesel trucks not equipped with devices to trap emissions as they exit the tailpipe. Though these devices have recently been introduced, they are not yet widely used.

It is noteworthy that so much of the black carbon pollution comes from activities that simultaneously produce CO_2, including inefficient engines for small vehicles in Asia and wasteful coal-fired power plants. But this need not be the case. For example, coal burning in industrial countries produces CO_2 without producing much black carbon due to measures taken in the past several decades to make fuel combustion more efficient and to curb local air pollution.

Most of the global warming caused by black carbon comes from its absorption of incoming sunlight. It is a primary component of the large brown clouds that cover vast areas of Eurasia and drift eastward across the Pacific Ocean to North America and westward from Indonesia across the Indian Ocean to Madagascar. These clouds—like some other forms of air pollution—partially mask global warming by blocking some of the sunlight that would otherwise reach lower into the atmosphere. Black carbon typically does not linger in the atmosphere for long periods of time, because it is washed out of the air by rain. That may be yet another reason why it was traditionally not included in the list of greenhouse gas pollutants. As a result, once we stop emitting black carbon, most of it will stop trapping heat in the atmosphere in a matter of weeks. Right now, however, we put such enormous quantities of black carbon into the air every day, the supply is continually replenished. And scientists have taken note that in areas of the world that experience long, dry seasons with no rainfall, black-carbon concentrations build up to extraordinarily high levels.

Moreover, scientists are increasingly concerned about black carbon because it also causes the earth to warm up in a second way: when it falls on ice and snow, it darkens the white reflective surface so much that sunlight that used to bounce off is absorbed instead, causing more rapid melting.

The overall reflectivity of the earth is an important factor in understanding the problem of global warming. The more sunlight bounces off the tops of clouds and the highly reflective parts of earth's surface, the less solar radiation is absorbed as heat. The less heat absorbed, the less trapped by global warming pollution when it is re-radiated toward space as infrared radiation.

This has led some scientists to suggest painting millions of roofs white and other steps to increase the reflectivity of the earth's surface. These ideas are worthy of serious consideration. But, in the meantime, we are losing much of the earth's natural reflectivity (or albedo, as scientists refer to it) with the melting of ice and snow—particularly in the Arctic and the Himalayas.

The fourth most significant cause of global warming is a family of industrial chemicals called halocarbons—including the notorious chloro-fluorocarbons (CFCs) Many are already being regulated and reduced under a 1987 treaty (the Montreal Protocol) that was adopted worldwide in response to the first global atmospheric crisis, the hole in the stratospheric ozone layer. As an added benefit of that treaty, this category of global warming pollution is now slowly but steadily declining. It still represents roughly 13 percent of the total problem—a significant number—so efforts to further strengthen the Montreal Protocol that are already under way will help. For example, many scientists are critical of the U.S. insistence in 2006 that the phaseout of methylbromide be delayed indefinitely for certain agricultural uses. In addition, there is growing concern among scientists that some of the chemicals used as substitutes for halocarbons—particularly chemicals known as hydrofluorocarbons—should also be controlled under the Montreal Protocol because they are potent global warming pollutants and their volume is growing rapidly.

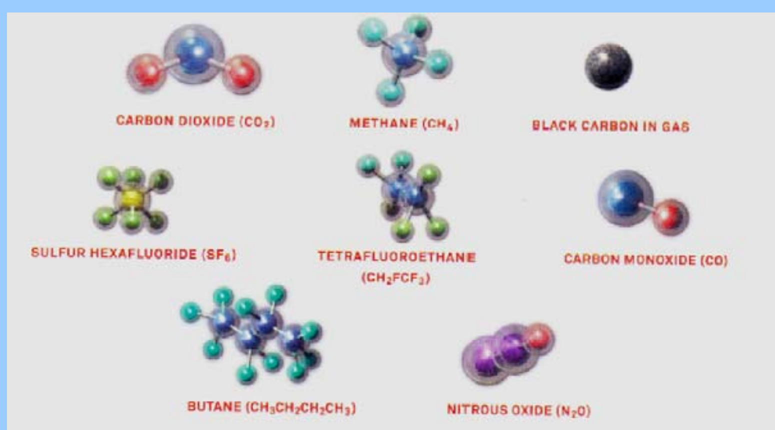
Three other chemical compounds in the halo-carbon family that do not destroy stratospheric ozone (and these were not covered in the earlier treaty) are also potent greenhouse gases. These are controlled under the Kyoto Protocol (which the United States didn’t ratify). Some halocarbons stay in the atmosphere for thousands of years. (One of them, carbon tetrafluoride, lingers in the atmosphere for an incredible 50,000 years—though, thankfully, it is produced in small volumes.)

It is important to note that the world’s efforts to protect the stratospheric ozone layer represent an historic success. Even though the affected industries initially fought acceptance of the science that alerted us to the gravity of the threat, political leaders in country after country wasted very little time in coming together across ideological lines to secure an effective treaty in spite of some residual uncertainty in the science. Three years after the treaty was signed, they revisited the subject and toughened the original standards. In the years since, it has been strengthened again several times. Significantly, some of the same corporations that had opposed the original treaty worked in favor of strengthening it after their experience in finding substitutes for the offending chemicals. As a result, the world is now well on the way to solving this particular problem. Scientists say it may take another 50 to 100 years before the stratospheric ozone layer is fully healed, but we are not moving in the right direction. They caution us, however, that the one thing that could reverse this trend is failure to solve global warming, which according to some scientists could threaten to make the ozone hole above Antarctica start growing again. Continued heating of the atmosphere (and cooling of the stratosphere) could threaten to restart the destruction of stratospheric ozone and thin the ozone layer to the point where it could once again become a dangerous threat to human life.

The next family of air pollutants contributing to global warming includes carbon monoxide and volatile organic compounds (VOCs). Carbon monoxide is mostly produced by cars in the U.S., but is also produced in large quantities in the rest of the world by the burning of biomass.

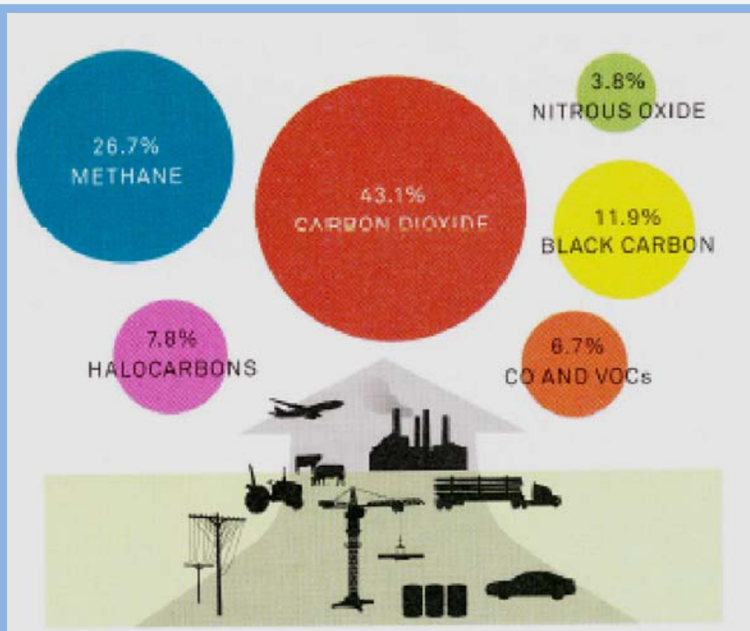
A GUIDE TO GLOBAL WARMING POLLUTANTS

All global warming comes directly or indirectly from the effects of six families of pollutants. The largest role is played by carbon dioxide (CO_2), the most abundant and most rapidly increasing greenhouse gas. Methane (CH_4) also a greenhouse gas, is the second worst cause, followed by black carbon (soot). Important roles are also played by industrial chemicals invented in the 20th century—chlorofluorocarbons; halocarbons, such as tetrufluoroethane (CH_2, FCF_3); and sulfur hexafluoride (SF_6). All of these chemicals trap heat in the atmosphere. Carbon monoxide (CO) and volatile organic compounds (VOCs)—such as butane—do not trap heat directly but interact with other pollutants to create compounds that do trap heat. Finally, nitrous oxide (N_2O)—which is mainly a by-product of nitrogen-intensive agriculture—plays a smaller but still significant role in trapping heat in the earth's atmosphere.



VOCs are produced mainly in industrial processes around the world, but in the U.S., a quarter of these emissions comes from cars and trucks. These pollutants actually do not trap heat themselves, but they lead to the production of low-level ozone, which is a potent greenhouse gas and unhealthy air pollutant.

These pollutants are not included in the official list of chemical compounds controlled under the Kyoto Protocol—just as black carbon is not yet included—but scientific experts include them among the causes of global warming because they interact with other chemicals in the atmosphere (including methane, sulfates, and, to a lesser extent, CO_2) in ways that further trap significant amounts of heat and contribute to global warming.



THE SOURCES OF GLOBAL WARMING

Global warming can be traced to six families of pollutants, whose proportional role in the problem is seen above. These gases and black carbon are emitted from many human endeavors, from transportation to farming to heating.

Source: Drew T. Shindell, et al., 30 October2009. *Science* 326:716-718.

Any comprehensive strategy for solving the climate crisis should, therefore, focus on these pollutants, along with the other five causes of global warming.

The details of such a strategy must also include attention to other chemicals in the atmosphere that add complexity to the problem, such as sulfur dioxide (which leads to the formation of sulfate particles), nitrogen oxides (which contribute to the formation of ozone), sulfates, nitrates, and organic carbon. All of these have a net cooling effect on their own, but they also interact with global warming pollution and impact public health and ecosystems in ways that affect problem-solving strategies.

The last cause of global warming is nitrous oxide. The vast majority of nitrous-oxide emissions comes from agricultural practices that rely heavily on nitrogen fertilizers, greatly magnifying the natural emissions resulting from the bacterial break-down of nitrogen in the soil. In the past 100 years—since two German chemists discovered a new process for combining hydrogen with atmospheric nitrogen to create ammonia—we have doubled the amount of available nitrogen in the environment. Traditionally, farmers rotated crops to replenish nitrogen depleted from the soil after several years of growing the same crop. By planting legumes and applying animal manure, farmers found they could restore fertility to their land. However, modern agriculture has come to rely heavily on vast quantities of synthetic ammonia fertilizers that continually add nitrogen to soils otherwise too depleted to grow crops. This Faustian bargain has greatly increased crop yields. The trade-off has been nitrous-oxide emissions into the atmosphere and nitrogen runoffs into rivers and creeks, where it stimulates the rapid and unsustainable growth of algae blooms. When these algae blooms die and decompose, the oxygen in the water is depleted, forming “dead zones” where fish and many other species cannot survive. Moreover, since these synthetic ammonia fertilizers require large amounts of fossil fuel to produce, the manufacturing process adds significant amounts of CO_2 to the atmosphere.

Smaller amounts of nitrous oxide are also emitted from burning fossil fuels, from a variety of industrial processes, and from poor management of livestock manure and human sewage.

Although nitrous oxide is the smallest contributor among the six causes of global warming, it is nevertheless significant and can be reduced if we change the way we use nitrogen.

Finally, it is important to note the role played in the atmosphere by water vapor. Some commentators like to point out that water vapor traps more heat than CO_2. While this is technically correct, the extent to which water vapor traps more heat than normal in the earth’s atmosphere is determined by the extent to which global warming pollutants raise the air and ocean temperatures, increasing the amount of water vapor the atmosphere can hold. The amount of water vapor in the air is responsive to its temperature and to atmospheric circulation patterns that help determine the relative humidity. Because changes in these variables are being driven by the emission of CO_2 and other global warming pollutants, human activities are really controlling the change in atmospheric water vapor. Consequently, the only way to reduce the role of water vapor is to solve the climate crisis.

So there it is: the solution to global warming is as easy to describe as it is difficult to put into practice. Emissions of the six kinds of air pollutants causing the problem—CO_2, methane, black carbon, halocarbons, nitrous oxide, and carbon monoxide, plus VOCs—must all be reduced dramatically. And we must simultaneously increase the rate at which they are removed from the air and reabsorbed by the earth’s oceans and biosphere.

Chapter 3

The Interconnected Biosphere: Science at the Ocean's Tipping Points*

Eleventh Annual Roger Revelle Commemorative Lecture

Jane Lubchenco, *Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator, and Laura E. Petes, NOAA, OAR, Climate Program Office*

ABSTRACT

Advances in social and natural sciences provide hope for new approaches to restore the bounty and resilience of ocean ecosystems. From new interdisciplinary approaches and conceptual frameworks, to new tools—such as catch shares, ecosystem-based management, marine spatial planning, and marine reserves—to new insights into strategies for adapting to the impacts of climate change and designing resilient and effective institutions, new knowledge is beginning to inform policies and practices. This decade is a pivotal one for the future of the ocean. The confluence of local, regional, and global changes in the ocean—driven by stressors, including nutrient pollution, habitat loss, overfishing, and climate change and ocean acidification—is rapidly transforming many once bountiful and resilient ocean ecosystems into depleted or disrupted systems. Degraded ecosystems cannot provide key ecosystem services, such as production of seafood, protection of coastlines from severe storms and tsunamis, capture of carbon, and provision of places for recreation. The accelerating pace of change presents daunting challenges for communities, businesses, nations, and the global community to make a transition toward more sustainable practices and policies. In this paper, we highlight new interdisciplinary approaches, tools, and insights that offer hope for recovering the bounty and beauty of the ocean and the ongoing benefits that they provide to people.

INTRODUCTION

Numerous studies have documented the depletion and disruption of ocean ecosystems at local to global scales, the consequences of these changes to human well-being, and the need for new attitudes, policies, and practices to recover and sustain healthy ocean ecosystems and the variety of human

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* First published in *Oceanography* 23:115-129 (2010); reprinted here by permission

activities that depend upon them (PEW Oceans Commission 2003; USCOP 2004; Millennium Ecosystem Assessment 2005; United Nations Environment Programme 2006). Depleted fisheries, endangered turtles and marine mammals, dead zones, bleached corals, and outbreaks of jellyfish, harmful algal blooms, and diseases are all symptoms of the population and ecosystem changes underway. These changes are the result of myriad interacting stressors, including over-fishing, chemical and nutrient pollution, use of destructive fishing gear, climate change, ocean acidification, habitat loss, and introduction of invasive species. However, they also reflect the failure of current management and policy, as well as a lack of general awareness of the causes and consequences of depletion and disruption. The prospect of significantly more disruption from climate change and ocean acidification looms large and lends urgency to an already serious situation.

Many ocean ecosystems appear to be at a critical juncture. Like other complex, nonlinear systems, ocean ecosystems are often characterized by thresholds or "tipping points," where a little more change in a stressor can result in a sudden and precipitous loss of ecological functionality. Some marine systems have already crossed a threshold, resulting in changes, such as a rapid fishery collapse (Millennium Ecosystem Assessment 2005; Biggs, Carpenter et al. 2009). Others may well be approaching tipping points. Actions taken now and in the coming decade will likely determine the future health of most, if not all, ocean and coastal ecosystems. In turn, the state of these ecosystems will affect economic and social well-being. Existing scientific knowledge is not being acquired or incorporated rapidly enough into public understanding or into management and policy decisions. This essay seeks to focus on some recent advances in social and natural sciences that are relevant to a transition toward more sustainable practices and policies. Some of the advances are beginning to be implemented but need to be scaled up; others have yet to be employed or translated into usable tools. New knowledge in high-priority areas is also needed.

The goal of this essay is to catalyze interest in using scientific knowledge to maximize the likelihood of achieving healthy, productive, and resilient coastal and ocean ecosystems and enabling a vibrant suite of sustainable human uses of oceans and coasts. In the following pages, we (1) highlight new scientific understanding in the broad areas of ecosystem services, coupled natural and social systems, and resilience: (2) focus on a few promising tools and approaches to address the challenges ahead; and (3) describe areas for further work.

ECOSYSTEM SERVICES LINK HUMAN WELL-BEING TO THE ENVIRONMENT

Managed and unmanaged ecosystems provide the life-support systems for people and all life on Earth (Daily, Söderqvist et al. 2000). Physical, chemical, and biological perturbations of the ocean, land, and atmosphere—especially over the last few decades—have significantly altered the functioning of ecosystems and thus the delivery of their life-supporting services (Vitousek, Mooney et al. 1997; Lubchenco 1998; NRC 1999; Millennium Ecosystem Assessment 2005; United Nations Environment Programme 2006; Carpenter, Mooney et al. 2009). The Millennium Ecosystem Assessment (2005) documents the dependence of human well-being on healthy ecosystems, the global loss of ecosystem services, and the options for reversing this trend. In short, human well-being depends upon services provided by ecosystems, but human activities have so utterly transformed ecosystems and altered their functioning that 60% of ecosystem services are currently at risk (Millennium Ecosystem Assessment 2005; United Nations Environment Programme 2006). However, in most cases, viable options exist for recovering and sustaining the delivery of services.

Ecosystem services are the benefits provided by ecosystems; they result from interactions of plants, animals, and microbes with one another and with the environment. Services vary according to the type of ecosystem (e.g., coral reef, mangrove, kelp forest, open ocean). Each ecosystem provides multiple types of services: provisioning services, such as seafood; regulating services, such as coastal protection or climate regulation; cultural services, such as recreation; and supporting services, such as nutrient cycling and primary production (Table 1); (Millennium Ecosystem Assessment 2005).

Table 1. Ecosystem services provided by the ocean. Provisioning, regulating, and cultural services provide direct benefits to humans; supporting services are necessary for the production of all other ecosystem services (Millennium Ecosystem Assessment 2005; United Nations Environment Programme 2006)

Provisioning	**Regulating**	**Cultural**
Seafood, habitat, fuel wood, genetic resources	Climate regulation, disease and pest regulation, coastal protection, detoxification, sediment trapping	Aesthetic, spiritual, educational, recreational
Supporting Nutrient cycling, primary production		

For example, a mangrove ecosystem provides wood fiber, fuel, and nursery habitat for numerous species (provisioning services); it detoxifies and sequesters pollutants coming from upstream, stores carbon, traps sediment, and thus protects downstream coral reefs, and buffers shores from tsunamis and storms (regulating services); it provides beautiful places to fish or snorkel (cultural services); and it recycles nutrients and fixes carbon (supporting services).

Ecosystem functioning and the delivery of services are affected by changes in biodiversity, habitat fragmentation and conversion, climate change, and alterations to biogeochemical cycles. When an ecosystem is converted to another use, some services may be lost and others gained. For example, when mangroves are converted to shrimp ponds, airports, shopping malls, agricultural lands, or residential areas, food production, space for commerce or transportation, or housing services are obtained, but the natural services are lost. Similarly, when river direction and flow are modified to obtain navigation and flood-control services, the replenishment of coastal wetlands and barrier islands is diminished, resulting in loss of habitat, nursery areas, carbon storage, and protection from storms. Typically, conversion or other alterations are implemented without consideration of the tradeoffs.

The importance of a service is often not appreciated until it is lost. Post Hurricane Katrina, residents of New Orleans speak openly about the need to restore barrier islands and coastal wetlands so they can function as "speed bumps" for hurricanes. This assertion is also borne out elsewhere: in the 2004 Indian Ocean tsunami, areas of India with intact mangroves suffered fewer losses of human lives and property than did areas where mangroves had been cleared, demonstrating the importance of the buffering capacity provided by these plants (Katherisan and Rajendran 2005). At the global scale, the loss of species from large marine ecosystems has led to a reduction in the ocean's capacity to provide food, improve water quality, and recover from disturbance (Worm, Barbier et al. 2006).

Although people will readily articulate some of the benefits they derive from the ocean (Figure 1), they are usually unaware of many others, and they often miss the key points that most of those benefits depend on healthy ocean ecosystems and that these ecosystems are already degraded or threatened.

Clearly, translating general scientific knowledge about the importance of ecosystem services into useful guidance and tools for decision makers is a high-priority challenge. Educating citizens and decision makers about the importance of services is necessary, but it is not sufficient without tools and information to translate that knowledge into practices and policies. Understanding, assessing, and measuring ecosystem services can be difficult (Carpenter and Folke 2006; Carpenter, Mooney et al. 2009). Moreover, most of the research on ecosystem services has been conducted in terrestrial systems. In addition, ecosystem services need to be explicitly linked to socio-ecological scenarios to demonstrate how ecosystems benefit humans (Tallis and Kareiva 2006).

The utility of understanding and communicating tradeoffs was demonstrated in the Catskill Mountains, where changes in watershed management to improve water quality for New York City were based on knowledge of the value provided by ecosystem services. In 1996, when drinking water quality fell below Environmental Protection Agency (EPA) standards due to degradation of the watershed, the City of New York faced the dilemma of whether to invest in Catskill watershed ecosystem restoration ($1.-1.5 billion) or a water filtration plant ($6-8 billion) (Chichilnisky and Heal 1998). The decision to invest in "natural capital" (in the form of ecosystem restoration) saved money and restored both the ecosystem services of interest (water purification and filtration) as well as other services, such as carbon storage and opportunities for recreation, none of which would have been obtained through building a new filtration plant (Heal, Daily et al. 2001).

Figure 1. Ecosystem services as articulated by the general public. Photos used with permission from the National Oceanic and Atmospheric Administration

There are several emerging scientific efforts to enhance our understanding of the benefits that humans obtain from ecosystems and to apply that knowledge in decision-making. The challenge of determining, measuring, and communicating the values of ecosystem services is being addressed through efforts such as the Natural Capital Project (http://www.naturalcapitalproject.org), a partnership among Stanford University, The Nature Conservancy, and the World Wildlife Fund to develop tools for facilitating incorporation of natural capital (i.e., valuation of ecosystem services) into decision making. Their first tool, InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), can model and map the delivery, distribution, and economic value of ecosystem services into the future. InVEST allows users to visualize the impacts of their potential decisions, which enables identification of tradeoffs among environmental, economic, and social benefits. This tool has already been applied successfully using stakeholder-defined scenarios to predict changes in land use and associated tradeoffs in the Willamette Valley, Oregon (Nelson, Mendoza et al. 2009). Although InVEST was initially focused on terrestrial ecosystems, it is now being applied to coastal and marine ecosystems to provide maps and projections of ecosystem services under different management alternatives for issues, such as tradeoffs associated with large-scale implementation of desalination plants in California (Ruckelshaus and Guerry 2009). Marine InVEST offers a promising new approach for incorporating scientific information about ecosystem services into decision making and resource management.

Effective valuation of ecosystem services requires acknowledging that global social change and global environmental change interact with one another

(Young, Berkhout et al. 2006). When facing decisions that affect ecosystem services, tradeoffs between social values and environmental outcomes can either be win-win, win-lose, or lose-lose, and the challenge is to develop solutions that are win-win, where both social and environmental goals are achieved (Tallis, Kareiva et al. 2008). Increased emphasis should be placed on incorporating social data and projections of social distributional effects into ecosystem services valuation in order to determine and maximize win-win outcomes (Tallis and Polasky 2009) and on obtaining basic information about the fundamental workings of coupled human-natural systems (Carpenter, Mooney et al. 2009).

One major obstacle to ecosystem services valuation is that detailed information on how people benefit from specific services at scales useful for decision making is currently sparse (Turner and Daily 2008). In addition, because ecosystem services valuation is a relatively new field of science, there are few examples of "lessons learned" to inform new efforts. Databases are a useful tool for providing centralized, publicly accessible sources of information. The Natural Capital Database currently under development, (www.naturalcapitalproject.org/database.html) will be a compilation of strategies and outcomes from conservation projects that have focused on ecosystem services. This information clearinghouse will allow decision makers and managers to learn lessons from previous efforts that they may be able to apply to their own planning processes.

UNDERSTANDING COUPLED SOCIAL-NATURAL SYSTEMS AS COMPLEX ADAPTIVE SYSTEMS

Until recently, studies of social systems and of natural systems proceeded independently of one another. Novel inter-disciplinary approaches have recently emerged for studying human and natural systems as coupled systems (Liu, Dietz et al. 2007; Berkes, Colding et al. 2008; Ostrom 2009) These efforts seek to understand the interconnectedness of people and ecosystems, the bases of decision making, and perceptions of risk, equity, and scale (Figure 2); (Ostrom, Burger et al. 1999; Dasgupta, Levin et al. 2000; Dietz, Ostrom et al. 2003; Kinzig, Starrett et al. 2003; McLeod and Leslie 2009) Interdisciplinary approaches will enable the changes in practices and policies needed to use ecosystems sustainably and to facilitate human well-being (Figure 3).

Insights from other scientific areas are also informing the understanding of coupled human and natural systems, specifically the study of complex adaptive systems. These systems are defined by the fact that dynamics of interactions at small scales affect macroscopic system dynamics, which then feed back to impact the small scales (Levin 1998).

Across numerous types of complex adaptive systems, the same key features appear necessary for a system to be robust and resilient (i.e. to have the capacity to absorb stresses and continue functioning (Levin and Lubchenco 2008): modular structure, redundancy of modules, diversity and heterogeneity of modules, and tight feedback loops (Levin 1999). Tradeoffs exist between elements, and therefore, optimum resilience may be obtained at intermediate levels of these components (Levin 1999).

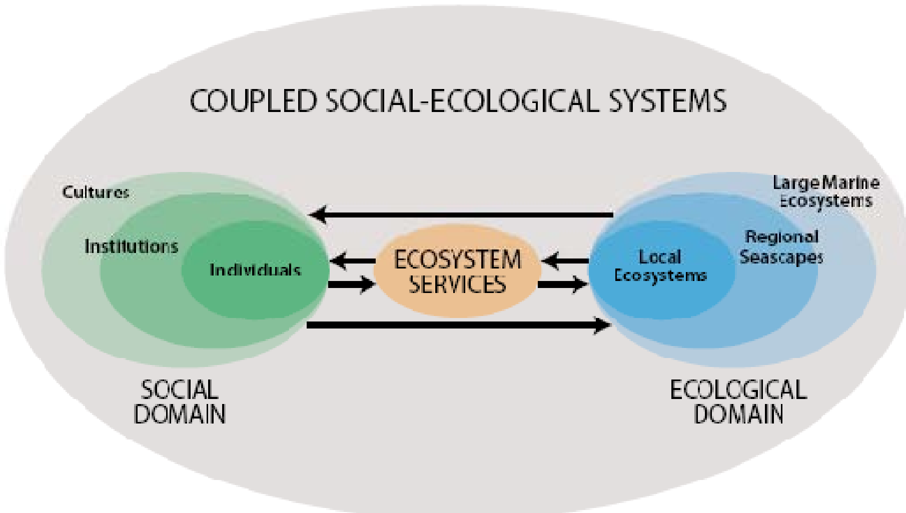

Figure 2. Schematic of nested interactions between human and ecological systems (McLeod and Leslie 2009). Social and ecological domains interact over multiple geographic and organizational scales; understanding connections across scales is critical to the long-term success of ecosystem-based management efforts. Ecosystem services represent a key connection between domains, and the flow of services is affected by both social and ecological factors.

Evidence suggests that ecosystems with higher diversity are more resilient (Millennium Ecosystem Assessment 2005). This has been documented for areas that are recovering from species loss: as diversity increases, valuable ecosystem services are restored, leading to higher resilience (Worm, Barbier et al. 2006). New interdisciplinary efforts, such as the Resilience Alliance (http://www.resalliance.org) and the Forum on Science and Innovation for Sustainable Development (http://www.sustainability science.org), are actively exploring the dynamics of socioecological systems in order to provide a foundation for sustainability.

These efforts acknowledge that the study of ecosystem resilience is complex and requires interdisciplinary tools, creative approaches (e.g., network analyses; (Janssen, Bodin et al. 2006), and collaborations; (Schellnhuber, Crutzen et al. 2004; Walker and Salt 2006; Carpenter, Folke et al. 2009; Leslie and Kinzig 2009). New approaches that would enhance the capacity of management systems to adapt quickly in response to changing conditions would be beneficial (Carpenter and Brock 2008).

Figure 3. Human and natural systems are inextricably linked. (a) Governor Deval Patrick of Massachusetts announces the Oceans Act of 2008 to initiate the development of a comprehensive spatial plan. (b) Exploring the rocky intertidal zone of the Olympic Coast National Marine Sanctuary. (c) Fishing for halibut in Sitka, Alaska, where a catch share program has been in place for a decade. (d) Louisiana school children work to restore wetlands through a NOAA Bay-Watershed Education and Training grant awarded to the Louisiana State University Coastal Roots Program. Photo a used with permission from the Massachusetts Governor's Office. Photos b, c, and d used with permission from the National Oceanic and Atmospheric Administration.

Incorporating social sciences into decision making and adaptive management is an arena where significant new advances have begun. The 2009 Nobel Prize in Economics to Elinor Ostrom explicitly recognizes the importance of interdisciplinary approaches, the key role that institutions play, and the multiple scales of decision making relevant to managing common-pool resources (e.g., (Ostrom 2009). Organization of human institutions can have a large impact on ecosystem resilience and sustainability; therefore, participator processes that facilitate experimentation, learning, and change will benefit ;planning efforts (Dietz, Ostrom et al. 2003). This raises the need to design strategies and institutions for integrating incomplete knowledge with experimental action into programs of adaptive management and social learning (National Research Council 1999) and to grow capacity to manage the ocean and coasts sustainably (National Research Council 2008).

In addition, it is important to understand what scientific information best meets the needs of decision makers and managers attempting to prepare for and respond to environmental change. Information users must be able to articulate their needs to the scientific community, who can in turn provide them with information that fits the scales and topics necessary for decision making. These interactions will require the creation of new relationships, institutions, and channels of communication, which social science research can help to inform. Studies on strategies for successful communication of complex scientific issues and uncertainty will also benefit these ongoing dialogues. A better understanding of social, cultural, and economic barriers to adaptive action and management is needed. Identifying barriers and designing strategies to eliminate them when possible will allow for action at all scales of governance.

EMERGING APPROACHES AND TOOLS TO ENHANCE ECOSYSTEM RECOVERY, RESILIENCE, AND SUSTAINABILITY

As emphasized by the Pew Oceans Commission (2003), the current problems in the ocean are both a failure of understanding and a failure of governance. Most people are unaware of the current state of the ocean or that the benefits they seek from the ocean are at risk unless changes are made. The mindset that the ocean is so vast and bountiful that it is infinitely resilient persists. Likewise, few are aware of how their individual choices affect the ocean or other people. Providing credible information from trusted sources will be critical for raising awareness about the need to improve practices and policies. In other words, the scientific advances described above need to be incorporated into public understanding.

This knowledge must also be translated into new tools, guidelines, and approaches for communities, interest groups, decision makers, and resource managers. A significant shift is underway in approaches to ocean management (Table 2), creating more demand for practical guidance and tools.

Table 2. A shift in approaches to management is underway for coastal and marine ecosystems.

Historical Approach	New Approach
Short-term perspective	Long-term and evolutionary perspectives
Single-sector focus	Multi-sector focus
Natural science approach	Coupled natural and social science approach
Single-species management	Ecosystem-based management
Focus on delivery of products	Focus on maintaining ecosystem resilience and delivery of ecosystem services
Greater use of fines	Greater use of incentives
Regulation of effort	Regulation of outcome
Command and control, centralized, top-down regulation	Top-down plus bottom-up decision making; more local control
Reactive	Anticipatory and precautionary
Static	Adaptive

Some of the new tools and approaches have already been mentioned, such as the Natural Capital Project's InVEST tool and coupled social-natural approaches to decision making. Others include integrated ecosystem assessments, ecosystem-based management (EBM), marine spatial planning (MSP), catch shares, nutrient-trading schemes, biodiversity banks, marine protected areas (MPAs) and marine reserves, and decision-support and visualization tools. Four of these tools are described below.

Marine Ecosystem-Based Management (EBM)

EBM simply means taking a place-based, ecosystem approach to management, with the goal of sustaining the long-term capacity of the system to deliver ecosystem services (Rosenberg and McLeod 2005). Doing so requires synthesizing and applying knowledge from social and natural sciences. EBM is different from traditional approaches that usually focus on a single species, sector, activity, or concern. In contrast, EBM considers the cumulative impacts of different sectors and the connections between people and ecosystems, as well as the connections among the different components of the ecosystem (Figure 4). Although many EBM concepts have been codified only recently (McLeod, Lubchenco et al. 2005), they are actively employed in multiple ecosystems around the world. Recent advances in understanding and practicing EBM are summarized in (McLeod and Leslie 2009) .

Marine Spatial Planning (MSP)

MSP, also called coastal and marine spatial planning, is an EBM tool for minimizing conflicts among users and reducing impacts on ecosystem functioning. Increasing demands on ocean space for diverse uses, including tourism, recreation, fishing, shipping, national security, oil and gas exploration, and wave and wind energy, have led to more and more conflicts among users, as well as additional impacts on already stressed ocean ecosystems (United Nations Environment Programme 2006; Douvere 2008). MSP is a process that enables integrated, forward-looking decision making through an ecosystem-based, spatially explicit approach (Ehler and Douvere 2007). Spatial planning has been practiced on land for centuries, as humans have determined how to allocate specific areas for multiple uses, including forestry, conservation, development, and agriculture.

The concept of zoning in the ocean is a relatively new idea. The first comprehensive MSP was developed in the 1980s for the Great Barrier Reef Marine Park in Australia. Specific areas are zoned for different uses, including fishing and tourism, and other areas are designated as fully protected, helping to minimize user conflicts and ecosystem impacts (Douvere 2008). Because of the interdependency of human and natural systems, the MSP process is most successful when it involves broad participation by stakeholder groups, scientists, and managers (Pomeroy and Douvere 2008). In addition to consideration of human uses, it is important for planners to understand the biological communities and the key processes that maintain them in order to create plans that maximize ecosystem resilience (Crowder and Norse 2008).

Efforts are currently underway to develop marine spatial plans for the United States. On December 14, 2009, President Obama's Interagency Ocean Policy Task Force released an interim framework for effective coastal and marine spatial planning. Two weeks later, the Commonwealth of Massachusetts became the first US state to release a comprehensive ocean management plan for its 1,500-mile coastline (Figure 3a). Other states and nations are pursuing use of this tool as a vehicle for more holistic management of ocean resources and ecosystems.

Marine Protected Areas (MPAs) and Reserves

MPAs provide a complementary tool for protecting habitat, biodiversity and ecosystem functioning (e.g., (Halpern, Lester et al. 2010). MPAs are areas of the ocean that are managed for a conservation benefit. This tool provides an ecosystem- and place-based approach to management, as opposed to a species-based approach. MPAs may be used alone or as part of an MSP framework.

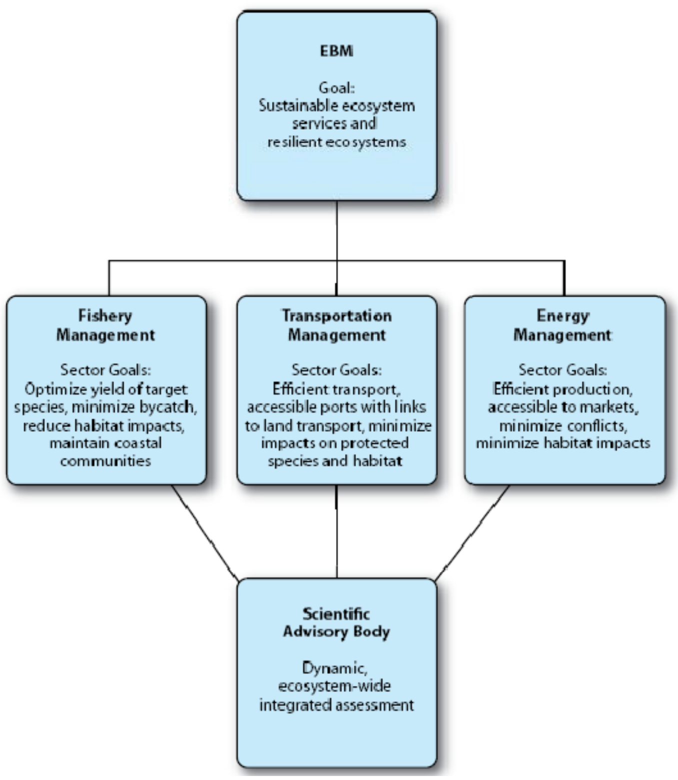

Figure 4. Framing ecosystem-based management (EBM) goals across sectors ((Rosenberg and Sandifer 2009). Used with permission from Island Press.

Fully protected (also called “no-take”) marine reserves are a type of MPA that are completely protected from all extractive and destructive activities (Lubchenco, Palumbi et al. 2003). Marine reserves currently constitute < 1% of the global ocean (Wood, Fish et al. 2008). Benefits of marine reserves include habitat protection, biodiversity conservation, enhancement of ecosystem services, recovery of over-exploited stocks, export of individuals outside the reserve, insurance against environmental uncertainty, and sites for scientific research, education, and recreation (Allison, Lubchenco et al. 1998). Scientific analyses of the hundreds of no-take marine reserves around the world provide compelling evidence that they do indeed protect biodiversity and habitats (Gaines, Lester et al. in press). Density, diversity, biomass, and size of organisms are higher inside reserves as opposed to outside (Figure 5; (Halpern 2003; Partnership for Interdisciplinary Studies of Coastal Oceans 2007; Hamilton, Caselle et al. 2010). On average, these benefits are rapid (often occurring within one to three years) and long-lasting (Halpern and Warner 2002). However, not all species respond rapidly, and the rates at which populations change depend on life histories and the availability of colonists (Babcock, Shears et al. 2010), as well as social factors (Pollnac, Christie et al. 2010).

Marine reserves provide a unique mechanism for protecting large-bodied individuals of fish and invertebrates. Large females (otherwise known as "big, old, fecund females" or BOFFs) have much greater reproductive potential than do smaller females (Figure 6) and are understood to be especially important for sustaining populations. Protection of BOFFs may also help to counter the negative evolutionary impacts of fishing that result in reproduction at smaller sizes (Baskett, Levin et al. 2005), and, in some cases, the distortion of size structure and social structure for fish that are sequential hermaphrodites.

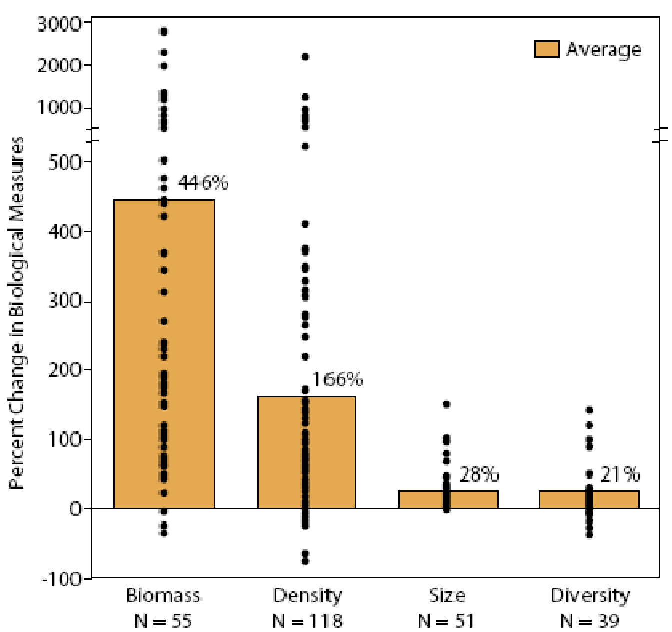

Figure 5. Impact of no-take marine reserves on biomass, density, size, and diversity of species inside of a reserve. Used with permission from the Partnership for Interdisciplinary Studies of Coastal Oceans; data from Lester,Halpern et al. (2009)

Productivity within marine reserves also leads to “spillover”—the migration of animals from inside the reserve to the outside—potentially enhancing commercial and recreational fisheries surrounding the protected area or contributing to recovery of depleted fisheries (Roberts, Bohnsack et al. 2001; Partnership for Interdisciplinary Studies of Coastal Oceans 2007). For example, coastal areas surrounding the Merritt Island, Florida, reserve exhibited a rapid increase in the number of world-record sized black drum, red drum, and spotted sea trout once the fully protected area was established (Roberts, Bohnsack et al. 2001)

Reproduction within reserves produces young that may be transported by ocean currents outside the reserve. This “export” of larvae is more difficult to quantify than “spillover” of juveniles or adults, but both processes transport benefits from inside a reserve to the surrounding areas.

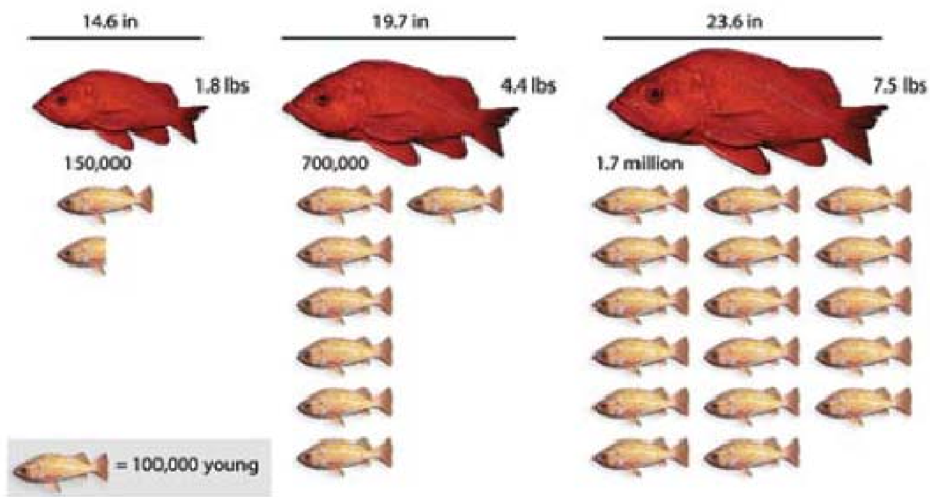

Figure 6. Relationship of number of young produced to body size of fish for vermillion rockfish. A 23-inch vermillion rockfish produces 17 times more young than it did when it was 14 inches long. Used with permission from the Partnership for Interdisciplinary Studies of Coastal Oceans**,** data from Love, Morris et al. (1990)

A network of marine reserves, which is a set of reserves separated by non-reserve waters but connected by the movement of young, juveniles, or adults, can be designed to maximize transport of benefits to the outside (McCook, Ayling et al. 2010; Pelc, Warner et al. 2010) . Because of spillover, export, and other benefits provided by reserves, optimal fisheries harvest occurs when some areas of a region are temporarily or permanently closed (Costello and Polasky 2008). Planning and implementation of marine reserve networks are facilitated by access to biological and socioeconomic information (Grorud-Colvert, Lester et al. 2010; Smith, Lynham et al. 2010). The availability of high-quality spatial information on the location of fish populations allows for spatial optimization in the implementation of marine reserve networks that lead to increased profit margins for surrounding fisheries (Costello, Rassweiler et al. 2010; Gaines, Lester et al. in press). For all of these reasons, no-take marine reserves and MPAs are increasingly seen as useful tools in a larger strategy to protect and restore coastal and ocean ecosystems.

Catch Shares

Catch shares provide an alternative to traditional fishery management by incorporating new understanding from social and economic sciences. Instead of individual commercial fishermen being incentivized by the "race to fish" to outcompete others, rights-based fisheries' reforms offer an alternative solution (Hilborn, Orensanz et al. 2005). In lieu of industry-wide quotas, fishermen are allocated individual quotas, referred to as "catch shares" of the total allowable catch, and the goal is to provide fishermen and communities with a secure asset in order to create stewardship incentives (Costello and Polasky 2008). Catch shares thus align economic and conservation incentives. They also hold fishermen accountable for adhering to the rules.

The concept of catch shares, pioneered in Australia, New Zealand, and Iceland, has now been implemented for hundreds of fisheries throughout the world. Effectiveness of catch shares was documented in a global analysis of over 11,000 fisheries. Results indicated that implementation of catch shares can halt, and even reverse, trends toward widespread fishery collapse (Figure 7; (Costello, Gaines et al. 2008; Heal and Schlenker 2008). This evidence suggests that catch shares offer a promising tool for sustainable fisheries management.

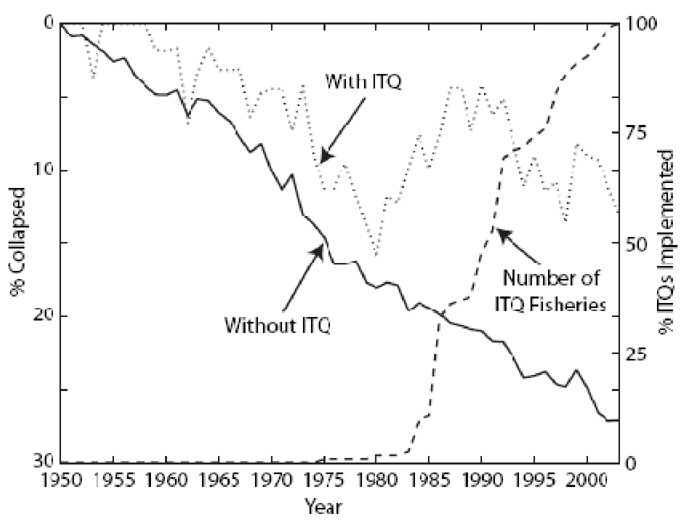

Figure 7. Percentage of fisheries collapsed (left y-axis) without (solid line) and with (dotted line) catch share management using the Worm et al. (2006) collapse threshold of 10% of historical maximum (modified from Costello et al. 2008). Individual transferable quotas (ITQs) are a form of catch shares. The number of catch share fisheries increases through time (right y-axis and dashed line). Used with permission from the American Association for the Advancement of Science

To date, 12 fisheries in the United States have adopted this management approach. The results have been impressive: sustainable fisheries, improved economic performance of the fishery, decreased environmental impact, and increased safety at sea. For example, in Alaska's halibut (Figure 3c) and sablefish fisheries, the length of the fishing season was extended from less than a week to eight months per year, bycatch dropped by 80%, and safety improved sharply (Redstone Strategy Group LLC and Environmental Defense Fund 2007). In the Gulf of Mexico's red snapper fishery, commercial overfishing ended for the first time in decades, fishermen are receiving higher dockside prices for their catch and reducing costs as they are able to better plan their trips, and discards have decreased by 70% (Redstone Strategy Group LLC and Environmental Defense Fund 2007) Catch shares are not necessarily suitable for every fishery, but they appear to hold promise for many.

Future Possible Tools

Other tools seem ripe for development but do not yet exist. One is a nutrient-trading scheme to decrease the flow of excess nutrients from agricultural and livestock areas into coastal waters. Dead zones (areas of low oxygen) in coastal oceans have spread exponentially since the 1960s as a result of nutrient runoff due to changes in agricultural and land-use practices; dead zones now occur over a total area of 245,000 km^2 (Diaz and Rosenberg 2008). Fertilizer use in the Mississippi River watershed, which drains 41% of the continental United States, leads to a severe, seasonal dead zone in the Gulf of Mexico that extends across 20,000 km^2 (Rabalais, Turner et al. 2002). One proposed approach for combating excess nitrogen input might be the establishment of cap-and-trade policy for nitrogen, where a limit would be set on nitrogen input for each region (Socolow 1999), with regions able to trade quotas. A similar approach was successfully used by the Environmental Protection Agency under the Acid Rain Program to cap emissions of sulfur dioxide to reduce the occurrence of acid rain. This program was so effective that sulfur dioxide reductions were achieved at significantly lower costs and at much faster rates than originally estimated.

Another potentially useful tool would involve better analytical methods for detecting an approaching ecological threshold or tipping point in time to avert potential disaster (e.g., a fishery collapse). Biggs et al. (2009) provide an example of such an early-warning indicator. The lack of relevant, long-term data sets may present considerable challenges in utilizing these tools; therefore, efforts to further develop them will need to occur in parallel with (and should inform the development of) improved monitoring efforts. In addition, the utility of such indicators will rest upon the adaptive capacity of management to avert the shift—both the ability of the management regime to respond rapidly and the ability to control the appropriate drivers of change (Carpenter and Brock 2008; Biggs, Carpenter et al. 2009).

None of the above tools offers a panacea, but each provides useful approaches that build on existing understanding from both natural and social sciences. Maintaining the suite of ecosystem services requires protecting the functioning of ecosystems. Integrated ecosystem assessments that elucidate how the different social and natural components interact provide a decision-making framework. Place- based, ecosystem-based, and adaptive management approaches are essential. New tools to facilitate understanding of and decisions about tradeoffs will be key. In short, effective management of coastal and marine ecosystems will require forward-thinking, holistic, and ecosystem-based approaches that involve users, managers, and scientific experts.

CHALLENGES AHEAD

Continuing to educate and engage citizens, provide information to guide decision making, and develop and implement new tools and approaches based on the more holistic understanding described above will undoubtedly bring significant benefits. For those approaches to be maximally effective, additional information about ecosystem and human patterns and processes is needed, such as basic patterns of biodiversity, understanding the scales over which key ecosystem processes operate, socioeconomic information at relevant scales, methods for identifying thresholds, and approaches for designing resilient institutions and management structures. This will also require significant advances in ecosystem-based science, ecosystem services, and resilience from a coupled human-natural system perspective.

In addition, information is not always available at the relevant spatial scale for management. For example, the majority of climate change scenarios have been developed for the global scale, but most of the impacts will be felt at local to regional scales. This mismatch of scales makes it difficult for managers to incorporate climate information into their planning processes. Similarly, effective sustainable management of large-scale resources (e.g., large marine ecosystems) requires collaboration among international, national regional, state, and local levels, which creates challenges (Ostrom, Burger et al. 1999). The need to address problems at the local to regional scale associated with shared global resources is increasing. Globalization is occurring throughout many of our coupled human-natural systems, leading to increased connectedness, with both positive and negative results (Young, Berkhout et al. 2006). A diversity of scales is necessary for effective, resilient management; by building on local and regional institutions to focus on global problems, the likelihood of success can be increased (Ostrom, Burger et al. 1999). The focus on understanding impacts of climate change on regions (U.S. Global Change Research Program 2009) is leading to increased attention towards the ability of climate models to resolve regional scales.

Both climate change and ocean acidification are likely to transform coastal and ocean species, ecosystems, and ecosystem services. Priority should be given to understanding the likely impacts of climate change and ocean acidification, as well as ways to ameliorate those impacts. Given the rapid pace at which ecosystems are changing, "learning by doing" becomes more difficult because past lessons no longer accurately predict the future (Ostrom, Burger et al. 1999).

Even though today's challenges are already substantial, climate change and ocean acidification will interact with and exacerbate the other drivers of change. Hence, to be relevant and useful, management and policy must focus on tomorrow's coupled human-natural systems, not today's or yesterday's. Doing so is not easy but not impossible. Likely keys to success include the following approaches:

- Avoiding irreversible changes (such as extinctions)
- Managing for resilience
- Managing with the expectation of surprises
- Creating flexible institutions with capacity to adapt rapidly
- Preserving as much biodiversity (genetic, species, and habitat) as possible
- Developing rules of thumb for managers in lieu of precise targets
- Minimizing impacts from stressors over which there is more immediate control
- Sharing information and lessons via learning networks
- Investing effort in scientific research to provide knowledge for the above strategies
- Supporting monitoring and analysis to guide management and policy decisions

In short, these strategies fall into two categories: (1) making better use of existing information, and (2) acquiring new knowledge that would enhance more sustainable practices and policies. Incorporating climate change and ocean acidification adaptation strategies into management and policy decisions provides a useful way to integrate a number of the above-mentioned approaches.

CONCLUDING REMARKS

Our future depends upon maintaining healthy ocean and coastal ecosystems and healthy human communities. Both are in flux, and each is coupled to the other. Ecosystem services link ecosystems to human well-being and provide a focus for understanding, policy, and management. Awareness that natural systems can undergo rapid change once a tipping point is reached lends urgency to the need for embracing novel tools and approaches, scaling up their use, and creating new knowledge, information, and tools.

Global threats to our coastal and marine ecosystems are rapidly increasing. We are currently operating in a "no analogue" state, in which human activities have driven global environmental change to a point that has never before been observed (Steffen et al., 2004). Biodiversity is declining, our natural resources are being depleted, and habitats are being destroyed. Along with these changes come the losses of valuable ecosystem services on which humans depend.

In addition to rapid shifts in ecosystems, social systems can also undergo rapid change once a tipping point is reached. Knowledge that rapid societal shifts occur can provide hope that successes in some places can be quickly adopted and implemented. The plethora of new advances and effective tools, successes at the local level, and engagement of citizens, businesses, and scientists around the world provide impetus for further engagement and hope that these efforts will succeed in transitioning to more sustainable practices and policies.

Priority actions include educating citizens and policymakers about the benefits of new approaches, strengthening interdisciplinary approaches to problem solving, reducing the stressors over which we have direct control (e.g. fisheries management, pollution, invasive species), reducing emission of greenhouse gases to slow down the rates of climate change and ocean acidification, protecting as much biodiversity as possible, and managing for ecosystem resilience. Holistic strategies for engaging stakeholders and for preserving or restoring ecosystem functioning and resilience are critical to success. Momentum is building, informed by scientific advances and public involvement. It's time to "seas the day."

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Chapter 4

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

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

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

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

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sustaining ocean goods and services, the world community should expect little action in return.

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

Why Large Marine Ecosystems?

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

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

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

The Role of the GEF

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

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

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

The Serious Nature of Coastal Depletion and Degradation

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

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

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

The GEF Support for Country-driven Action at Different Scales

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

A five-module indicator approach to the assessment and management of LMEs has proven useful in ecosystem-based projects in the United States and elsewhere (Duda and Sherman 2002). The modules are adapted to LME conditions through a Transboundary Diagnostic Analysis (TDA) process to identify key issues, and a Strategic Action Program (SAP) development process for the groups of nations or states sharing an LME to remediate the issues. These processes are critical for integrating science into management in a practical way, and for establishing appropriate governance regimes to change human behavior in different sectors.

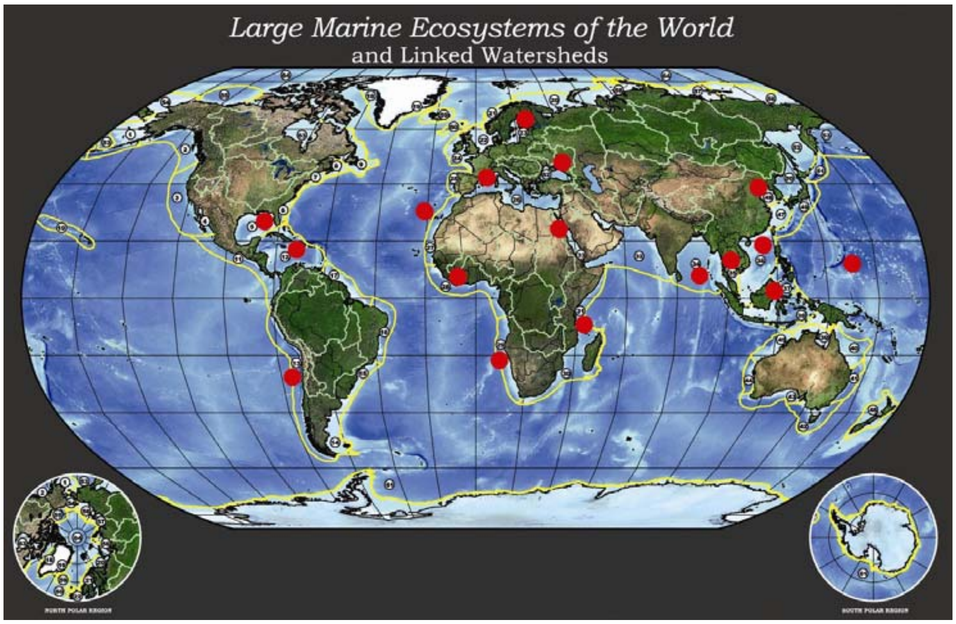

Figure 1. Global Distribution of Large Marine Ecosystem Projects Funded by the GEF. The red dots on the map represent the location of the 16 operational LME projects approved by the GEF Council and with GEF International Waters funding. These are (from left to right and top to bottom): the Caribbean,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

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

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

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

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

The Benguela Current LME Project

In the mid 1990s, the governments of South Africa, Namibia and Angola requested GEF's assistance for a project focusing on the sustainable management and utilization of the Benguela Current LME with a focus on living marine resources, the reduction of mining impacts, predicting environmental variability and improving ecosystem forecasting, managing land-based pollution, protecting biological diversity, and strengthening capacity to adapt to fluctuating climatic conditions that threaten fisheries. During a 12-month project development period, the three countries reached consensus on a strategic approach for the project, based on GEF procedures for developing a TDA and SAP, which was signed in 2000 by three ministers from each nation. As the first GEF project to successfully complete this initial work, the Benguela Current (BCLME) project serves as a successful model for other LME projects. Especially significant were the national dialogues fostered in inter-ministerial committees. They proved to be an important factor in aligning different ministries related to land and water activities to work in an integrated, ecosystem-based fashion.

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

The Danube/Black Sea Basin under the GPA

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

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

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

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

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

GEF Support for the LME Movement

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

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

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

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

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

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

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

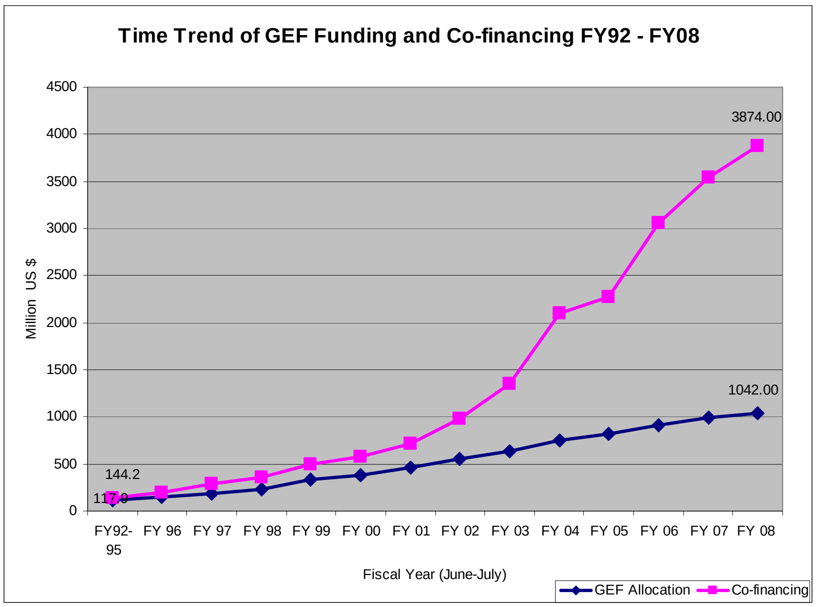

Figure 2. Time trend of GEF funding and co-financing for International Waters Focal Area Projects in FY92-FY08.

The LME Movement: the Imperative for Securing Livelihoods

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

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

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

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Chapter 5

Accelerated Warming and Emergent Trends in Fisheries Biomass Yields of the World's Large Marine Ecosystems*

Kenneth Sherman[1,2], Igor Belkin[3], Kevin D. Friedland[1], John O'Reilly[1] and Kimberly Hyde[1]

Abstract
Since 1995, international financial organizations have extended explicit support to developing coastal countries for assessing and managing goods and services using the modular approach at the LME scale. At present, 110 countries are engaged in LME projects along with 5 UN agencies and $1.8 billion in financial support from the Global Environment Facility (GEF) and the World Bank. Sixteen LME projects are presently focused on introducing an ecosystems approach to the recovery of depleted fish stocks, restoration of degraded habitats, reduction and control of pollution, conservation of biodiversity, and adaptation to climate change. In recognition of the observational evidence of global warming from the 4th Assessment Report of the (IPCC 2007) and the lack of information on trends in global warming at the LME scale where most of the world's marine fisheries biomass yields are produced, we undertook a study of the physical extent and rates of sea surface temperature trends in relation to fisheries biomass yields and SeaWiFS derived primary productivity of the world's LMEs.

Introduction

The heavily exploited state of the world's marine fisheries has been well documented (Garcia and Newton 1997; FAO 2004; González-Laxe 2007). Little, however, is known of the effects of climate change on the trends in global fisheries biomass yields. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change stated with "high confidence" that changes in marine biological systems are associated with rising water temperatures affecting shifts in pelagic algae and other plankton, and fish abundance in high latitudes (IPCC 2007). The Report also indicated that adaptation to impacts of increasing temperatures in coastal systems will be

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more challenging in developing countries than in developed countries due to constraints in adaptive capacity. From a marine resources management perspective, the 8 regions of the globe examined by the IPCC (i.e. North America, Latin America, Europe, Africa, Asia, the Australia and New Zealand region and the two Polar regions), are important fisheries areas but at a scale too large for determination of temperature trends relative to the assessment and management of the world's marine fisheries biomass yields produced principally in 64 large marine ecosystems (LMEs) (Figure 1). These LMEs, in coastal waters around the globe, annually produce 80% of the world's marine fisheries biomass (Figure 2).

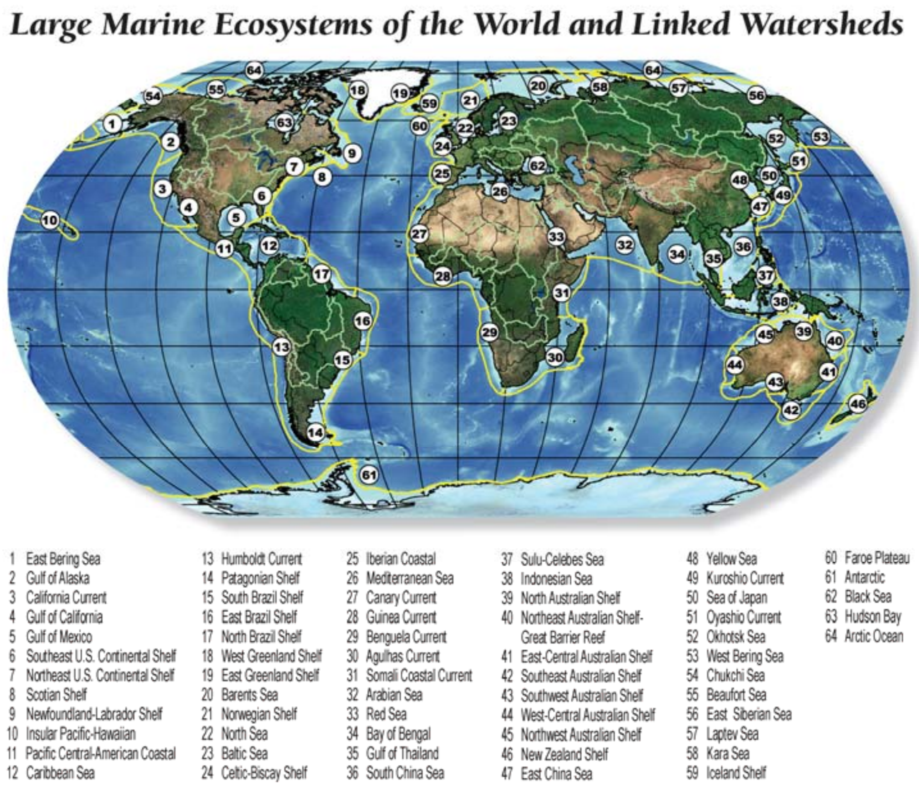

Figure 1. Large Marine Ecosystems are areas of the ocean characterized by distinct bathymetry, hydrography, productivity, and trophic interactions. They annually produce 80% of the world's fish catch. They are national and regional focal areas of global effort to reduce the degradation of linked watersheds, marine resources, and coastal environments from pollution, habitat loss, and over-fishing.

Large Marine Ecosystems are areas of an ecologically based nested hierarchy of global ocean biomes and ecosystems (Watson, Pauly et al. 2003). Since 1995, LMEs have been designated by a growing number of coastal countries in Africa, Asia, Latin America, and eastern Europe as place-based assessment and management areas for introducing an ecosystems approach to recover, develop, and sustain marine resources. The LME approach to the assessment and management of marine resources is based on the operationalization of five modules, with suites of indicators for monitoring and assessing changing conditions in ecosystem: (i) productivity, (ii) fish and fisheries (iii) pollution and ecosystem health, (iv) socioeconomics, and (v) governance (Duda and Sherman 2002). The approach is part of an emerging effort by the scientific community to relate the scale of place-based ecosystem assessment and management of marine resources to policy making and to tighten the linkage between applied science and improved management of ocean resources within the natural boundaries of LMEs (Wang 2004; COMPASS 2005).

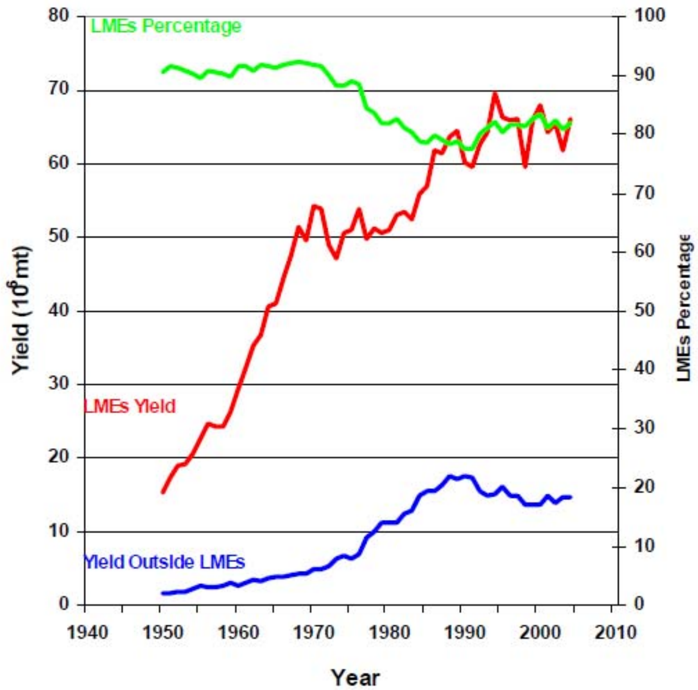

Figure 2. Annual global marine fisheries biomass yields in metric tons of the world's LMEs. Green line = percentage of the world catch. Red line = the biomass yield trend in all LMEs together. Blue line = biomass yield trend from areas outside LMEs. From the University of British Columbia's Sea Around us Project.

METHODS

Fisheries biomass yields are not presented here as representative of individual fish stock abundances. They are representative of fisheries catches and are used here to compare the effects of global warming on the fishery biomass yields of the World's LMEs. The comparative analysis of global temperature trends, fisheries biomass yields, and primary productivity is based on available time-series data at the LME scale on sea surface temperatures, marine fisheries biomass yields, and SeaWiFS-derived primary productivity values.

LME Sea Surface Temperatures (SST)

Sea surface temperature (SST) data is a thermal parameter routinely measured worldwide. Subsurface temperature data, albeit important, are limited in the spatial and temporal density required for reliable assessment of thermal conditions at the Large Marine Ecosystem (LME) scale worldwide. The U.K. Meteorological Office Hadley Center SST climatology was used in this analysis (Belkin 2009), as the Hadley data set has resolution of 1 degree latitude by 1 degree longitude globally. A detailed description of this data set has been published by Rayner et al. (2003). Mean annual SST values were calculated for each 1° x 1° cell and then were area-averaged by annual 1° x 1° SSTs within each LME. Since the square area of each trapezoidal cell is proportional to the cosine of the middle latitude of the given cell, all SSTs were weighted by the cosine of the cell's middle latitude. After integration over the LME area, the resulting sum of weighted SSTs was normalized by the sum of the weights, that is, by the sum of the cosines. Annual anomalies of annual LME-averaged SST were calculated. The long-term LME-averaged SST was computed for each LME by a simple long-term averaging of the annual area-weighted LME-averaged SSTs. Annual SST anomalies were calculated by subtracting the long-term mean SST from the annual SST. Both SST and SST anomalies were plotted using adjustable temperature scales for each LME to depict temporal trends. Comparisons of fisheries biomass yields were examined in relation to intervals of 0.3°C of increasing temperature.

LME Primary Productivity

The LME primary productivity estimates are derived from satellite borne data of NOAA's Northeast Fisheries Science Center, Narragansett Laboratory. These estimates originate from SeaWiFS (satellite-derived chlorophyll estimates from the Sea-viewing Wide Field-of-view Sensor), Coastal Zone Color Scanner (CZCS), a large archive of *in situ* near-surface chlorophyll data, and satellite sea surface temperature (SST) measurements to quantify spatial and seasonal variability of near-surface chlorophyll and SST in the LMEs of the world. Daily binned global SeaWiFS chlorophyll *a* (CHL, mg m^{-3}), normalized water leaving radiances, and photosynthetically available radiation (PAR, Einsteins m^{-2} d^{-1}) scenes at 9 km resolution for the period January 1998 through December 2006 were obtained from NASA's Ocean Biology Processing Group. Daily global SST (^{o}C) measurements at 4 km resolution were derived from nighttime scenes composited from the AVHRR sensor on NOAA's polar-orbiting satellites and from NASA's MODIS TERRA and MODIS AQUA sensors. Daily estimates of global primary productivity (PP, gC m^{-2} d^{-1}) were calculated using the Ocean Productivity from Absorption and Light (OPAL) model, a derivative of the model first formulated in Marra et al. (2003). The OPAL model generates profiles of chlorophyll estimated from the SeaWiFS chlorophyll using the algorithm from Wozniak et al. (2003) that uses the absorption properties in the water column to vertically resolve estimates of light attenuation in approximately 100 strata within the euphotic zone. Productivity is calculated for the 100 layers in the euphotic zone and summed to compute the integral daily productivity (gC m^{-2} d^{-1}). Monthly and annual means of primary productivity (PP) were extracted and averaged for each LME. Significance levels (alpha=0.01 and 0.05) of the regression coefficients of the nine years of Sea WiFS mean annual primary productivity data were determined using a t-test according to Sokal and Rohfl (1995). Time series trends plotted for each LME are available online (www.lme.noaa.gov).

Fisheries Biomass Yield Methods

Prior to the *Sea Around Us Project*, projections of marine fisheries yields at the LME scale, were largely defined by the range of vessels exploiting a given resource (Pauly and Pitcher 2000). The need for countries to manage fisheries within EEZ's (Exclusive Economic Zones) under UNCLOS (UN Convention of the Law of the Sea) initiated efforts to derive fisheries yields at the national level (Prescott-Allen 2001) and consistent with the emergence of ecosystem-based management at the LME scale (Sherman, O'Reilly et al. 2003) (Pauly, Alder et al. 2008). The time series of fisheries biomass yields (1950-2004) used in this study are based on the time-series data provided at the LME scale by the Sea Around Us Project at the University of British Columbia (Pauly, Alder et al. 2008) The method used by the Sea Around Us Project to map reported fishery catches onto 180,000 global spatial cells of ½ degrees latitude and longitude was applied to produce profiles of 54-yr. mean annual time-series of catches (biomass yields) by 12 species or species groups for the world's LMEs (Watson, Pauly et al. 2003; Pauly, Alder et al. 2008). In addition, plots on the status of the stocks within each of the LMEs according to their condition (e.g. undeveloped, fully exploited and overexploited) in accordance with the method of Froese and Kesner-Reyes (2002), and illustrated by Pauly et al. (2008), were used to examine trends in yield condition among the LMEs. Fisheries biomass yields were examined in relation to warming trends for 63 LMEs for the period 1982 to 2004. Fisheries biomass yield trends were plotted for each LME using the LOESS smoothing method (tension=0.5) and the emergent increasing and decreasing patterns examined in relation to LME warming data (Cleveland and Devlin 1988). Observed trends were compared to earlier studies for emergent spatial and temporal global trends in LME fishery biomass yields.

RESULTS

Comparative SST Clusters

The LME plots of SST and SST anomalies are presented in two sets of four plates, with each set containing a total of 63 figures: four plates for SST and four plates for SST anomalies 1957-2006. These can be viewed at www.lme.noaa.gov. The Arctic Ocean LME was not included in this analysis because of the perennial sea ice cover. Other Arctic LMEs also feature sea ice cover that essentially vanishes in summer, thus making summer SST assessment possible. The 1957-2006 time series revealed a global pattern of long-term warming. However, the long-term SST variability since 1957 was not linear over the period. Specifically. most LMEs underwent a cooling between the 1950s and the 1970s, replaced by a rapid warming from the 1980s until the present. Therefore we re-calculated SST trends using only the last 25 years of data (SST data available at www.lme.noaa.gov, where SST anomalies are calculated for each LME).

The most striking result is the consistent warming of LMEs, with the notable exceptions of two, the California Current and Humboldt Current. These LMEs experienced cooling over the last 25 years. Both are in large and persistent upwelling areas of nutrient rich cool water in the Eastern Pacific. The SST values were partitioned into 0.3°C intervals to allow for comparison among LME warming rates. The warming trend observed in 61 LMEs ranged from a low of 0.08°C for the Patagonian Shelf LME to a high of 1.35°C in the Baltic Sea LME. The relatively rapid warming exceeding 0.6°C over 25 years is observed almost exclusively in moderate- and high-latitude LMEs. This pattern is generally consistent with the model-predicted polar-and-subpolar amplification of global warming (IPCC 2007). The warming in low-latitude LMEs is several times slower than the warming in high-latitude LMEs. In addition to the Baltic Sea, the most rapid warming exceeding 0.96°C over 25 years is observed in the North Sea, East China Sea, Sea of Japan/East Sea, and Newfoundland-Labrador Shelf and Black Sea LMEs.

Comparisons of warming were made among three temperature clusters of LMEs.

1) **Super fast warming** LMEs with D(SST) between >0.96°C -1.35°C
2) **Fast warming** LMEs .67°C – 0.84°C.
3) **Moderate warming** LMEs have D(SST) between >0.3-0.6°C;
4) **Slow warming** LMEs, have D(SST) between 0.0°C-0.28°C. If super-fast warming LMEs are combined with fast warming LMEs (0.67°C to 1.35°C), 18 are warming at rates two to four times higher than the global air surface temperature increase of 0.74°C for the past 100 years as reported by the IPCC (2007) (Figure 3 and Annex 1).

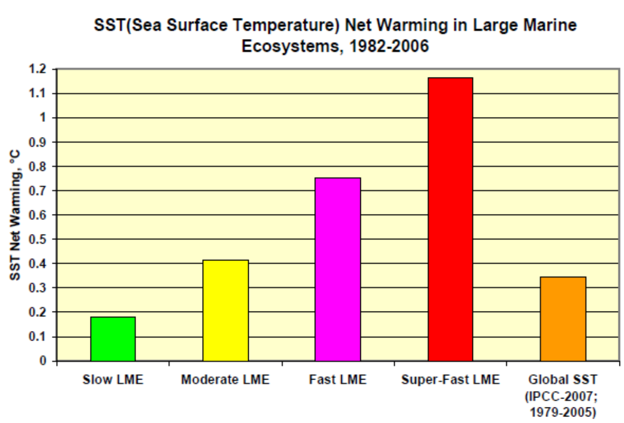

Figure 3. Comparison of SST warming rates in Large Marine Ecosystems 1982-2006 (Belkin 2009). The fast and super-fast warming LMEs (pink and red bars respectively) warmed approximately two-to-four times faster than the global ocean as a whole (beige bar), while the slow LMEs (green bar) warmed more slowly than the global ocean. All estimates of warming rates are based on the best available global SST climatology produced by the U.K. Meteorological Office, Hadley Centre.

Primary Productivity

No large scale consistent pattern of either increase or decrease in primary productivity was observed. Of the 64 LMEs examined, only four 9-year trends were significant (P<0.05). Primary productivity declined in the Bay of Bengal, and increased in the Hudson Bay, Humboldt Current and Red Sea LMEs). The general declining trend in primary productivity with ocean warming reported by Behrenfeld (2006) was limited to the Bay of Bengal LME. No consistent trend among the LMEs was observed. However, as previously reported (Nixon, Oviatt et al. 1986; Ware and Thomson 2005; Chassot, Mélin et al. 2007) fisheries biomass yields did increase with increasing levels of primary productivity (P<0.001) in all 63 LMEs, and for LMEs in each of the warming clusters (Figure 4).

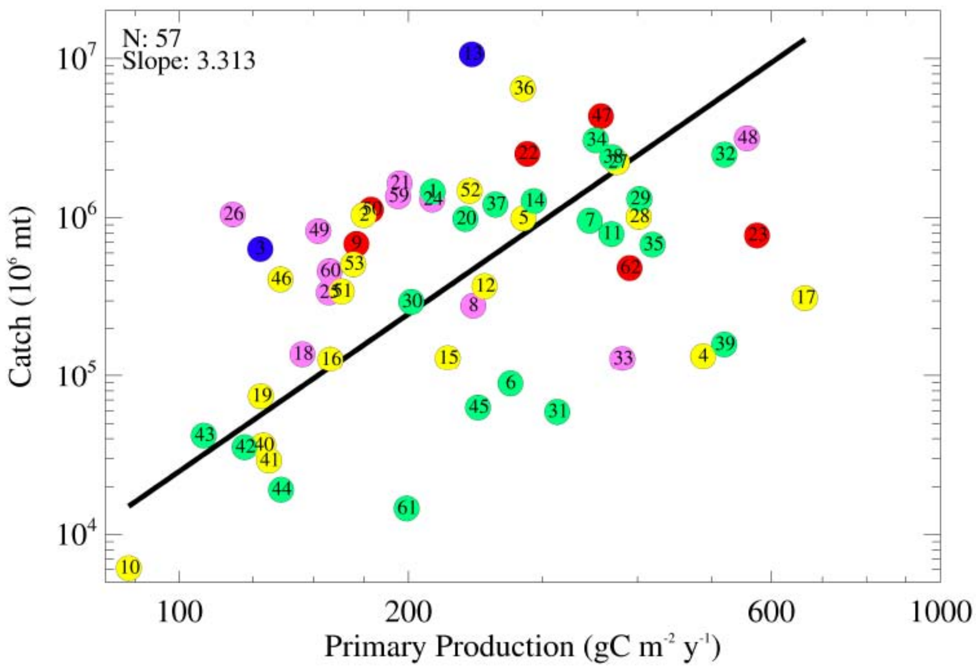

Figure 4. Positive correlation of 5-yr. mean annual fisheries biomass yield with 9-yr. mean annual primary production in fast warming (red), moderately warming (yellow) and slower warming (green) LMEs. The two blue circles represent cooling LMEs. P<0.001.

Fisheries biomass yield trends

The effects of warming on global fisheries biomass yields were non-uniform in relation to any persistent global pattern of increasing or decreasing yields. The relationship between change in LME yield and SST change was not significant; the slight suggestion of a trend in the regression, was influenced by the data for the Humbolt LME. The results on trends in fisheries biomass yieldsdivided the LMEs into two groups. Increasing yields were observed in

31 (49.2 percent) and decreasing trends in 32 (50.8%) of LMEs. Differences were similar in fast warming (eight increasing, ten decreasing) and moderate warming LMEs (ten increasing, eight decreasing). In the slower warming LMEs, most (14) were undergoing increasing biomass yields and 6 were in a decreasing condition. Linear warming trends from 1982 to 2006 for each LME were distributed in distinct global clusters, 1) the fast warming LME clusters were in the Northeast Atlantic, African and Southeast Asian waters; 2) the moderate warming LMEs were clustered in the Atlantic and North Pacific waters; and 3) the slow warming LME clusters were located principally in the Indian Ocean, and also in locations around the margins of the Atlantic and Pacific Oceans (Figure 5).

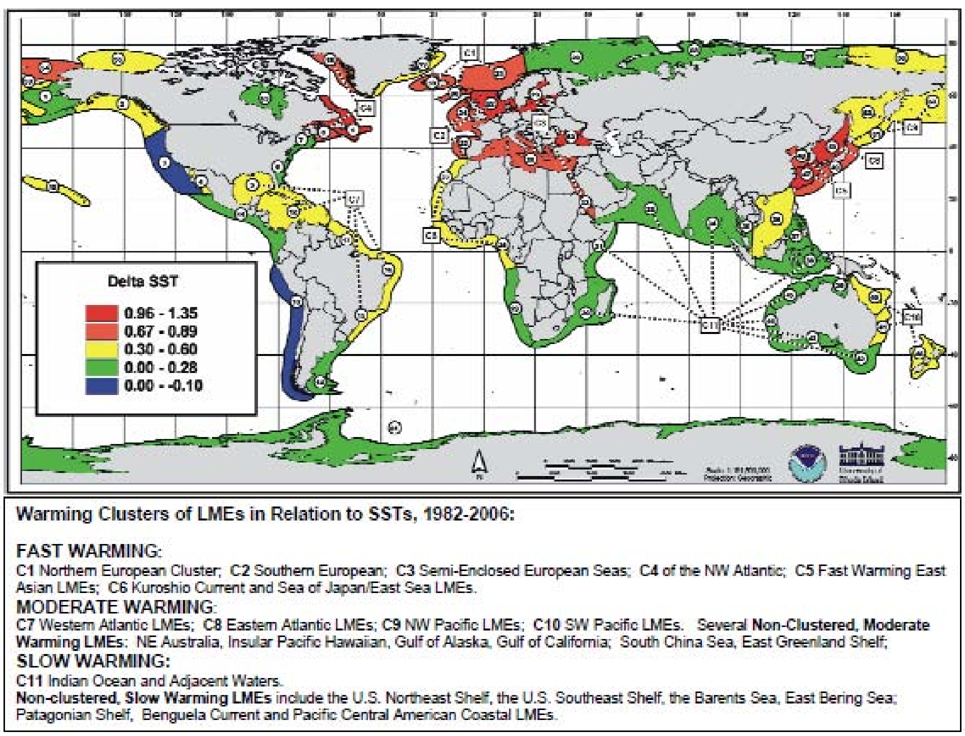

Figure 5. Map showing Warming Clusters of LMEs in relation to SSTs, 1982-2006

Comparative fisheries biomass yields in relation to warming: Fast warming European LMEs

In the **Norwegian Sea, Faroe Plateau, and Iceland Shelf,** the fisheries biomass yield is increasing. These three LMEs account for 3.4 million tons, or 5% of the world biomass catch (Figure 6). This cluster of LMEs is influenced from bottom-up forcing of increasing zooplankton abundance and warming hydrographic conditions in the northern areas of the North Atlantic, where stocks of herring, blue whiting and capelin are benefiting from an expanding prey field of zooplankton (Beaugrand, Reid et al. 2002; Beaugrand and

Ibanez 2004) supporting growth and recruitment of these three species. The warming trend in the Norwegian Sea driving the increase in biomass of herring, capelin and blue whiting yields has been reported by (Skjoldal and Saetre 2004). On the Faroe Plateau LME, Gaard et al. (2002) indicate that the increasing shelf production of plankton is linked to the increased production of fish and fisheries in the ecosystem. Astthorsson and Vilhjálmsson (2002) have shown that variations of zooplankton in Icelandic waters are greatly influenced by large scale climatic factors and that warm Atlantic water inflows favor zooplankton that supports larger populations of capelin that serve as important prey of cod. The productivity and fisheries of all three LMEs are benefiting from the increasing strength of the sub-Polar gyre bringing warmed waters to the LMEs of the region generally in the northern northeast Atlantic and contributing to decreasing production and fisheries yields in the relatively warmer southern waters of the northeast Atlantic (Richardson and Schoeman 2004).

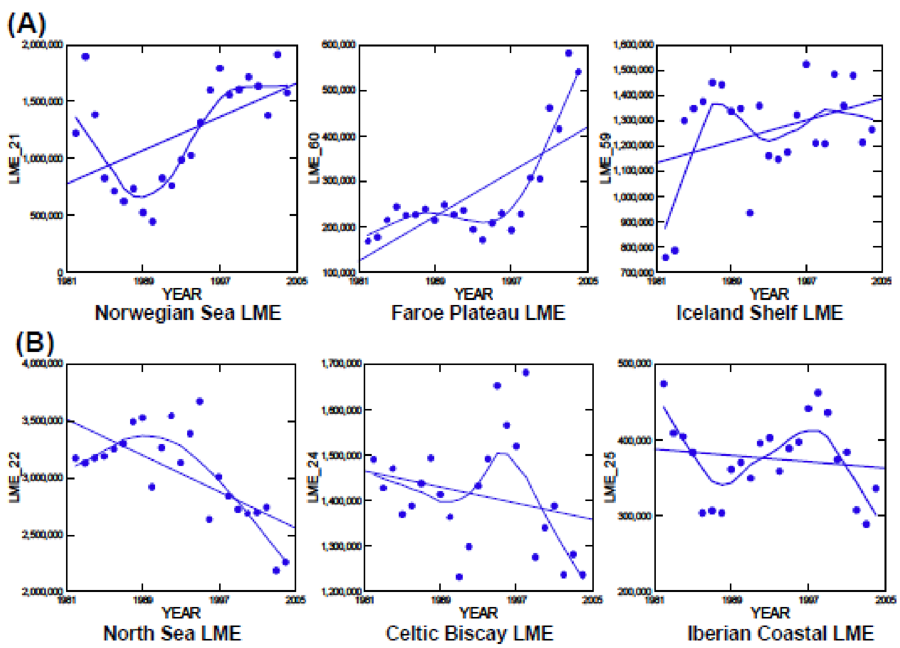

Figure 6. Fast Warming LMEs and biomass yield trends for the increasing European Northern (Cluster 1) [Norwegian Sea LME, Faroe Plateau LME, Iceland Shelf LME] and the declining European Southern (Cluster 2) biomass yield trends [North Sea LME, Celtic Biscay LME and Iberian Coastal LME]

In southern Europe three LMEs, the **North Sea, Celtic Biscay, and Iberian Coastal LMEs** in fast warming clusters are experiencing declines in biomass trends representing 4.1 mmt (6.4 percent) of the mean annual global biomass yield (Figure 6). It has been reported that zooplankton abundance levels in the three LMEs are in decline, reducing the prey field for zooplanktivores (Beaugrand, Reid et al. 2002; Valdés and Lavin 2002; Valdés, López-Urrutia et al. 2007). Although we did not detect any significant decline in primary productivity in the three LMEs, the declining phytoplankton level in the region (Richardson and Schoeman 2004) is consistent with the declines in primary productivity in warming ocean waters reported by Behrenfeld (2006). The fisheries biomass yields of 80 percent of the targeted species are in an overexploited or fully exploited condition, suggesting that the observed decline in biomass yield of pelagic species is related to both heavy exploitation and warming.

The three semi-enclosed European LMEs, the **Mediterranean, the Black Sea, and the Baltic Sea,** and the adjacent area of the **Red Sea**, are surrounded by terrestrial areas and are fast warming, with heavy fishing as a dominant feature. The four LMEs contribute 2.4 million metric tons (3.7%) of the mean annual global biomass yield. In three European LMEs, the fisheries biomass trend is decreasing, while in the Red Sea it is increasing. In the case of the **Black Sea**, the fisheries biomass is severely depleted, with 85percent of fisheries stocks overexploited due to heavy fishing and a trophic cascade (Daskalov 2003). In the Baltic Sea, Red Sea and Mediterranean Sea LMEs, 78 percent of the stocks are in a fully exploited condition. Mixed species dominate in the **Red Sea,** where 88 percent of the species fished are fully exploited and 10 percent are overexploited. It appears that heavy exploitation is the dominant driver of the biomass trends observed in all four LMEs.

Fast warming clusters of the Northwest Atlantic (C4) LMEs and the Asian (C5, C6) LMEs

The three LMEs in this region contribute 1.1 million metric tons (1.7percent) to the global biomass yield. In two LMEs of the Northwest Atlantic, the downward trends in fisheries yield have been attributed to the cod collapse in the **Newfoundland-Labrador Shelf** (Rice 2002), and to the cod collapse and collapse of other demersal fisheries in the **Scotian Shelf** LME from excessive fishing mortality (Choi, Frank et al. 2004; Frank, Petrie et al. 2005). In the **West Greenland Shelf LME,** where the cod stock has collapsed from excessive fishing mortality, there is a recent increase in the landings of shrimp and other species (Aquarone and Adams 2008) .

Biomass yields of the fast warming LMEs of East Asian Seas

The 7.5 million metric tons biomass yields of the **Yellow Sea and East China Sea LMEs** constitute 11percent of the global yield. In both LMEs, yields are increasing. The principal driver of the increase is food security to accommodate the needs of the People's Republic of China and Korea (Tang and Jin 1999; Zhang and Kim 1999; Tang 2003; Tang 2006). Biomass yields are dominated by heavily fished "mixed" species. Seventy percent or more of the species constituting the yields are fully exploited or overexploited, suggesting that the principal driver of increased biomass yields is full exploitation rather than global warming.

The fast warming **Kuroshio Current and Sea of Japan/East Sea LMEs** show declining fisheries trends. They contribute 1.9 million metric tons (2.9 percent) to the global marine fisheries yield. For these two LMEs, exploitation levels are high with 90 percent of the species in a fully exploited to overexploited condition. The fisheries are also subjected to periodic oceanographic regime shifts affecting the abundance of biomass yields (Chavez, Ryan et al. 2003). Among the fast warming East Asian Seas LMEs, no analysis has been conducted for the ice-covered **Chukchi Sea LME**, as the data is limited and of questionable value.

Moderate Warming Western Atlantic LMEs (C7), Eastern Atlantic (C8) LMEs, and LMEs of the Asian Northwest Pacific region

A large cluster of moderately warming LMEs can be found in the Trade Winds region of the Atlantic Ocean. This is an important cluster of LMEs contributing 5.1 million metric tons (7.9 percent) to the mean annual global biomass yield. Five LMEs are clustered in the Western Atlantic, and two in the Eastern Atlantic. In the West Atlantic Ocean, the **Gulf of Mexico LME** fisheries biomass yields are decreasing, while in the **Caribbean, North Brazil, East Brazil, and South Brazil Shelf LMEs** fisheries biomass yields are increasing.

The fisheries biomass yield trends in the Atlantic Ocean region appear to be driven principally by heavy exploitation rather than climate warming. The Caribbean, North Brazil, and East Brazil Shelf LMEs are in a fully exploited and over-exploited fisheries condition equal to or greater than 88 percent of the stocks. In the South Brazil Shelf, 60 percent of fisheries are fully exploited or overexploited. The East Brazil Shelf and South Brazil Shelf LMEs are dominated by small pelagics and/or "mixed species"

The two LMEs of the Eastern Atlantic are important sources of food security to the over 300 million people of West African countries adjacent to the LMEs. The **Canary Current and the Guinea Current** are showing increasing trends in biomass yield with "mixed species" dominant (Heileman 2008). The fisheries stocks in both LMEs are at risk. Oceanographic perturbations are also a source of significant variability in biomass yields in the Guinea Current (Hardman-Mountford and McGlade 2002; Koranteng and McGlade 2002) and in the waters of the Canary Current LME (Roy and Cury 2003)(www.thegef.org, IW Project 1909).

Three LMEs, the **Sea of Okhotsk,** the **Oyashio Current,** and the **West Bering Sea**, contribute 2.3 million metric tons (3.5 percent) to the mean annual global biomass yield. They are in a condition where 78 percent of the fisheries stocks are overexploited. The **Oyashio Current** and the **West Bering Sea LMEs** show decreasing trends in fisheries yields. In the Sea of **Okhotsk**, the biomass yields are dominated by targeted table fish including pollock and cod. The increasing yield trend in the **Sea of Okhotsk LME** is related principally to a high level of overexploitation (Shuntov, Dulepova et al. 1999).

Moderately warming Southwest Pacific LMEs (C10) and other Non-clustered, moderately warming LMEs

The three moderately warming LMEs, two on the east coast of Australia **(Northeast and East Central Australia LMEs)** and the **New Zealand Shelf LME,** contribute 0.4 million metric tons (0.7 percent) to the mean annual global biomass yield. Biomass yields are decreasing in the Australian LMEs, whereas they are increasing in the New Zealand Shelf LME under the present condition of full exploitation. Whether their conditions are the result of top down or bottom up forcing is not clear. However, Individual Transferable Quota (ITQ) management to promote the recovery and sustainability of high priority fisheries stocks is in place. Stewardship agencies in Australia and New Zealand have implemented management actions for the recovery and sustainability of the overexploited species.

Six moderately warming LMEs occur in separate locations. Taken together they contribute 7.7 million metric tons (11.8 percent) to the mean annual global biomass yields. In the **Pacific,** landings are too low in the moderately warming **Insular Pacific Hawaiian LME** to draw any conclusion on biomass yield. In the moderate warming **Gulf of Alaska LME**, the overall 25-year fisheries biomass trend is decreasing. However, this LME shows evidence of a relatively recent upturn in yield, attributed to increases in biomass of Pacific salmon populations in response to climate warming (Overland, Boldt et al. 2005).

The biomass of the moderately warming **Gulf of California LME** is in a declining trend. The dominant biomass yield in this LME is from small pelagics and "mixed species," suggestive of top down fishing as the principal driver of the decline. The **South China Sea** fisheries biomass yields are increasing. The dominant biomass yield of the LME is of "mixed species" and the level of exploitation is high with 83 percent fully exploited and 13 percent overexploited. In this case, high population demand for protein by the adjacent countries contributes to drive the biomass yield upward.

The **Arctic** region's **Beaufort Sea LME**, landings data are unavailable. The moderate warming **East Greenland Shelf** fisheries biomass yields are increasing with capelin, redfish and shrimp dominant; following the earlier collapse of cod and other demersal species. The role of global warming in relation to cause and effect of increasing yields is not known.

Slow Warming Indian Ocean and Adjacent LMEs (C11)

The ten LMEs of the Indian Ocean, **Arabian Sea, Bay of Bengal, Indonesian Sea, Agulhas Current, Somali Current, North Australia, West**

Central Australia, Northwest Australia, Southeast Australia and Southwest Australia LMEs are in the slow range of climate warming and their biomass trends are all increasing. This group of LMEs contributes 8.6 million metric tons, or 13.2 percent of the global biomass yield. The slow warming is consistent with the IPCC forecast of slow but steady warming of the Indian Ocean in response to climate change (IPCC 2007). While biomass yields are increasing, the landings adjacent to developing countries are composed primarily of mixed species and small pelagics (Heileman 2008) and the stocks are predominantly fully exploited and/or overexploited, suggesting that top down fishing is the predominant influence on the condition of biomass yield.

In the adjacent Southwest Pacific waters, the slow warming **Sulu-Celebes** and **Gulf of Thailand** LMEs contribute 1.8 million metric tons (2.8 percent) to the mean annual global biomass yield.

The consistent pattern of increasing yields of the Indian Ocean LMEs adjacent to developing countries is driven principally by the demand for fish protein and food security (Ahmad, Ahmed et al. 1998; Dwivedi and Choubey 1998). In the case of the 5 LMEs adjacent to Australia, the national and provincial stewardship agencies are promoting stock recovery and sustainable management through ITQs. The fisheries stocks in the LMEs adjacent to developing countries are under national pressure to further continue to expand the fisheries to provide food security for the quarter of the world's population inhabiting the region. Given the demands on fisheries for food security for the developing countries bordering the Indian Ocean, there is a need to control biomass yields and sustain the fisheries of the bordering African and Asian LMEs.

Other slow warming LMEs:
The Northwest Atlantic and the United States East Coast, Barents Sea, East Bering Sea, Patagonian Shelf, Benguela Current, and Pacific Central American Coastal LMEs

There is slow warming taking place in the Northeast US Shelf and in the Southeast US Shelf. The LMEs contribute 1.0 million metric tons (1.6 percent) to the mean annual global marine biomass yield. For both LMEs, the declines are attributed principally to overfishing (NMFS 2006) For these two LMEs and the Gulf of Mexico, the Gulf of Alaska, the East Bering Sea, Chukchi Sea, Beaufort Sea, Insular Pacific Hawaiian Islands, and the Caribbean, the United States has underway a fisheries stock rebuilding program for increasing the spawning stock biomass of overfished species (NMFS 2007).

For several of the slow warming LMEs bordering the Arctic including the Laptev Sea, Kara Sea, East Siberian Sea and Hudson Bay, biomass yield data is at present incomplete and is not included in the trend analyses. In the case of the **Barents Sea LME**, there is a decreasing biomass trend attributed to the over-exploited condition of many fish stocks inhabiting the LME. During the present warming condition, variability in ice cover has an important influence on biomass yields (Matishov, Denisov et al. 2003).

Four widely separated LMEs, the **East Bering Sea**, the **Patagonian Shelf**, **Benguela Current,** and **Pacific Central American LMEs** are located in slow warming waters. Together they contribute 3.3 million metric tons (5.1 percent) to the mean annual global biomass yield. In the North Pacific Ocean, the slow warming East Bering Sea has an overall decline in fisheries biomass yield. However, in recent years there has been an upturn in yield, attributed to climate warming and increases in biomass of Alaska Pollock and Pacific Salmon populations (Overland, Boldt et al. 2005). In the Southwest Atlantic Ocean Patagonian Shelf LME, increasing biomass yields are reflective of a very high level of fisheries exploitation, overshadowing any climate change effects, where 30 percent of fisheries are fully exploited, and 69% are overexploited. The increasing biomass trends of the Pacific Central American Coastal LME are the result of high levels of exploitation driven principally by the need for fish protein and food security of the adjacent developing countries and secondarily by oceanographic regime shifts (Bakun, Csirke et al. 1999).

The biomass yields of the Benguela Current (BCLME), southwest African coast are in a declining trend. The living resources of the BCLME have been stressed by both heavy exploitation and environmental perturbations during the past 25 years (van der Lingen, Freon et al. 2006) The southwestward movement of sardines (Sardinella) populations from the coastal areas off Namibia to southeastern South Africa has been attributed to recent warming. The southerly migration has disrupted the Namibian fisheries. A further southerly movement of sardines and anchovies from the vicinity of island colonies of African penguins off South Africa led to a decrease in availability of small pelagic fish prey of penguins resulting in a 40 percent penguin population decline (Koenig 2007).

Discussion

Emergent trends

From the analysis, we conclude that in four LME cases the warming clusters of LMEs are influencing 7.5 million metric tons or 11.3 percent of the world's fisheries biomass yields. The first and clearest case for an emergent effect of global warming on LME fishery yields is in the increasing biomass yields of the fast warming temperature clusters affecting 3.4 million metric tons (5.0 percent) of global yields for the Iceland Shelf, Norwegian Sea, and Faroe Plateau LMEs in the northern Northeast Atlantic. Warming in this region has exceeded levels expected from entering the warm phase of the Atlantic Multi-decadal Oscillation ((Trenberth and Shea 2006). The increase in zooplankton is related to warming waters in the northern areas of the Northeast Atlantic (Beaugrand, Reid et al. 2002) leading to improved feeding conditions of three zooplanktivorous species that are increasing in biomass yields. Herring, blue whiting, and capelin yields are increasing in the Iceland Shelf and Norwegian Sea LMEs, and blue whiting yields are increasing in the Faroe Plateau LME.

The second case is in the contrasting declines in biomass yields of the fast warming cluster of more southern Northeast Atlantic waters including the North Sea, the Celtic-Biscay Shelf, and Iberian Coastal LME where declines in warm water plankton (Valdés, López-Urrutia et al. 2007) and northward movement of fish (Perry, Low et al. 2005) are a negative influence on 4.1 million metric tons (6.3 percent) of the mean annual global biomass yields. Recent investigations have found that SST warming in the northeast Atlantic is accompanied by increasing zooplankton abundance in cooler more northerly areas, and decreasing phytoplankton and zooplankton abundance in the more southerly warmer regions of the northeast Atlantic in the vicinity of the North Sea, Celtic-Biscay Shelf and Iberian Coastal LMEs (Richardson and Schoeman 2004). Due to tight trophic coupling fisheries are adversely affected by shifts in distribution, reduction in prey and reductions in primary productivity generated by strong thermocline stratification inhibiting nutrient mixing (Behrenfeld, O'Malley et al. 2006).

In the third case, recent moderate warming of the Gulf of Alaska, and slow warming of the East Bering Sea are supporting increasing levels of zooplankton production and recent increasing biomass yields of Pacific Salmon (Hunt, Stabeno et al. 2002; Overland, Boldt et al. 2005; Grebmeier, Overland et al. 2006).

The biomass yields of the fourth case are more problematic. Biomass yields of all 10 LMEs (8.6 million metric tons) (13.2 percent) around the western and central margin of the **Indian Ocean** are increasing. The increasing yields of the five LMEs adjacent to developing countries, the Agulhas Current, Somali Current, Arabian Sea, Bay of Bengal and Indonesian Sea are dominated by mixed species and small pelagic species, driven by the fish protein and food security needs of nearly one quarter of the world's population inhabiting the bordering countries of Africa and Asia (Heileman and Mistafa 2008). The overexploited condition of most species is at present masking any gains in biomass yield that may be attributed to the slow and steady warming of waters predicted for the Indian Ocean by the IPCC (2007) and observed during the present study. In contrast, the slow warming five Australian LMEs on the eastern margin of the Indian Ocean are driven principally by economic considerations and are closely monitored by governmental stewardship agencies that practice an adaptive management system of Individual Transferable Quotas (Aquarone and Adams 2008). Taken together, the 8.6 million metric tons mean annual biomass yield of the Indian Ocean LMEs are critical for food security of the heavily populated adjacent countries. In this region there is a need to exercise a precautionary approach (FAO 1995) to recover and sustain the fisheries in the LMEs of east Africa and Asia, in the slow warming clusters.

Precautionary Cap and Sustain Action

From a global perspective 38.2 million metric tons or 58 percent of the mean annual 2001-2006 biomass yields are being produced in 29 LMEs adjacent to developing countries. This vital global resource is at risk from serious overexploitation. Given the importance for sustaining 58 percent of the world's marine fisheries biomass yield, it would be prudent for the GEF supported LME assessment and management projects to immediately cap the total biomass yield at the annual 5-year mean (2000-2004) as a precautionary measure and move toward adoption of more sustainable fisheries management practices. Projections of the effects of global warming indicate reductions in the level of primary productivity in warmer waters of the globe (Behrenfeld and Falkowski 1997; Beaugrand, Reid et al. 2002; Beaugrand and Ibanez 2004; Richardson and Schoeman 2004; Sarmiento, Slater et al. 2004; Schmittner 2005) (Annex 2).

The management strategies for protecting the 26.8 million metric tons or 42 percent of global marine biomass yields in LMEs adjacent to the more developed countries have had variable results ranging from highly successful fisheries biomass yield recovery and sustainability actions for stocks in LMEs adjacent to Australia, New Zealand, the United States, Norway, and Iceland to the less successful efforts of the European Union and LMEs under EU jurisdiction in the Northeast Atlantic (Gray and Hatchard 2003). An ecosystem-based cap and sustain adaptive management strategy for groundfish based on an annual overall total allowable catch level and agreed upon TACs for key species is proving successful in the management of the moderately warming waters of the Gulf of Alaska LME and slow warming East Bering Sea LME Alaska Pollock and Pacific Salmon stocks, providing evidence that cap and sustain strategies can serve to protect fisheries biomass yields (Witherell, Pautzke et al. 2000; NPFMC 2002).

In LMEs where primary productivity, zooplankton production and other ecosystem services are not seriously impaired, exploited, overexploited and collapsed stocks as defined by Pauly and Pitcher (2000) can be recovered where the principal driver is excessive fishing mortality and the global warming rates are moderate or slow. The principal pelagic and groundfish stocks in the slow warming US Northeast Shelf ecosystem have been targeted for rebuilding from the depleted state of the 1960s and 1970s by the New England Fisheries Management Council and the Mid Atlantic Fisheries Management Council. In collaboration with NOAA-Fisheries and the results of productivity and fisheries multi-decadal assessment surveys it was concluded that the principal driver of the declining trend in biomass yield was overfishing. Reductions in foreign fishing effort in the 1980s resulted in the recovery of herring and mackerel stocks.

Further reductions in US fishing effort since 1994 initiated recovery of spawning stock biomass of haddock, yellowtail flounder and sea scallops. Similar fish stock rebuilding efforts are underway in all 10 of the LMEs in the US coastal waters (NMFS 2007).

From our analysis, it appears that the emerging increasing trends in biomass yields can be expected to continue in fast warming LMEs of the northern North Atlantic (Iceland Shelf, Faroe Plateau, Norwegian Sea) and the moderate and slow warming LMEs of the northeast Pacific (Gulf of Alaska, East Bering Sea and the U.S. Northeast Shelf). The countries bordering these LMEs (U.S., Norway, Faroes Islands) have in place sufficiently advanced ecosystem-based capacity to support adaptive assessment and management regimes for maintaining sustainable levels of fishery biomass yields.

Since many countries lack the capacity for conducting annual assessments for a large number of marine fish species, and since the effects of climate warming are uncertain in the observed slow warming and increasing fisheries biomass yields of LMEs adjacent to east Africa and south Asia along the margins of the Indian Ocean, it would be prudent for the bordering countries to implement precautionary action to protect present and future fishery yields with a cap and sustain strategy aimed at supporting long term food security and economic development.

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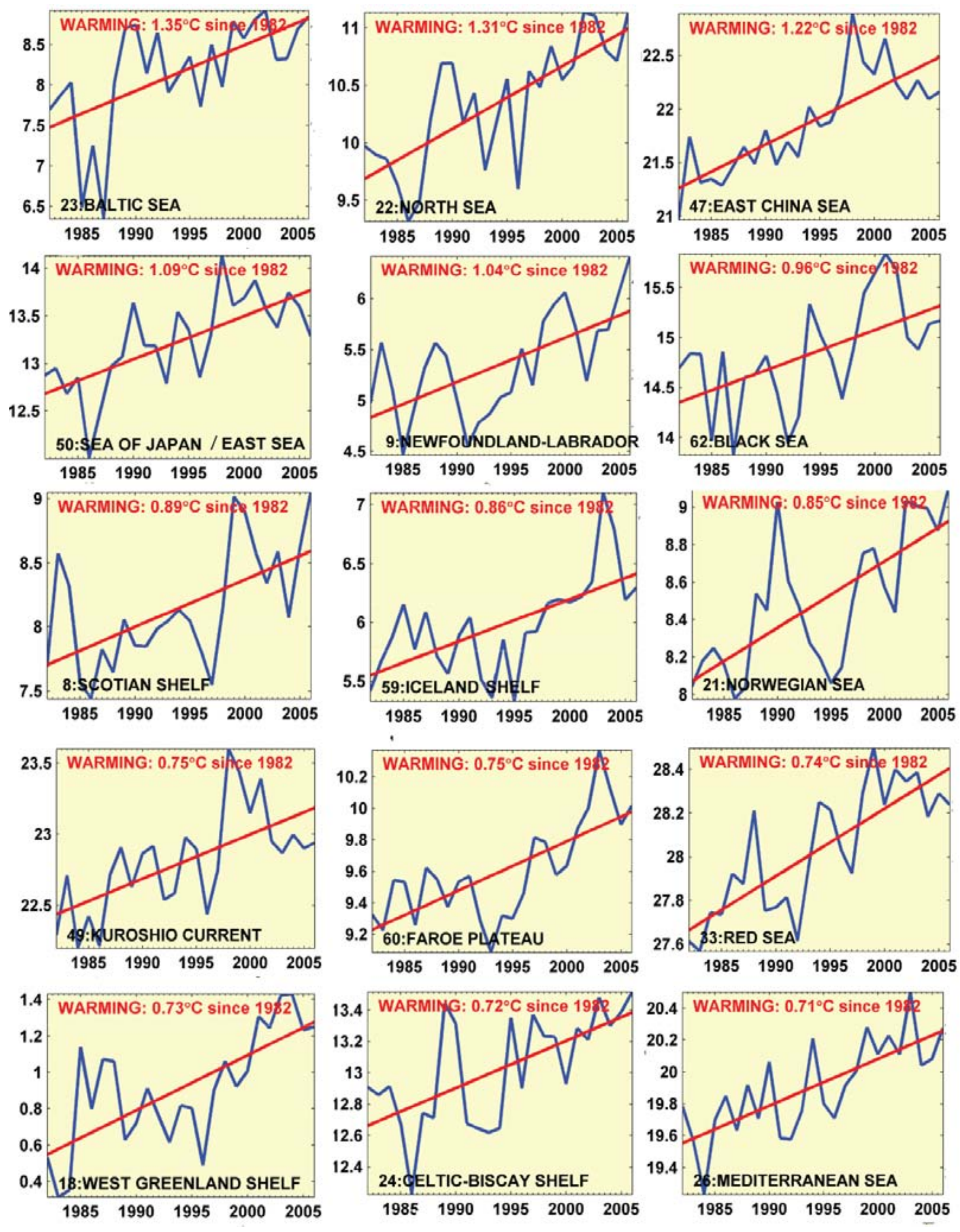
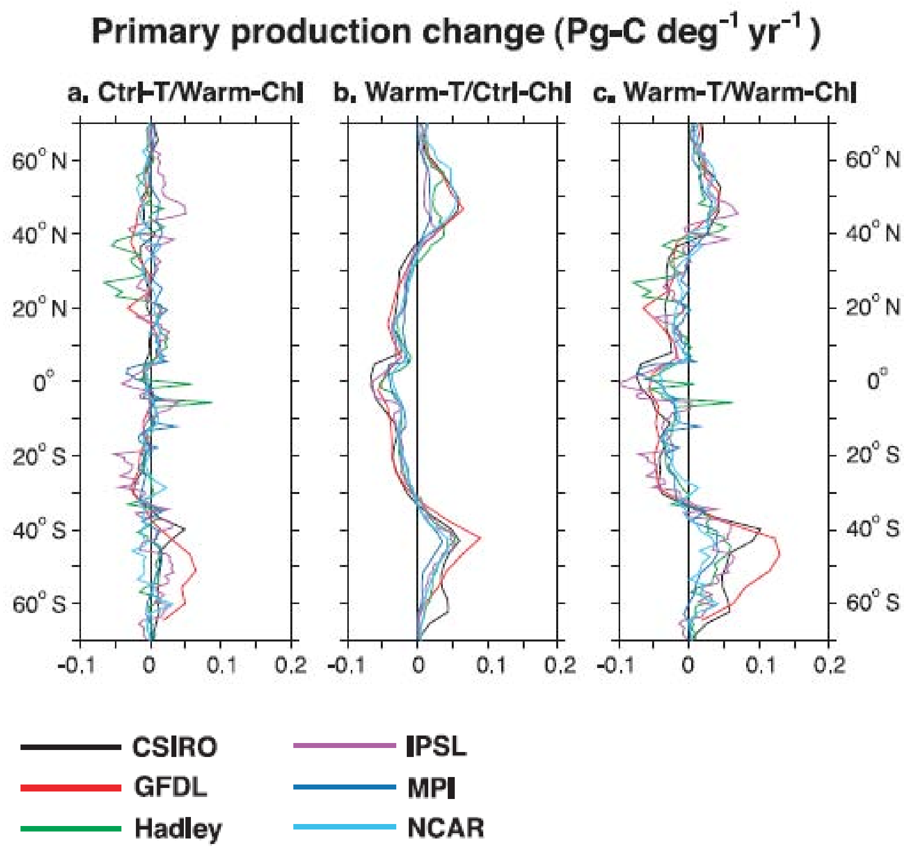
ANNEX 1



Increasing sea surface temperatures in 15 of the fast warming LMEs (1982-2006)

ANNEX 2



Zonally integrated response of primary production calculated with the Behrenfeld and Falkowski [1977] algorithm using chlorophyll calculated from the empirical model (equation (2). The figure shows the difference between the warming and the control simulation for each of the six AOGCMs [Atmosphere-Ocean General Circulation Models] averaged over the period 2040 to 2060 (except for MPI, which is for the period 2040 to 2049). (a) The increase in primary production that occurs in response to the chlorophyll change only, with temperature kept constant at the control scenario. (b) The increase in primary production that occurs in response to the temperature increase only, with chlorophyll kept constant at the control scenario. (c) The increase in primary production that occurs in response to the combined effect of the chlorophyll change and temperature increase.

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Chapter 6

Database-driven models of the World's Large Marine Ecosystems*

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Keywords:
Ecopath with Ecosim; ecosystem model; global modeling; LME.

Abstract
We present a new methodology for database-driven ecosystem model generation and apply the methodology to the world's 66 currently defined Large Marine Ecosystems. The method relies on a large number of spatial and temporal databases, including FishBase, SeaLifeBase, as well as several other databases developed notably as part of the *Sea Around Us* project. The models are formulated using the freely available Ecopath with Ecosim modeling approach and software. We tune the models by fitting to available time series data, but recognize that the models represent only a first-generation of database-driven ecosystem models. We use the models to obtain a first estimate of fish biomass in the world's LMEs. The biggest

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hurdles at present to further model development and validation are insufficient time series trend information, and data on spatial fishing effort.

Introduction

There is a global trend toward ecosystem-based management of marine resources. This is in line with international agreements, most recently as expressed through the Johannesburg and Reykjavik Declarations, and supported by the UN Food and Agricultural Organization through the Code of Conduct for Responsible Fisheries (FAO, 2003). Ecosystem modeling has an important role to play in implementation of ecosystem-based fisheries management through its capabilities to examine ecological, economical and social tradeoff in an integrated manner. Though there has been progress, we are still far from seeing ecosystem models used for management in more than a few of the world's Large Marine Ecosystems (LMEs). LMEs refer to 66 marine ecosystems with unique sets of ecological, oceanographic and biogeochemical characteristics identified by Sherman over the last two decades (Sherman et al., 2005). We attribute the limited application of ecosystem modeling in the LME context to a combination of factors, of which lack of experience may be more important than lack of data. Ecosystem modeling indeed calls for integration and analysis of data from the entire ecosystem, and this can be a daunting task for anyone. Ecosystem models are data hungry, and few models have been fed sufficiently. This is not, generally, because "data are not available", as many believe. Rather, it is a question of realizing what is needed, what is available, and how to best use the data for analysis. Particularly, there are increasing numbers of global databases that greatly help researchers obtain the basic biological and physical parameters to develop ecosystem models. The many training courses that we have conducted around the world have served to build capacity for ecosystem modeling. We have realized, however, that training alone does not suffice; there is considerable work involved in the steps described above, and we here report on a procedure for 'database-driven ecosystem model generation', expected to further enhance the level of ecosystem modeling, as well as to make it more accessible. In this paper, we describe how we link into a large number of spatial and temporal databases describing the world's oceans, their resources, and how the resources are exploited. We extract data from these databases, and use these data to modify a generic ecosystem model in order to obtain ecosystem models for each of the 66 LMEs in the World's oceans. Here we use these models to estimate fish biomass in the world's LMEs, and anticipate that the models will see much further use and enhancement.

Model methodology

The Ecopath with Ecosim (EwE) modeling approach

EwE is an ecosystem modeling approach and software that is being used for ecosystem-based fisheries management throughout the world (see Christensen and Walters, 2005). The approach started out in the early 1980s when Jeff Polovina of the NOAA Pacific Islands Fisheries Science Center in Honolulu was tasked with developing an ecosystem model to integrate information from a major, multi-disciplinary study of productivity in the French Frigate Shoals ecosystem in the Northwestern Hawaiian Islands (Polovina, 1984; Polovina, 1993). Polovina examined the ecosystem models then in use for fisheries research (notably Andersen and Ursin, 1977; and Laevastu and Favorite, 1980), and developed a simple mass-balance model, with the main purpose of evaluating consistency in estimates of production (and by deduction, state variables) for ecosystem components at all trophic levels, as well as to estimate how much demand there was for production (and, again, by deducing state variables) for groups where no estimates of biomass were available. Polovina called his model 'Ecopath', and this quantified food web model has since been further developed to become the most-widely applied approach for ecosystem modeling, with hundred of published models (Morissette, 2007). We have described the modeling approach in many publications over the years, and refer to such for computational details, (e.g., Christensen and Pauly, 1992; Walters et al., 1997; 1999; 2000; Christensen and Walters, 2004; Christensen et al., 2005).

Of special importance here is that we recently have re-developed the approach in an object-oriented programming environment (Christensen and Lai, 2007), a prerequisite for the automated model setup. We rely on being able to call the various components of the EwE modules, read, add, and change parameters, run the various models, make new scenarios etc, all from code, in order to be successful with an undertaking of this scale.

Data sources

We base the database-driven model-generation approach for the world's LMEs on a number of spatial, global databases, the majority of which were and are being developed by the *Sea Around Us* project at the Fisheries Centre of the University of British Columbia (www.seaaroundus.org). The project is designed to document how we exploit the ocean's living resources, the consequences of the exploitation, and what can be done to improve ocean conditions (Pauly, 2007). As part of this the *Sea Around Us* project has developed spatial databases for catches, effort, and prices, and other information related to productivity and fisheries (see below). Here, we build on these databases in combination with the EwE ecosystem modeling approach and software, which is developed as part of the project to construct ecosystem models of each of the world's 66 LMEs.

Given that most of the databases we use for the ecosystem model construction have been developed and described elsewhere, we give here only a very brief introduction to the individual data sources, and we concentrate our description on the aspects that have direct relevance for the model construction. We present an overview of the data sources in Table 1.

Table 1. Data sources and databases used for the database-driven ecosystem model construction. All data sets are digitized and allocated to spatial cells of with either ½° latitude by ½° longitude, or 1° latitude by 1° longitude resolution. Datasets currently available online are indicated.

Topic	Data source, reference
Fish species, growth parameters, diets	FishBase; www.fishbase.org
Non-fish species, growth parameters, diets	SeaLifeBase; www.sealifebase.org
Marine mammal diet	Pauly et al. (1998b), Kaschner (2004)
Marine mammal abundance	Christensen (2006)
Marine bird, abundance, diet and consumption	Karpouzi, 2005, Karpouzi et al., 2007
Primary productivity	Carr (2002), Marra et al. (2003), Behrenfeld and Falkowski (1997), Dunne et al., (in prep.)
Zooplankton biomass	FAO (1972; 1981)
Meio- and macro-benthos biomass	Peters-Mason et al. (unpublished data)
Mesopelagics	Gjøsaeter and Kawaguchi (1980); digitized by Sea Around Us project
Abundance trends for marine populations	Sea Around Us project (unpublished data)
Fisheries catches	Sea Around Us project; www.seaaroundus.org
Off-vessel prices	Sea Around Us project; www.seaaroundus.org

Functional groups and basic parameters

Ecopath, and also the time-dynamic Ecosim model (Walters et al., 1997; Walters et al., 2000) and the time- and spatial-dynamic Ecospace model (Walters et al., 1999), all rely on describing quantified food webs of life in the ocean. For practical reasons (notably due to uncertainty about diets for individual species but also to make the model parameterization more manageable) we aggregate species in 'functional groups,' which may consist of ecologically similar species, of individual species, or of life-stages of individual species or groups of species.

To develop the database-driven models we have cooperated with FishBase (Froese and Pauly, 2009) to define a functional taxonomy for fishes based on their asymptotic length, their feeding habits, and their vertical distribution characteristics. While the information is available from FishBase for splitting the fishes into piscivores, benthivores, and herbivores, we simplify the model parameterization by omitting this classification in the definition of the functional groups. We do, however, consider the feeding habits implicitly when deriving diet compositions for the individual LMEs.

We separate between 'small' species with asymptotic length <30 cm, 'medium' with length 30-89 cm, and 'large' with asymptotic length of 90 cm or more. We further separate between pelagics, demersals, bathypelagics, bathydemersals, benthopelagics, reef fishes, sharks, rays, and flatfishes. We separate invertebrates into cephalopods, other molluscs, krill, shrimps, lobsters and crabs, jellyfishes, zooplankton, megabenthos (>10 mm), macrobenthos (1-10 mm), meiobenthos (0.1-1 mm), and corals, soft corals, sponges, etc. Marine mammals are split into baleen whales, toothed whales, dolphin and porpoises, and pinnipeds (seals and sea lions), and aggregate all seabirds in one functional group. Primary producers are included as phytoplankton and benthic plants.

An overview of the functional groups is presented in Table 2, which also shows the basic (default) input parameters for all groups, as well as indicating the parameters that are supplied as part of the database-driven model-generation. The combined excretion and egestion rate was set to 0.2 (dimensionless) for all groups, apart from zooplankton where 0.4 was used based on experience from many other models (Christensen and Walters, 2004).

Table 2. Functional groupings and basic input parameters for the LME models. B is biomass ($t{\cdot}km^{-2}$), P/B the production/biomass ratio ($year^{-1}$), EE is the (dimensionless) ecotrophic efficiency, P/Q the (dimensionless) production/consumption ratio. The 'e' indicates that the parameter is estimated as part of the mass-balance calculations of Ecopath, '-' indicates a trivial parameter that does not need input (e.g., if P/B and Q/B are given, then P/Q is known), '*' indicates that the parameter in question is obtained from databases as part of the model construction, and 'n.a.' indicates that the parameter is not defined.

	Group name	B	P/B	EE	P/Q
1	Pelagics small	e	0.9 (*)	0.8	0.25
2	Pelagics medium	e	0.5 (*)	0.8	0.25
3	Pelagics large	e	0.3 (*)	0.8	0.2
4	Demersals small	e	1.5 (*)	0.8	0.25
5	Demersals medium	e	0.6 (*)	0.8	0.2
6	Demersals large	e	0.3 (*)	0.8	0.15
7	Bathypelagics small	*	0.5 (*)	-	0.25
8	Bathypelagics medium	e	0.3 (*)	0.8	0.2
9	Bathypelagics large	e	0.1 (*)	0.8	0.2
10	Bathydemersals small	e	0.5 (*)	0.95	0.2
11	Bathydemersals medium	e	0.3 (*)	0.7	0.2
12	Bathydemersals large	e	0.1 (*)	0.85	0.25
13	Benthopelagics small	e	0.6 (*)	0.95	0.25
14	Benthopelagics medium	e	0.4 (*)	0.9	0.25
15	Benthopelagics large	e	0.2 (*)	0.9	0.25
16	Reef fish small	e	1.0 (*)	0.8	0.25
17	Reef fish medium	e	0.6 (*)	0.8	0.2
18	Reef fish large	e	0.3 (*)	0.5	0.15
19	Sharks small medium	e	0.5 (*)	0.9	0.2
20	Sharks large	e	0.2 (*)	0.2	0.15

21	Rays small medium	e	0.4 (*)	0.6	0.2
22	Rays large	e	0.2 (*)	0.8	0.15
23	Flatfish small medium	e	0.8 (*)	0.9	0.25
24	Flatfish large	e	0.3 (*)	0.9	0.15
25	Cephalopods	e	2.0	0.7	0.2
26	Shrimps	e	2.5	0.7	0.3
27	Lobsters crabs	e	2.0	0.9	0.3
28	Jellyfish	0.5	10	e	0.25
29	Molluscs	e	2.0	0.8	0.3
30	Krill	e	5.0	0.9	0.25
31	Baleen whales	*	0.03	e	*
32	Toothed whales	*	0.05	e	*
33	Pinnipeds	*	0.15	e	*
34	Birds	*	0.1	e	*
35	Megabenthos	e	3.0	0.8	0.3
36	Macrobenthos	*	10	e	0.35
37	Corals	0.1	1.0	e	0.67
38	Soft corals, sponges, etc	2	0.2	e	0.2
39	Zooplankton other	e	30	0.9	0.25
40	Phytoplankton	*	*	e	n.a.
41	Benthic plants	2	10	e	n.a.
42	Meiobenthos	4	40	e	0.4
43	Dolphins porpoises	*	0.08	e	*
44	Detritus	100	n.a.	e	n.a.

The ecotrophic efficiencies (EE), in Table 2 for the exploited species are used only for initial parameterization. Once the model-generation procedure is past the initial step, the default EE input would be used to calculate a start biomass. The calculated biomass will subsequently be changed to ensure that the functional group does not crash (i.e., is reduced by 99%) over time when observed catches are removed by subtraction from biomass at each time step, and in order to fit the biomass better using a random optimization search procedure (Christensen and Walters, in prep.). We explain the fitting in more details in the sections “database-driven model generation” and “time series weighting for SS”, below.

We used an assumed diet composition for each functional group as a starting point (Christensen et al., 2008). For each LME, however, we modify the diets through an automated procedure based on diet data extracted from global databases of marine animals, notably, for fish from FishBase and for invertebrates from SeaLifeBase (Palomares and Pauly, 2009), for marine mammals from Pauly et al. (1998b) and Kaschner (2004), and for marine birds from Karpouzi (2005). We refer to these sources for details.

Production rates for exploited groups

To obtain a weighted production/biomass ratio (which for biomass-dynamic groups corresponds to total mortality rate, Z, when there is no biomass accumulation) for each of the exploited functional groups, we develop a simple population dynamics model with monthly time steps for each species (i) represented in the catches. For this, we estimate bodyweight, W_t at age (t, months) based on the von Bertalanffy growth equation,

$$W_{tt} = W_\infty \cdot \left(1 - e^{-K \cdot t}\right)^3$$

where K is the von Bertalanffy metabolic parameter (year^{-1}), and W_∞ is the asymptotic weight (g). The natural mortality rate at age (M_t, year^{-1}) is then estimated from the weight at age, based on Lorenzen (1996) as,

$$M_t = M_u \cdot W_t^{W_b}$$

where M_u is 3.08 at latitudes <30°, 3.13 at latitudes between 30° and 60°, and 1.69 at higher latitudes. The values for W_b are -0.21, -0.309 and -0.292 for the same latitudes, respectively. For each LME we estimate the mean latitude of all cells of a ½ degree latitude by ½ degree longitude grid, and use this for the calculations.

We next assume that the fishing mortality at age (F_t, year^{-1}) in 1950 can be estimated from a logistic function,

$$F_t = \frac{C_{1950}}{C_{\max}} \cdot K \cdot \left(1 - e^{-\boldsymbol{K} \times (\boldsymbol{W_t} - \boldsymbol{a}_0)}\right)^3$$

where C_{1950} is the catch for the species in 1950, C_{max} is the maximum annual catch during 1950-2004 for the species, a_0 is the weight at recruitment to the fishery, here assumed to be $0.1 \cdot W_\infty$. With this, we can now estimate the number at age (N_t) as,

$$\boldsymbol{N_t} = \boldsymbol{N_{t-1}} \cdot \boldsymbol{e}^{-(\boldsymbol{M_t} + \boldsymbol{F_t})/12}$$

by setting $N_1 = 1$ as we only need relative numbers and biomass. The biomass of the age class is estimated as

$$B_t = N_t \cdot W_t$$

For the species (i), we sum up, to get $B_i = \sum_t B_t, M_i = \sum_t M_t \cdot B_t,$ and, $F_i = \sum_t F_t \cdot B_t.$ Next, we want to integrate over species within a functional group. For this, we assume that the contribution of the individual species (i) can be based on their contribution to catches. We acknowledge that this is a very rough assumption, assuming the same catchability and targeting for all species within a group, but see this as the only possible first assumption. It will be possible to modify this assumption later; this is only a first step. We thus estimate the functional group production/biomass ratio, (P/B, year^{-1}) from,

$$P / B = \sum_{i} (C_{i,1950} / F_i) \cdot (F_i + M_i) / \sum_{i} (C_{i,1950} / F_i)$$

which is simply a weighted average of $F_i + M_i$, with each (i) weighed by $C_{i,1950} / F_i$.

Maximum fishing mortality rates

We estimate an overall natural mortality rate (M, year^{-1}) for each exploited fish species based on Pauly (1980),

$$\ln M = -0.2107 + 0.4627 \cdot \ln T + 0.6757 \cdot \ln K - 0.0824 \cdot \ln W_\infty$$

where T is the ambient temperature (°C), K is the von Bertalanffy curvature parameter (year^{-1}), and W_∞ is the asymptotic weight (g). We weigh the exploited species by their overall catch over time to obtain a weighted natural mortality rate for each exploited functional group.

For each functional group, we then set the maximum allowable fishing mortality, F_{lim}, to four times the natural mortality rate obtained from the Pauly equation. We use F_{lim} as a reference point in Ecosim, so that if the estimated fishing mortality (obtained using a 'conditioned on catch' model forcing procedure where *F = (observed catch)/(model biomass)*) exceeds F_{lim} we limit the fishing mortality to this reference value. This ensures a smooth decline in population size (but not immediate collapse) even if B_{1950} has been underestimated during early steps of the time series fitting procedure. That fitting procedure then seeks to move the population out of the 'crash zone'.

Primary productivity

Ecosim models are sensitive to changes in ecosystem productivity, and we have generally found a need to include both fisheries impact and temporal change in system productivity to reproduce historic abundance trends in ecosystems (Christensen and Walters, 2005). It is therefore extremely important to include changes in system productivity in the models throughout the simulation period. While global, spatial estimates are available from satellites for the recent decade, we do, however, need to use models to obtain estimates going back in time to the start of our simulation, i.e. to 1950, just like we need models to go forward to evaluate impact of climate changes. Fortunately such models are being developed in response to the need to evaluate the impact of climate change, and we here include four different models, though we have only used one set of data to date for the actual simulations conducted.

We used two different modeling approaches to simulate primary production. The first approach uses an empirical model to estimate chlorophyll based on physical properties. This technique, described in detail in Sarmiento et al. (2004), fits observed SeaWiFS (http://oceancolor.gsfc.nasa.gov/SeaWiFS/) chlorophyll data to a function of sea surface temperature, sea surface salinity, maximum winter mixed layer depth, and growing season length for different biogeochemical provinces (Longhurst, 1998), and then uses the empirical fits to predict chlorophyll under varying physical conditions. The resulting chlorophyll values were converted to primary production values based on three different algorithms: Carr (2002), Marra et al. (2003), and Behrenfeld and Falkowski (1997). All three algorithms estimate primary production as a function of surface chlorophyll, light, and temperature. The second modeling approach used was a lower trophic level biogeochemical model run within a coupled atmosphere ocean general circulation model (Dunne et al., in prep.).

Our intention for including four different primary production series (as a starter) is to be able to evaluate different scenarios for how future fish production may be impacted by climate change. We see this as an important use of the database-driven ecosystem models.

The primary production estimates were available on a 1° latitude by 1° longitude basis, with coastal cells excluded. We estimated primary production by LME by averaging the monthly primary production estimates over all cells with estimates within a given LME. We further estimated the average annual primary production by LME by averaging the monthly estimates within each year. In the averaging we did not consider that the cells had variable sizes; since coastal cells were excluded, all cells within an LME will have similar size.

The primary production estimates were obtained as mg $Chl \cdot m^{-3} \cdot day^{-1}$; we assumed this pertained to a water column of 50 meters, and that the average chlorophyll content in phytoplankton was 2.6% by weight of organic carbon (Riemann et al., 1989). We next converted the estimate of g carbon m^{-2} to g wet weight m^{-2} based on a conversion factor of 1:9 (Pauly and Christensen, 1995). We note that the conversion factors used will have negligible impact on the simulations performed here; what is important is not the overall level of system productivity, but how productivity changes over time. We consider it safe to assume that the conversion factors are not time varying, and that they, therefore, have little impact on the overall results.

From the sources above we estimated total primary production as well as standing stock of phytoplankton (from the SeaWiFS chlorophyll estimates) for use as biomass measures, and from the ratio of the two we obtained production/biomass ratios to use for the individual LMEs. In Ecosim simulations, we forced the biomass over time to match the selected series, and also fixed the production/biomass ratio over time, so that modeled total primary production would follow the selected series closely.

Primary production estimates were missing for some of the inland seas, and for those we followed a prioritized list where we used the Carr estimates if available. If not, we used the Marra et al. estimates, the Behrenfeld and Falkowski estimates, or, finally, the Dunne et al. estimates. In all cases, we used the annual primary production estimates to drive the ecosystem models, as we are not evaluating seasonal match-mismatch, and the monthly estimates will likely add more noise than signal.

An example of the primary production estimates is shown in Figure 1 for the Humboldt Current LME. It is noteworthy that at the scale of the LME, which stretches from northern Peru to the south tip of Chile, there is relatively little inter-annual variability, even though this area is strongly influenced by periodic El Niño/La Niña Southern Oscillations events. There were, e.g., El Niño events in 1976-1977, 1982-1983, 1986-1987, 1991-1994, and 1997-1998. We actually see stronger temporal variation in other LMEs, e.g., the Gulf of Mexico.

Zooplankton

The biomass estimates are based on a map of zooplankton abundance in the upper 100 m of the world's oceans, published by FAO (1972; 1981), and based on the work of V.G. Borogov et al. (1968). The original map was digitized by the *Sea Around Us* project, and the original estimates in $mg \cdot m^{-3}$ (wet weight) were re-expressed in $t \cdot km^{-2}$. We apply the estimates of zooplankton biomass to the upper 100 meter of the water column, and assume that abundances at greater depths are negligible.

Benthos

Biomass estimates for two size-categories of benthos, macro-benthos and meio-benthos are from a spatial GIS-layer developed at the Conservation Biology Marine Institute, Bellevue WA, USA in cooperation with the *Sea Around Us* project (Peters-Mason et al., unpublished data). Peters-Mason et al. evaluated 28 publications with geo-referenced estimates of meio-fauna (0.1 – 1 mm, N = 184 samples, notably foraminiferans, nematodes, and harpacticoid copepods) and macro-fauna (1 – 10 mm, N = 140 samples, notably polychaetes, crustaceans, and mollusks). Samples of larger benthos ('mega-fauna', notably cnidarians, crustaceans and echinoderms) were too sparse in the literature to allow derivation of global estimates. We extract estimates of benthos abundance from this source with a half-degree by half-degree resolution globally, and sum the abundance by LME. No information about temporal trends in benthos abundance was available at the scale of interest, and we therefore let the abundance and productivity patterns be estimated from the time-dynamic simulations.

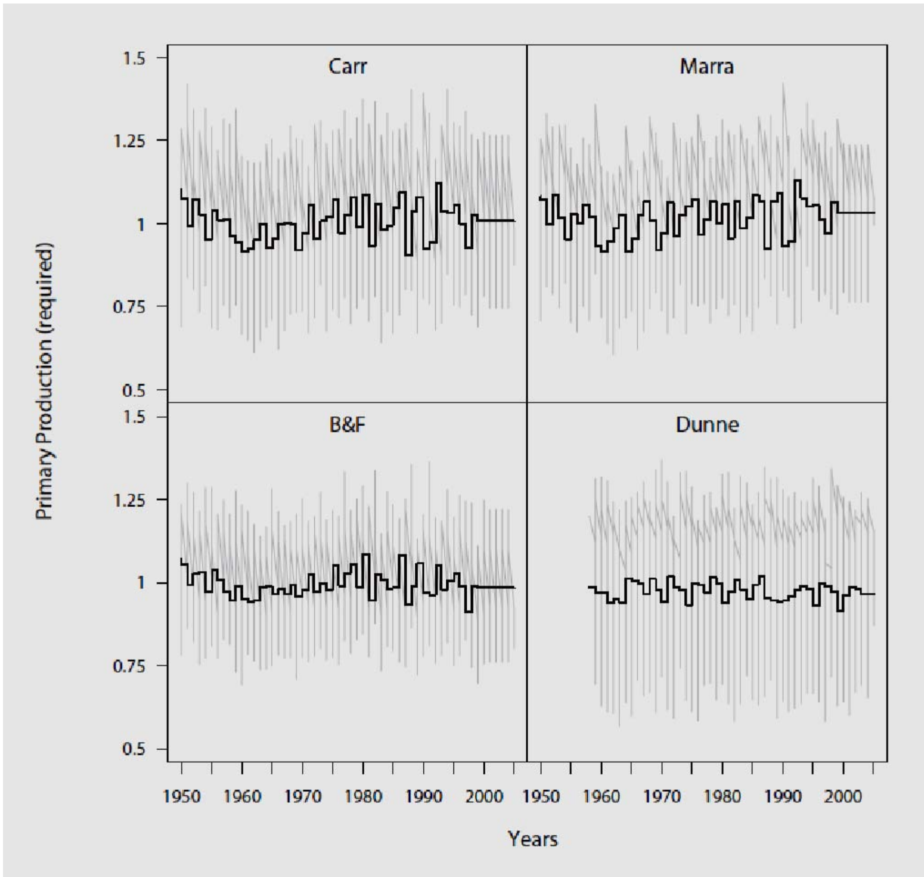

Figure 1. Primary production estimates (relative) for the Humboldt Current (LME 13) for the time period 1950-2004. Estimates are expressed relative to the 1950 values, and are based on the methods of Carr (2002), Marra et al. (2003), Behrenfeld and Falkowski (1997), and Dunne et al. (in prep.) Darker lines indicate annual, lighter monthly values.

Mesopelagics

A combined spatial biomass of small and large mesopelagic fishes was obtained from the information provided by Gjøsaeter and Kawaguchi (1980) based on extensive trawl-surveys in the world oceans. The maps were digitized and validated by Lam and Pauly (2005). The derived GIS-layer is incorporated in the *Sea Around Us* database, and we extract estimates by half-degree and sum up to the LME-level for all LMEs.

Marine mammals

We used published reconstructions of marine mammal population estimates and trends for all extant species of marine mammals with an exploitation history (Christensen and Martell, 2005; Christensen, 2006). This work included creation of a global database of marine mammal whaling, sealing and bycatch/discards estimates, and we combined this database with a spatial database of marine mammal distribution and relative abundance, covering all marine species (Kaschner, 2004; Kaschner et al., 2006).

Combining the estimates of abundance by species by year, and the relative species distributions we obtain estimates of the spatial abundance of marine mammal species by year. For each spatial cell we sum up the abundance to the LME-level, and thus obtain species-weighted marine mammal abundance by LME. We are currently not allocating the catch database of marine mammal kills to spatial cells, because the whaling database as implemented does not have the required spatial information, and we are thus unable to estimate mortality by LME by year. Instead, we force marine mammal abundance directly in the Ecosim model runs, i.e. we provide that abundance as a 'known' biomass time series from which time series Ecosim predictions of marine mammal food consumption and impact on prey are generated. We assume that the trend has been the same throughout the species' distribution area.

We obtain estimates of annual consumption for marine mammal species based on estimated consumption/biomass ratios and species abundance estimates, and for each LME summed up by species to obtain the total consumption by the marine mammal biomass. The consumption/biomass (Q/B, year^{-1}) estimates are based on an assumption of baleens feeding eight months a year. Based on Reilly et al. (2004), we have for baleen whales,

$$Q / B = 8 \cdot 30 \cdot 1.66 \overline{W}^{0.559} / \overline{W}$$

where $\overline{W}$ indicates average individual weight (kg).
For toothed whales and dolphins we use an empirical equation developed by Hunt et al. (2000), as modified by Piroddi (2008),

$$Q / B = 365 \cdot 317 \overline{W}^{0.714} / (\overline{W} \cdot 1207)$$

For otariids (eared seals),

$$Q / B = 365 \cdot 320 \overline{W}^{0.714} / (\overline{W} \cdot 1134)$$

And for other pinniped species,

$$Q / B = 365 \cdot 200 \overline{W}^{0.714} / (\overline{W} \cdot 1134)$$

where the last three equations are described in more detail by Piroddi (2008).

Marine birds

We used a global database of seabird distribution, abundance, and utilization, (Karpouzi, 2005; Karpouzi et al., 2007), to obtain spatial estimates of marine bird abundance by species, as well as estimates of food consumption by marine birds. Details about the approximation approach is presented by Christensen et al (2008).

The daily food intake (DFI) for marine birds was estimated based on the bioenergetic model of the ICES Working Group on Seabird Ecology (ICES, 2000), expressing DFI for each bird species as

$$DFI = \frac{ER}{\sum_j DC_j \times ED_j} \cdot \frac{1}{AE}$$

where *ER* is the energy requirement, DC_j is the fraction that each prey species *j* contributes to the bird's diet, ED_j is the energy density of prey *j*, and *AE* is the mean assimilation efficiency for the bird (assumed to be 0.75). See Karpouzi (2005) for details of the calculations.

Based on diet information collated by Karpouzi (2005), we derive estimates for 24 prey types of how to allocate the bird diet composition (prey composition) to the functional groups used in the present study, (see Christensen et al., 2008 for details). For each LME, we used the relative bird species abundance by year to calculate annual consumption and biomass as well as an initial diet for 1950, i.e. bird abundance was treated as a forcing variable like marine mammal abundance.

Abundance trends for marine populations

We have developed a database with more than 2600 trends for marine populations with focus on fish species. The trends are from a variety of sources and represent survey estimates, estimates from assessments, as well as fisheries-dependent estimates such as commercial CPUE series. The vast majority of trend series are from temperate areas, but we have taken care to increase the spatial coverage, and we, e.g., have a fair representation from the western and southern Africa. The trend database is important for fitting the time-dynamic LME models, notably with regards to assessment of compensatory responses to fishing (density-dependence). This aspect is very important for evaluating carrying capacity of LMEs to support future fisheries.

We extract trends for the LMEs by functional group by first selecting all trend series for which the taxon is allocated to the given functional group in the *Sea Around Us* taxon database, and which are from the same FAO statistical area (www.fao.org) as the given LME. All trend series are geo-referenced, and we weigh the series by a squared inverse distance weighting to the LME (border nearest the trend location, to obtain a weighted trend series by functional group by LME.

While the trend series derived in this manner are only to be considered a first attempt at providing comprehensive time series information, they do provide a starting point that goes beyond what we most often have seen for ecosystem models. We emphasize though, that it is very important to thoroughly search and evaluate all sources of information for a given LME as part of the modeling process.

Fisheries

Catches

The *Sea Around Us* project studies the impact of fisheries on the world's marine ecosystems. To this end, the project uses a Geographic Information System to map global fisheries catches from 1950 to the present, with explicit consideration of coral reefs, seamounts, estuaries and other critical habitats of fish, marine invertebrates, marine mammals and other components of marine biodiversity (Watson et al., 2004). Summary data are freely available from the project website, and are meant to support studies of global fisheries trends and the development of sustainable, ecosystem-based fisheries policies. For the present study, we link directly to the underlying spatial catch dataset, enabling analysis with (rule-based) spatial resolution, albeit here summed up to the LME-level. The catches are available online at www.seaaroundus.org.

Fishing effort

Ecosim's ability to explain historical abundance trend patterns is typically best in cases where historical fishing impacts can be estimated from changes in historical fishing efforts, rather than by subtracting historical catches from model biomasses over time, (which often causes dynamic instability in the model equations). At present, the effort measures we have access to are quite tentative and lacking in spatial resolution (Gelchu, 2006; Alder et al., 2007). We are currently expanding on the effort estimation procedures (Watson et al., 2006a; b), and expect to have more detailed, spatial effort measures available by mid-2009 (Watson et al., in prep.) For the present study, we have been unable to use effort estimates to drive the modeling as the available estimates have too little detail with regard to fleet definitions to be able to determine the diversity of fleets needed to capture changes in target species over time. We therefore do not use effort as a model driver here; instead we use only the catch estimates by target groups and years to drive the models over time.

Prices and cost of fishing

A global ex-vessel price database has been developed as part of the *Sea Around Us* project (Sumaila et al., 2007, available online at www.seaaroundus.org). The database includes all catch categories (typically at the species-level), and gives nominal and real (standardized to 2000 $US) prices by country for 1950 onwards. We calculate average price by functional groups from this database, expressed as real prices for 2000, based on the species catch composition in the individual LMEs. We have access to regional prices by the functional groupings (see www.seaaroundus.org) used for the model, and will consider using these in subsequent iterations of this modeling complex.

Work on populating cost estimates for the various fisheries is presently underway in connection with the further development of the ex-vessel price database. We recognize that the cost of fishing is very different in various parts of the world, while the prices of export-quality fish commodities are of a more global character. This has implications for what price/cost structure to use for the individual, spatial regions in the forward-looking simulations. This will need further consideration in the next round of simulations. For the time being, we use a global price average in the models, not country-specific prices from the countries fishing in the individual LMEs. All catches are allocated to countries fishing, and as we have country-specific ex-vessel prices, we will use these in coming iterations of the ecosystem models.

Database-driven model generation

We have developed an approach that relies on a number of databases, spatial and temporal, to construct ecosystem models using an automated procedure. We call this approach 'database-driven ecosystem model generation', and have described aspects of many of the databases we build on above.

Based on the database-parameterized Ecopath models for each of the LMEs, we have developed a modeling process to represent time-dynamics and to tune the models to the time series data (Figure 2). For each LME, we identify the spatial cells within it, and search a series of databases (as described above) for information about these cells. This information is passed to the static Ecopath model, and the time-dynamic Ecosim model. The Ecopath model is then balanced, Ecosim is run with time series, and the tuning may impact both Ecopath and Ecosim parameters. We consider this tuning necessary for evaluating carrying capacity, as well as for any other study that seeks to evaluate the potential impact of changes in fishing pressure or environmental productivity.

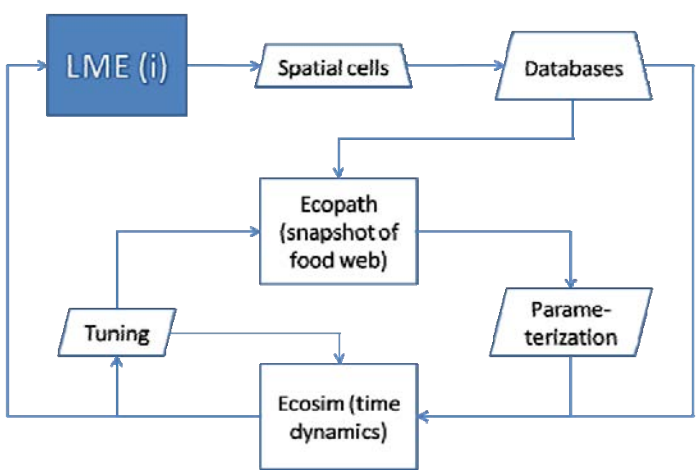

Figure 2. Modeling process for the LME models.

For each LME model, we extract time series information from a range of sources as explained above, and illustrated in Figure 3.

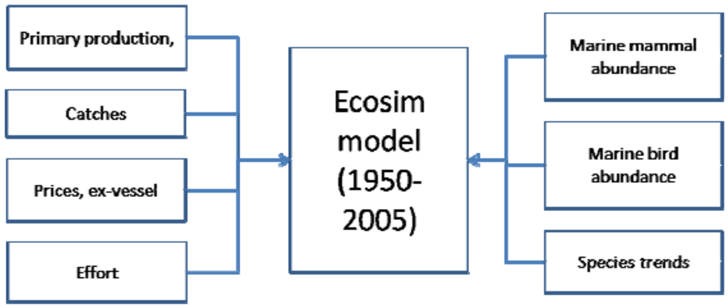

Figure 3. Time series extraction from databases for time-dynamic Ecosim runs for each of the World's 66 LMEs.

In summary form, the method for extracting the data, parameterizing the model, and fitting it to time series data follows a stepwise approach, most easily explained in pseudo-code form:

- Read information assigning all ½° latitude by ½° longitude spatial cells to LMEs, and read size of all cells.
- Read how all exploited species are assigned to taxonomic categories.
- Extract real ex-vessel prices by taxonomic unit (typically species), and by year, 1950-2004.
- Do the following steps for each of the 66 LMEs:
    - Open a generic Ecopath model; copy and rename it to indicate the current LME number, e.g., LME1.
    - Make a list of all cells included in the current LME.
    - Read Ecopath parameters for these cells; set EE to be estimated for groups with data, and add remarks to the model. This is initially for:
        - Mesopelagic biomass.
        - Macro- and meio-benthos biomass.
        - Zooplankton biomass.
    - Read catches for each cell by taxonomic unit (typically species) and by year.
        - Assign catches to functional groups.
        - Sum up catches over all cells by functional groups.
        - Calculate total ex-vessel price over all cells by functional groups.
        - Calculate average ex-vessel price.
        - Add the catches for the first year as landings estimates in the Ecopath model.
        - Store time series of catches for use in Ecosim.
        - We currently do not use the time series of prices.
    - Read effort estimates.

  - Our current effort estimates show too little detail. We therefore omit this step at present.
- Read marine mammal information.
  - Estimate consumption rates.
  - Estimate marine mammal abundance by year from distributions and population trends.
  - Estimate marine mammal diet and consumption/biomass ratio for the first year from total consumption by prey species over all cells.
- Read marine birds information.
  - Sum up biomass by year.
  - Sum up consumption for each prey species and estimate diet and consumption/biomass ratio.
- Read fish diets from FishBase and diet for other species from SeaLifeBase.
  - Allocate species information to functional groups.
  - Calculated average diet for functional groups with information.
- Add a tentative biomass (as a prior estimate of absolute biomass) to the time series data set used for Ecosim fitting for each of the exploited groups, based on the assumption that the fishing mortality in the year with maximum catch corresponds to the natural mortality.
- Check if there are any groups that lack biomass estimates, and have neither catch nor predators.
  - For such groups, Ecopath cannot estimate biomasses, and the biomass is initially set to 0.001 $t{\cdot}km^{-2}$.
- Run Ecopath; load Ecosim scenario, and read time series information obtained above.
- Read primary production and chlorophyll estimates.
  - We currently have included four approaches for estimating primary production, and for each of these we include monthly and annual estimates as forcing functions.
    - One of the series is used to force the production/biomass ratio for phytoplankton, (order of selection described earlier).
  - Chlorophyll estimates are (after conversion) used to force the phytoplankton biomass.
- Check model for mass balance.
  - If any of the ecotrophic efficiencies, (EE, indicating the proportion of production that is ‘used’ in the system – mainly for catches and predation), exceeds unity then:
    - Predation on pinnipeds can be overestimated; if so reduce the contribution of pinnipeds to their predators’ diets.
    - For groups where we calculate EE based on other basic input, change this to an assumed EE of 0.95 and calculate P/B instead.
  - Repeat this procedure until the model is balanced.

- Run Ecosim and store the initial model log residuals (SS) between observed and estimated series (Table 3).
    - Check if there are any groups that are 'crashing', (i.e. end biomass < start biomass / 100), or whose catch is lower than in the Ecosim data time series (F has exceeded F_{lim}).
    - If there are such problem groups, then gradually increase the biomass of the groups in question, while ensuring that no other group in the system becomes unbalanced because of increased predation pressure.
    - Iterate a gradual biomass increase until every group is capable of having produced observed catches without collapsing completely.
- Run Ecosim and store the SS for Table 3 again.
- Fit the model to the time series data using a random optimization procedure (Matyas search, Christensen and Walters, in prep.) now incorporated in EwE6.
    - Set initial wide bounds for the biomass, P/B (and hence Q/B as Q/B here is estimated from P/B), and vulnerabilities.
    - Sample each parameter based on a narrow coefficient of variation.
    - When a better fit (lower SS) is obtained, resample the parameters from a normal distribution with a band around the last 'best fit' parameters.
    - Iterate until there have been at least 10,000 iterations, and continue until there has not been a better fit in the last 1000 iterations.
- Open the spatial- and time-dynamic Ecospace model.
    - Create a base map for the LME with habitat definitions based on depth strata.
    - Extract spatial primary production estimates and store these.
    - The Ecospace models are not described in this contribution, but are included with the data files.
- Save the model

- Move to the next LME.

Table 3. Residuals from the time series fitting of LME models. The ratio, by LME, indicates the ratio between the summed squared log residuals (log observed/predicted) before and after fitting, indicating how much the fitting procedure improved the fit. Fitting is done by fitting one vulnerability parameter and the initial 1950-biomass for each consumer group with time series.

LME	Ratio (%)	LME	Ratio (%)
1	0.2	34	0.5
2	2.0	35	0.5
3	1.6	36	0.7
4	4.8	37	0.0
5	2.3	38	0.1
6	2.7	39	0.1

7	0.9	40	0.0
8	1.0	41	0.6
9	0.2	42	0.1
10	0.2	43	2.6
11	0.0	44	0.2
12	0.2	45	0.4
13	1.4	46	0.1
14	0.8	47	0.0
15	0.4	48	0.1
16	2.2	49	0.1
17	0.0	50	0.2
18	1.1	51	0.1
19	0.9	52	3.1
20	4.2	53	0.0
21	1.4	54	0.0
22	1.0	55	71.7
23	1.2	56	n.a.
24	2.6	57	n.a.
25	4.6	58	0.0
26	1.5	59	3.8
27	0.9	60	1.2
28	0.0	61	0.0
29	0.9	62	0.1
30	1.5	63	87.9
31	0.4	64	0.0
32	0.0	65	50.1
33	0.2	66	2.2

Time series weighting for SS

The random optimization search procedure for parameter estimates that better fit historical abundance trend data relies upon improving a sum of squares fitting criterion, SS. For fitting relative abundance data, the SS term for each abundance trend series is a sum over time of squared deviations between observed trend index value and predicted index value, where the predicted index value is a scaling or catchability coefficient (evaluated at its conditional maximum likelihood value) times modeled biomass. When several time series contribute sums of values over time to the overall SS, the weight *W* of individual time series are estimated from the inverse spatial distance from the LME, raised to the third power. If the distance is more than 40 half-degree cells or if the time series is from another FAO area, it is not used. Further, we halved the weight if the method used for estimating the relative abundance time series is fishery-dependent, while we doubled the weight if the time series is from an assessment. The weights are scaled so that the average trend time series weight for each LME-model is 1.

For catches, we used a high weighting factor (10) for all catch series. Given that we force the catches in Ecosim to match the time series catches, (thus, by default, the observed catch = simulated catch), this factor should not contribute to the SS calculation, unless Ecosim for some reason cannot match the forced catch. This can either be because the population has crashed, or because the estimated fishing mortalities exceed a set maximum. If the simulation cannot match the catch, then the high weighting factor will penalize the model parameter values leading to the poor match, by assigning those values a high SS value.

'Prior' biomasses for each of the exploited groups were obtained based on the assumption that fishing mortality equaled natural mortality in the year with maximum catch; these estimates were assigned a weight of 1. Each such biomass contributes $(B_i - \hat{B}_i)^2$ to the fitting SS, where B_i is model predicted biomass for whatever year had maximum catch, and $\hat{B}_i$ is the catch-based prior estimate, $\hat{B}_i = \max C_i / M_i$.

Results

Model parameters

A notable finding from this first round of database-driven ecosystem model generation is that the initial approach (where we use 'generic' parameters for many of the basic input parameters for the Ecopath model) will need to be substantially improved. We find from trial runs of the EwE policy optimization procedure, for instance, that it tends to overestimate potential yield from high-latitude systems. This is connected to our use of a 'generic' production/biomass (P/B) factor for many functional groups. We have partly remedied this by using P/B-estimates based on the Lorenzen-model (1996), but find that further work is required. In the next iteration of the procedure, we intend to test the empirical equation of Gascuel et al. (2008) for estimation of P/B as a function of trophic level and mean water temperature.

It is also clear that we need more detailed estimates of fleet effort to improve the drivers for the time-dynamic simulations.

Time series fitting

The present study represents a first attempt to automate the model time series fitting procedure. Over the last years, we have worked with numerous ecosystem models and fitted these models to time series data (see Christensen and Walters, 2005), but this has always been done with careful inspection of the models, and with a qualified eye evaluating the tactics of the fitting by focusing attention on poor model fits. When doing this, we look for model time series that diverge greatly from data; then ask why that divergence has occurred, and modify the Ecosim parameters and time series inputs accordingly. In the manual fitting, emphasis is on careful examination of how individual groups react in the model.

We present an example of some of the diagnostic plots showing how the time-series biomass trend data affect simulated outputs from Ecosim (Figure 4). In this example there are numerous time series for biomass (indicated by the different-colored circles on the biomass plot) indicating a downward trend over time. This trend is picked up well by Ecosim (the line on the plot), and we see from the second plot (mortality) that the downward trend in the early 1970s may be associated with predation increase, rather than catches, which only increased some years later.

The development of the automatic fitting procedure has now reached a state where the model fits are beginning to be comparable to many manually conducted model fits, and we know that we can improve the procedure further through inclusion of additional rules. We have taken great care to make the fitting procedure rule-based to ensure reproducibility, to enable us to develop finer scale ecosystem models, and to be able to continuously update the models as more data become available. A manual element in the fitting procedure would make this impossible.

In Table 3 we review the sum of squared log residuals (SS) fitting criterion for the individual LME models before the automated time series fitting, after the fitting, and the ratio between the two. For 60% of the models the automated procedure has reduced the SS with 99% or more, while the average reduction is 98.6%. The low SS values after fitting indicates that we have been able to fit several or most relative abundance time series quite well.

Even if the reduction is quite impressive for many models, we note that this is usually because the models with high initial SS will have a number of groups that ‘crashed’. Once a crash happens, the SS will shoot up (since the SS calculation heavily penalizes inability to explain historical catch data due to collapse in simulated population size to levels too low to have produced the catch). Avoiding such crashes will therefore have a disproportionally large impact on the SS compared to what subsequent fitting may provide. The reduction is mostly obtained by increasing the start biomass for the impacted group, but we also provide other diagnostics and remedies as described in the methodology section. Notably, as part of the random optimization-fitting procedure we vary both the initial biomasses and vulnerabilities (Christensen and Walters, in prep.) The procedure may thus find that a lower initial biomass can be used for a group, if the group is assumed to be closer to its carrying capacity (i.e. to be taking a higher proportion of the prey potentially available to it).

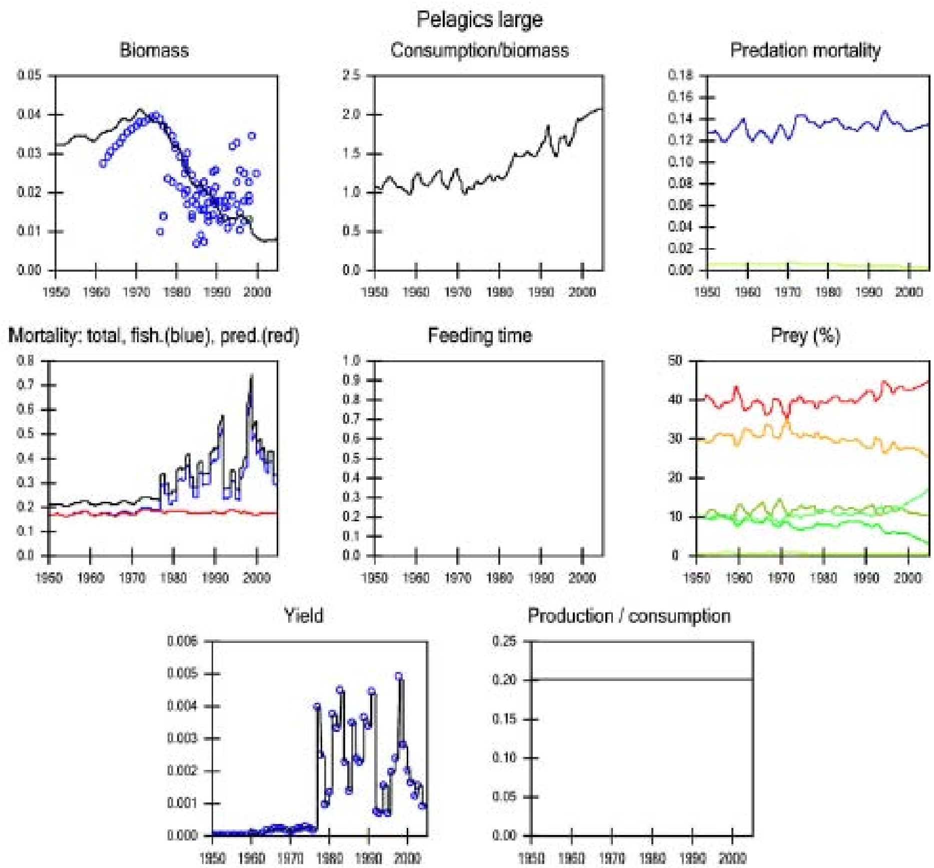

Figure 4. Ecosim time plot for the large pelagics on the New Zealand Shelf (LME 46). There are numerous time series of biomass (for various species in various places, unit t · km^{-2}) indicated by the circles on the first plot, which also shows the Ecosim biomass trajectory as a line. The yield plot (unit t · km^{-2} · year^{-1}) shows that Ecosim (line) used the reported catches (circles) to drive the simulations. Mortality, consumption/biomass, and predation mortality are rates (year^{-1}), and prey diets are relative measures. Predators and prey identities are not indicated, but available in the model output.

For manual model fitting, Ecosim provides important diagnostics in the form of a plot showing all the time series fits in a model. We here give an example of such a plot comparing population trend time series with Ecosim predictions for the New Zealand Shelf model (LME 46) in Figure 5. The fits are perfect for the marine mammals in Figure 5 (first four plots) since for these groups we force Ecosim to use biomasses from the estimated time series; the same is the case for the phytoplankton (bottom row). For the other groups the fits are of variable quality, and it is clear that the fitted parameter values generally are not very capable of reproducing variation in the population trend series. However, tight fits should not be expected due to variance in the observed data and because the trends are for individual species, while the Ecosim simulations are for functional groups including numerous species.

In this initial iteration of the database-driven ecosystem models, we have used catches to drive the Ecosim simulations. For groups where we have no trend series, this may cause the groups' biomass to be too stable over time; the initial biomass may be overestimated as this reduces the risk of the group crashing due to high catches. If, for such groups, the catches decrease over time, this may well result in the groups' biomasses being estimated to increase due to perceived lower fishing pressure. It may well be, in reality, that the fishing pressure stays high, and that the catches decline because of lower biomass. We cannot avoid such cases given our quite limited number of population trend series, and this serves to (1) strengthen the case for using fishing effort to drive the simulations, and (2) illustrate why we do not currently want to use the models for predictions about how the ecosystems may react to future changes in fishing pressure. To do so calls for improved detailed estimates of spatial fishing effort.

Biomass of fishes in the world's LMEs

We use the 66 LME models to obtain a first estimate of the total biomass in 1950 of fishes in the world's LMEs, see Figure 6. The term 'fishes' is here defined as being represented by functional groups 1-24 in Table 2. The biomass is estimated so as to be sufficient to support the catches obtained in the LMEs from 1950 to 2004, while accounting for predator demand through the food web as well.

We estimate the total biomass of fish in the LME areas to 1.1 billion tonnes. There are to our knowledge only two other estimates of fish biomass, one, estimating the total fish biomass to approximately 1 billion tonnes based on size spectra (Jennings et al., 2008), the other, which is based on the approach presented there estimates the global fish biomass to approximately 2 billion tonnes (Wilson et al., 2009).

The biomass estimate for global LMEs can be compared to a total annual catch of approximately 60 million tonnes per year since the mid-1980s, the vast majority of which was obtained from within the LMEs. While this may seem to indicate a low exploitation pressure (catch/biomass ratio) we note that the biomass is dominated by fish groups of little or no commercial interest (Table 4).

No less than 58% of the estimated total biomass is thus represented by small demersals (group 3) and small bathypelagics (group 7), both with asymptotic lengths of less than 30 cm, and both with no or only minimal potential commercial interest given their sparse densities (Pauly et al., 1998a).

We here abstain from presenting estimates of temporal trend in biomass, primarily for lack of reliable, detailed estimates of fishing effort over time and space. Development of such is a priority for further development of the approach reported on here.

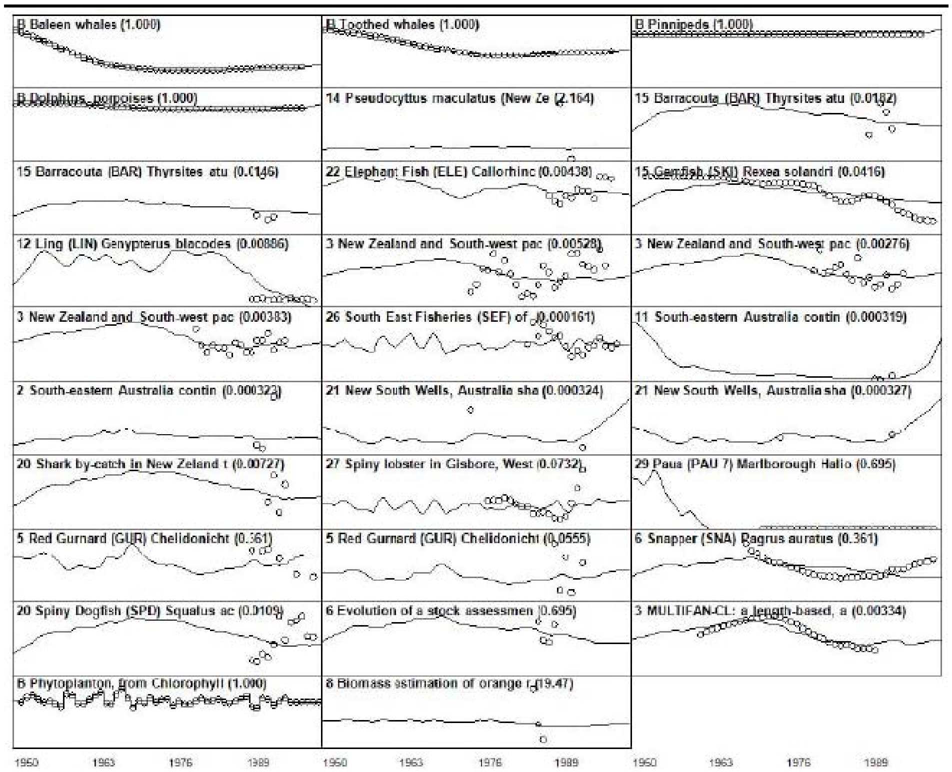

Figure 5. Time series fits for relative biomasses on the New Zealand Shelf (LME 46). Lines indicate the Ecosim estimates, and dots indicate the time series data used for fitting the model. The time series are applied to a single group, and hence, may supply diverging information. The phytoplankton biomass trend is used to force the simulations. The values in brackets indicate time series weights, while the initial numbers indicate functional group numbers.

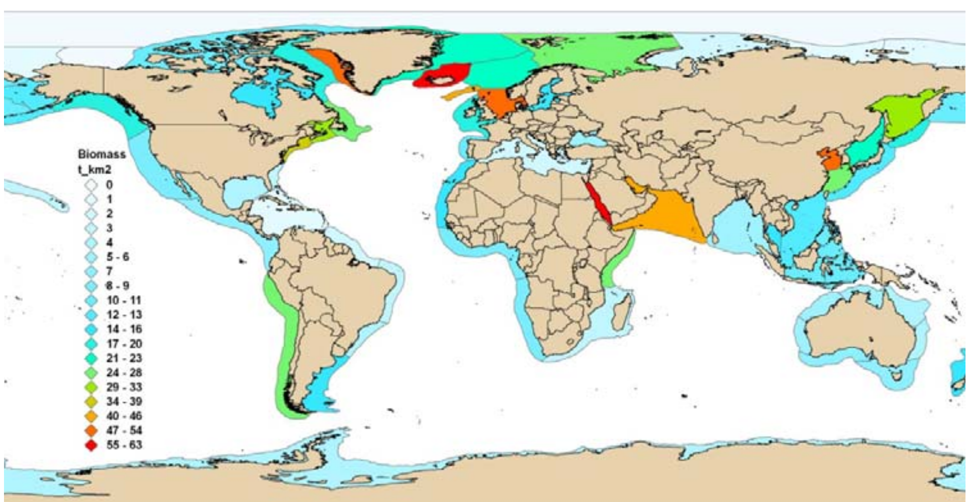

Figure 6. Fish biomass in the world's LMEs, expressed in $t \cdot km^{-2}$. The biomass estimates includes mesopelagics, which reportedly are especially abundant around the Arabian peninsula.

Table 4. Fish biomass (10^3 t · km^{-2}) by functional groups in the world's 66 LME in 1950. The catch column gives the current catches by functional group (10^3 t · km^{-2} · $year^{-1}$). The ratio is the catch/biomass ratio, and is included to indicate that the major part of the fish biomass is represented by groups that are of little commercial interest.

		Biomass (1950)	Catch (2000)	Ratio
1	Pelagics small	88,796	17,123	0.193
2	Pelagics medium	63,821	10,187	0.160
3	Pelagics large	14,469	1,501	0.104
4	Demersals small	203,221	7,245	0.036
5	Demersals medium	36,877	2,915	0.079
6	Demersals large	23,944	1,625	0.068
7	Bathypelagics small	440,863	10	0.000
8	Bathypelagics medium	682	85	0.125
9	Bathypelagics large	85	0	0.000
10	Bathydemersals small	4,667	3	0.001
11	Bathydemersals medium	3,020	93	0.031
12	Bathydemersals large	3,165	121	0.038
13	Benthopelagics small	44,529	37	0.001
14	Benthopelagics medium	68,980	2,423	0.035
15	Benthopelagics large	79,481	5,903	0.074
16	Reef fish small	9,629	270	0.028
17	Reef fish medium	3,797	588	0.155
18	Reef fish large	663	62	0.093
19	Sharks small medium	467	8	0.017
20	Sharks large	1,869	240	0.128
21	Rays small medium	2,841	198	0.070
22	Rays large	379	43	0.113
23	Flatfish small medium	5,392	651	0.121
24	Flatfish large	2,444	181	0.074

Discussion

We are presenting a new approach to modeling, and this raises a pertinent question: what is it good for? We regard it a major advantage that by making the model construction database-driven we enrich the models with information that likely would not otherwise have been used for the model construction. We are also making it much easier to get started with the modeling process by presenting a draft model for improvement.

We consider the models of appropriate quality for use to address large-scale issues, such as for instance how marine ecosystems biodiversity and productivity may be impacted by policy questions, e.g., in connection with UNEP's Global Environmental Outlook series. For more local use, i.e., for use of the individual LME-models, we see the models providing a well-defined starting point, but one, which should be enriched through local data from the LME. Notably, we do not supply effort time series, and such are very important to drive the models over time. Also, the species-resolution is very poor in the models as the functional groups are defined in a very generic manner. This poses a problem for using the models for management purposes as well as to address more specific biodiversity questions. For such use it is important to further enrich the models, and this is indeed a case where modelers should consider whether it isn't better to actually develop the ecosystem models from scratch.

It is a potential danger that by automating the model construction process, the potential users may not have a full understanding of the data limitations and of what is required to use the models as part of the actual management process. We would be very hesitant to use any model for management without a thorough understanding of the model's behavior. We thus caution strongly against the direct use of the database-driven models for management purposes.

Large Marine Ecosystems face serious threats throughout the world. One important threat is that they are overfished due to excessive effort capacity. To evaluate what has happened, what is happening, and what may happen under alternative future scenarios, it is important to have ecosystem modeling as part of the toolbox for ecosystem-based management. Ecosystems models integrate a diversity of information, including ecological, economical and social considerations, and provide our best hope for expanding our understanding of how to sustainably manage the ocean's resources for the benefit of present and future generations.

We have taken a step for making ecosystem modeling more accessible by developing capabilities for database-driven ecosystem model generation. We encourage the scientific community to cooperate with us on developing model capabilities within the projects and to enable cooperation that will further enrich the models, and lead to their successful application.

Overall we see a need for developing better databases related to spatial effort estimation, and we encourage analysis of the economical and social aspects of the fish production chain, from sea to consumer. Given information from throughout the fishing sector, ecosystem models combined with economical value chain modeling can be used to evaluate how food security, economic and social parameters may be impacted by fisheries management decisions.

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Chapter 7

Land-based Nutrient Loading to LMEs: A Global Watershed Perspective on Magnitudes and Sources*

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Abstract

Land-based nutrient (nitrogen and phosphorus) inputs to coastal systems around the world have markedly increased due primarily to the production of food and energy to support the growing population of over 6 billion people. The resulting nutrient enrichment has contributed to coastal eutrophication, degradation of water quality and coastal habitats, and increases in hypoxic waters, among other effects. There is a critical need to understand the quantitative links between anthropogenic activities in watersheds, nutrient inputs to coastal systems, and coastal ecosystem effects. As a first step in the process to gain a global perspective on the problem, a spatially explicit global watershed model (NEWS) was used to relate human activities and natural processes in watersheds to nutrient inputs to LMEs, with a focus on nitrogen.

Many LMEs are currently hotspots of nitrogen loading in both developed and developing countries. A clear understanding of the relative contribution of different nutrient sources within an LME is needed to support development of effective policies. In 73% of LMEs, anthropogenic sources account for over half of the dissolved inorganic nitrogen (DIN) exported by rivers to the coast. In most of these, agricultural activities (fertilizer use and wastes from livestock) are the dominant source of DIN loading, although atmospheric deposition and, in a few LMEs, sewage can also be important.

Over the next 50 years, human population, agricultural production, and energy production are predicted to increase especially rapidly in many developing regions of the world. Regions of particular note are in southern and eastern Asia, western Africa, and Latin America. Unless substantial technological innovations and management changes are implemented, this will lead to further increases in nutrient inputs to LME coastal waters with associated water quality and ecosystem degradation. An approach is needed

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such as that being developed in Global Environment Facility (GEF) sponsored LMEs programs where all stakeholders – including scientists, policy makers and private sector leaders – work together to develop a better understanding of the issues and to identify and implement workable solutions.

Introduction of the Problem

Human activities related to food and energy production have greatly increased the amount of nutrient pollution entering the coastal environment from land-based sources (Howarth et al. 1996; Seitzinger and Kroeze 1998; Galloway et al. 2004; Green et al. 2004). Small amounts of nutrient enrichment can have beneficial impacts to some coastal waters and marine ecosystems by increasing primary production which can have potentially positive impacts on higher trophic levels. However, a high degree of nitrogen and phosphorus enrichment, causing eutrophication of coastal and even inland waters, tends towards detrimental effects including degradation of fisheries habitats. The negative effects of eutrophication begin with nutrient uptake by primary producers that can result in blooms of phytoplankton, macroalgae, and nuisance/toxic algae. When phytoplankton blooms die and sink, decomposition of the biomass consumes and may deplete dissolved oxygen in the bottom water resulting in hypoxic or "dead zones." There are many other effects of nutrient over-enrichment including increased water turbidity, loss of habitat (e.g., seagrasses), decreases in coastal biodiversity and distribution of species, increase in frequency and severity of harmful and nuisance algal blooms, and coral reef degradation, among others (National Research Council 2000; Diaz et al. 2001; Rabalais 2002).

Nutrient over-enrichment and associated coastal ecosystem effects are occurring in many areas throughout the world and a number of recent assessments have begun to document their regional and global distribution. The European Outlook reported that in 2000, more than 55% of ecosystems were endangered by eutrophication. This includes the notable hypoxic/anoxic zones in the Baltic Sea, Black Sea and Adriatic Sea, among many others. In the USA, a recent assessment of over 140 coastal systems by the National Oceanic and Atmospheric Administration found that in 2004 50% of the assessed estuaries had a high chlorophyll a (phytoplankton) rating and 65% of the assessed estuaries were moderately to highly eutrophic (Bricker et al. 2007). In a recent literature review by the World Resources Institute (Selman et al. 2008), 375 eutrophic and hypoxic coastal systems were identified around the world, including many areas in developing countries.

The need to address nutrient over-enrichment as a priority threat to coastal waters and Large Marine Ecosystems (LMEs) has been recognized at national and global levels. The Global Plan of Action for the Protection of the Marine Environment from Land-based Activities (GPA), which was adopted by 108 Governments and the European Commission in 1995, recognized the need for global, regional and national action to address nutrients impacting the coastal and marine environment. Continued widespread government support to address nutrients has been noted in both the Montreal and Beijing

Declarations. In 2002, the World Summit on Sustainable Development convened in Johannesburg identified substantial reductions in land-based sources of pollution by 2006 as one of their 4 marine targets. Over 60 countries have developed national policies or national action plans to address coastal nutrient-enrichment within the context of sustainable development of coastal areas and their associated watersheds.

Over the next 50 years, human population, agricultural production, and energy production are predicted to increase especially rapidly in many developing regions of the world (Hassan et al. 2005). Unless substantial technological innovations and management changes are implemented, this will lead to further increases in nutrient (nitrogen and phosphorus) inputs to the coastal zone with associated water quality and ecosystem degradation. In order to optimize use of land for food and energy production while at the same time minimizing degradation of coastal habitats, there is a critical need to understand the quantitative links between land-based activities in watersheds, nutrient inputs to coastal systems, and coastal ecosystem effects.

In this chapter we primarily address the links between land-based activities in watersheds and nutrient inputs to coastal systems around the world. Here we use a global watershed model (NEWS) to examine the patterns of nutrient loading and source attribution at global and regional scales and then apply the model at the scale of large marine ecosystems (LMEs) (Sherman & Duda 1999). Within all LMEs, 80% of the world's marine capture fisheries occur (Sherman 2008) which emphasizes the importance of cross political-boundary management of these international marine ecosystem units, as in the Global International Waters Assessment (GIWA; UNEP 2006). Various aspects including ecosystem productivity, fish and fisheries, pollution and ecosystem health, socioeconomic conditions, and governance, have been examined for many individual LMEs, but limited assessments across all LMEs have been made with a primarily fisheries emphasis (e.g., Sea Around Us Project 2007). In individual LMEs, few estimates of nutrient loading have been made, and only in the Baltic Sea LME has source apportionment been investigated (HELCOM 2004, 2002). At the end of the chapter we return to coastal ecosystem effects.

A Watershed Perspective

Rivers are a central link in the chain of nutrient transfer from watersheds to coastal.systems. Nutrient inputs to watersheds include natural (biological N_2-fixation, weathering of rock releasing phosphate) as well as many anthropogenic sources. At the global scale, anthropogenic nitrogen inputs to watersheds are now greater than natural inputs (Galloway et al. 2004). Anthropogenic nutrient inputs are primarily related to food and energy production to support the over 6 billion people on Earth with major sources including fertilizer, livestock production, sewage, and atmospheric nitrate deposition resulting from NOx emissions from fossil fuel combustion.

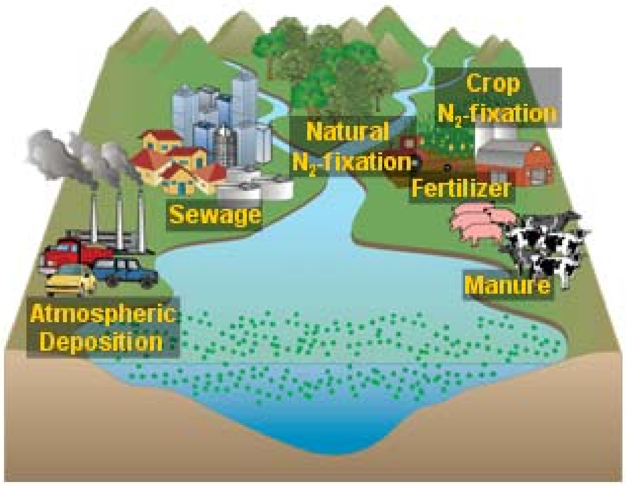

Figure 1. Watershed schematic of nitrogen inputs and transport to coastal systems. Symbols for diagram courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science.

Uneven spatial distribution of human population, agriculture, and energy production leads to spatial differences in the anthropogenic alterations of nutrient inputs to coastal ecosystems (Howarth et al. 1996; Seitzinger and Kroeze 1998; Green et al. 2004; Seitzinger et al. 2005). While many site-specific studies have documented river transport of nutrients (nitrogen (N), phosphorus (P), carbon (C) and silica (Si)) to coastal systems, there are many more rivers for which there are no measurements; sustained monitoring of temporal changes in exports is rarer still. A mechanism is needed to develop a comprehensive and quantitative global view of nutrient sources, controlling factors and nutrient loading to coastal systems around the world under current conditions, as well as to be able to look at past conditions and plausible future scenarios.

A Global Watershed Nutrient Export Model (NEWS)

In order to provide regional and global perspectives on changing nutrient transport to coastal systems throughout the world, an international workgroup (Global NEWS – Nutrient Export from WaterSheds; (www.marine.rutgers.edu/globalnews) has developed a spatially explicit global watershed model that relates human activities and natural processes in watersheds to nutrient inputs to coastal systems throughout the world (Beusen et al. 2005; Dumont et al. 2005; Harrison et al. 2005a and b; Seitzinger et al. 2005). Global NEWS is an interdisciplinary workgroup of UNESCO's Intergovernmental Oceanographic Commission (IOC) focused on understanding the relationship between human activity and coastal nutrient enrichment.

In addition to current predictions, the NEWS model is also being used to hindcast and forecast changes in nutrient, carbon and water inputs to coastal systems under a range of scenarios. In this chapter we briefly describe the NEWS model and then present results for mid-1990's conditions at both global scales and as specifically applied to LME regions.

NEWS Model Basics. The NEWS model is a multi-element, multi-form, spatially explicit global model of nutrient (N, P, and C) export from watersheds by rivers (Table 1). The model output is the annual export at the mouth of the river (essentially zero salinity). The NEWS model was calibrated and validated with measured export near the river mouth from rivers representing a broad range of basins sizes, climates, and land-uses. Over 5000 watersheds are included in the model with the river network and water discharge defined by STN-30 (Fekete et al. 2000; Vörösmarty et al. 2000a and b). The input databases are at the scale of 0.5^{o} latitude by 0.5^{o} longitude.

Table 1. Nutrient forms modeled in Global NEWS. DIC and DSi sub-models (in italics) are currently in development.

	Dissolved		Particulate
	Inorganic	Organic	
N	DIN	DON	PN
P	DIP	DOP	PP
C	*DIC*	DOC	POC
Si	*DSi*		

Whereas previous efforts have generally been limited to a single element or form, the Global NEWS model is unique in that it can be used to predict magnitudes and sources of multiple bio-active elements (C, N, and P) and forms (dissolved/particulate, organic/inorganic). It is important to know coastal nutrient loading of multiple elements because different elements and elemental ratios can have different ecosystem effects. The various forms of the nutrients (dissolved inorganic and organic and particulate forms) also have different bioreactivities. For example, the dissolved inorganic nitrogen (DIN) pool is generally considered to be bio-available, while only a portion of river transported dissolved organic nitrogen (DON) is readily available for uptake by micro-organisms, including bacteria and some phytoplankton (Bronk, 2002; Seitzinger et al., 2002a). However, DON can be an important N source and it is implicated in the formation of some coastal harmful algal blooms (Paerl, 1988; Berg et al., 1997 and 2003; Granéli et al., 1999; Glibert et al., 2005a and b). Particulate and dissolved species can also have very different impacts on receiving ecosystems.

The NEWS model predicts riverine nutrient export (by form) as a function of point and non-point nutrient sources in the watershed, hydrological and physical factors, and removal within the river system (Figure 2) (Beusen et al. 2005; Dumont et al. 2005; Harrison et al. 2005a and b; Seitzinger et al. 2005). A further feature of the model is that it can be used to estimate the relative contribution of each watershed source to export at the river mouth. The NEWS model builds on an earlier model of dissolved inorganic N (DIN) export (Seitzinger and Kroeze 1998).

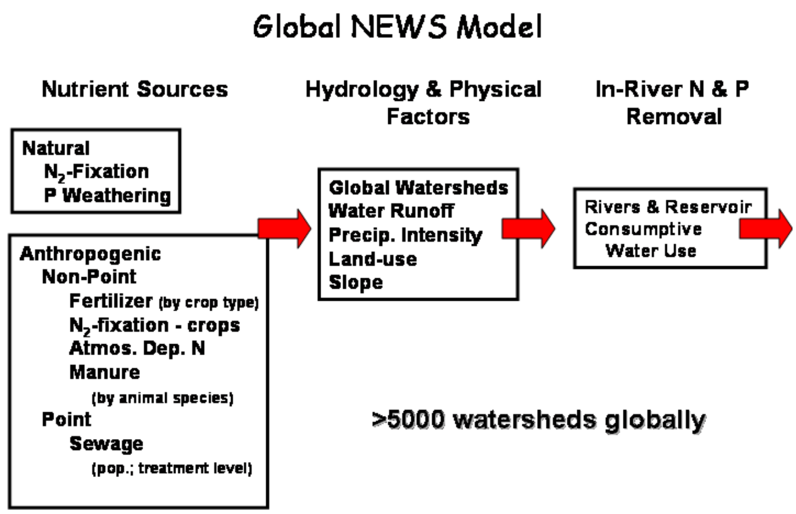

Figure 2. Schematic of some of the major inputs and controlling factors in the Global NEWS watershed river export model.

There is considerable detail in the input databases and model parameterizations that reflect food and energy production and climate (Figure 2). For example, crop type is important in determining fertilizer use, the amount of manure produced is a function of animal type (e.g., cows, camels, chickens, goats, etc.), nutrient loading from sewage depends not only on the number of people in a watershed but also on their connectivity to a sewage system and level of sewage treatment, atmospheric nitrate deposition is related to fossil fuel combustion. A number of hydrological and physical factors are important in transferring nutrients from soils to the river, with water runoff being important for all elements and forms. Once in the river, N and P can be removed by biological and physical processes during river transport within the river channels, in reservoirs, and through water removal for irrigation (consumptive water use).

NEWS Model Output: The NEWS model has provided the first spatially distributed global view of N, P and C export by world rivers to coastal systems. At the global scale rivers currently deliver about 65 Tg N and 11 Tg

P per year according to NEWS model predictions (Tg = tera gram = 10^{12} g) (Figure 3). For nitrogen, DIN and particulate N (PN) each account for approximately 40% of the total N input, with DON comprising about 20%. This contrasts with P, where particulate P (PP) accounts for almost 90% of total P inputs. However, while DIP and dissolved organic P (DOP) each contribute only about 10% of total P, both of these forms are very bioreactive and thus may have a disproportionate impact relative to PP on coastal systems.

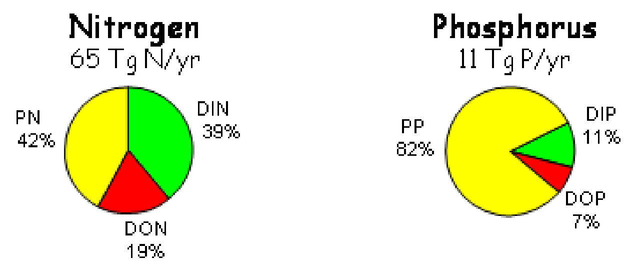

Figure 3. Global N and P river export to coastal systems by nutrient form based on the NEWS model (Dumont et al. 2005; Harrison et al. 2005a).

There is large spatial variation around the world in river nutrient export, including different patterns for the different nutrient forms (DIN, DON and PN) (Figure 4). Using N yield (kg N per km^2 watershed per year that is exported to the river mouth), DIN yield shows considerable variation at regional and continental scales, as well as among adjacent watersheds. As might be expected based on past measurements of river nutrient export, the NEWS model predicts relatively high watershed yields in the eastern USA, the Mississippi basin, and much of western Europe. Of particular note, however, are also the high DIN yields from developing regions including much of southern and eastern Asia, Central America and small coastal watersheds in western Africa.

The large spatial variation in N yield reflects the variable magnitudes of the different nutrient sources and controlling factors among watersheds. This underscores the importance of the need for a clear understanding of the nutrient sources and controls within LMEs at many scales in order to develop effective policies and implementation strategies to control coastal nutrient loading.

N and P differ markedly in the relative contribution of different nutrient sources to river nutrient export (Seitzinger et al. 2005). At the global scale, natural sources account for about 40% of DIN and DIP river export (biological N_2-fixation and rock weathering, respectively) (Figure 5). Anthropogenic sources for DIN export are dominated by agriculture (fertilizer and manure) in contrast to DIP where sewage accounts for ~60% of river export. This difference in major sources, illustrates the need for different strategies to reduce nitrogen or phosphorus loading to coastal systems.

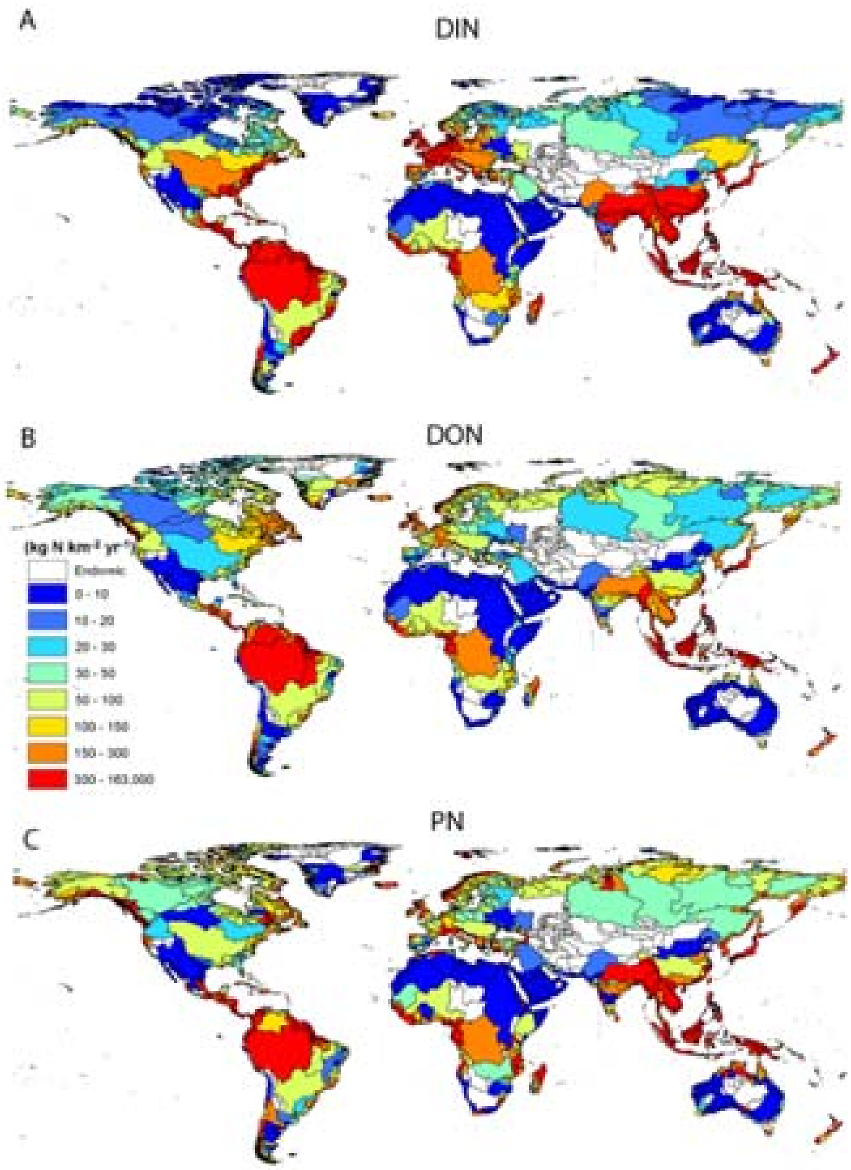

Figure 4. NEWS-model-predicted A) DIN, B) DON, and C) PN yield (kg N km-2 yr-1) to coastal systems from basins globally. Model output replotted from Harrison et al., 2005b, Dumont et al 2005, and Beusen et al. 2005.

Of course there is considerable variation in the relative contribution of nutrient sources at continental, regional and watersheds scales, and this must be known and taken into consideration when developing nutrient reduction strategies. At the continental scale, for example, in South America livestock production (manure) is by far the largest anthropogenic N source contributing to river DIN loading to coastal systems (Figure 6). This contrasts with Asia where fertilizer use is about twice as great as livestock production in contributing to river DIN loading.

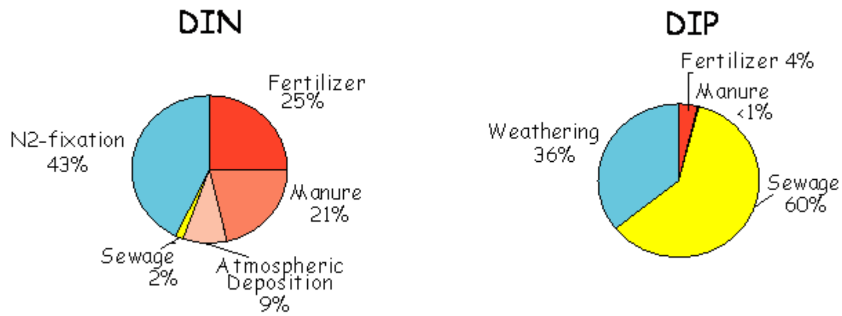

Figure 5. Contribution of different sources to DIN and DIP river export globally.

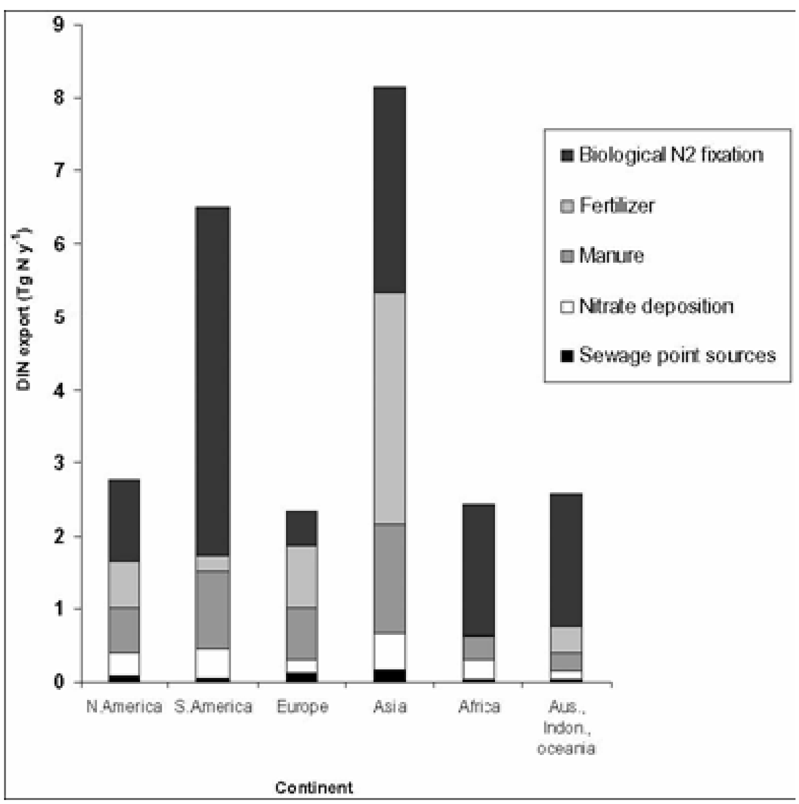

Figure 6. Contribution of N sources in watersheds to model predicted DIN river export to the coastal zone of each continent. (Figure from Dumont et al. 2005)

NEWS Model Application to LMEs

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

Few estimates of nutrient loading have been made in individual LMEs, and only in the Baltic Sea LME has source apportionment been investigated (HELCOM 2004, 2002). As a first step in bridging the gap between land-based activities and LME waters, we examined the relative magnitudes and distribution of DIN loading from watersheds to LMEs globally. We focused on N because it is often the most limiting nutrient in coastal waters and thus important in controlling coastal eutrophication. DIN is often the most abundant and bioavilable form of nitrogen, and therefore contributes significantly to coastal eutrophication.

Watershed DIN export to rivers predicted by the NEWS model described above was compiled for each of the 64 LMEs (2002 delineation; Duda & Sherman 2002) except for the Antarctic (LME 61) where database information was limited. Total DIN load to each LME was aggregated from all watersheds with coastlines along that LME for point sources and only those watersheds with discharge to that LME for diffuse sources. This work was part of the GEF Medium-Sized Project: Promoting Ecosystem-based Approaches to Fisheries Conservation and LMEs (Component 3: Seitzinger and Lee 2007).

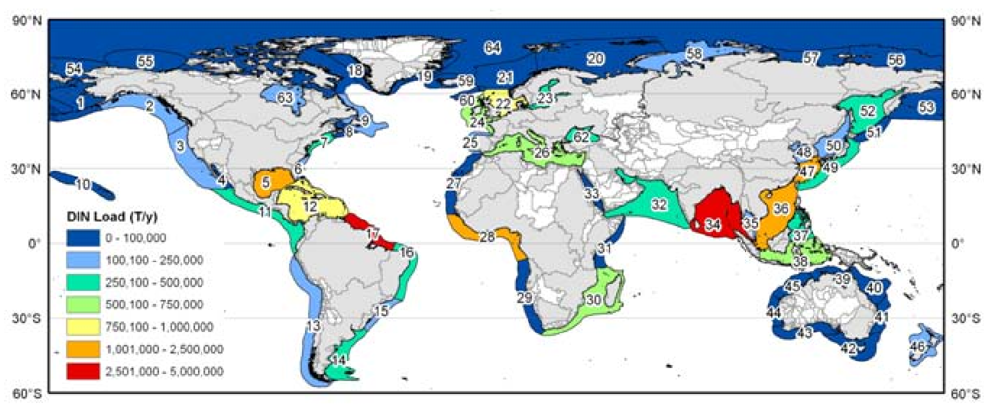

Figure 7. DIN inputs to LMEs from land-based sources predicted by the NEWS DIN model. Watersheds discharging to LMEs are grey; watersheds with zero coastal discharge are white. Units: Tons N/y. See Table 2 for LME identification**.**

Table 2. LMEs identified by name and number (see Fig. 7 and 8)

LME #	LME name	LME #	LME name
1	East Bering Sea	33	Red Sea
2	Gulf of Alaska	34	Bay of Bengal
3	California Current	35	Gulf of Thailand
4	Gulf of California	36	South China Sea
5	Gulf of Mexico	37	Sulu-Celebes Sea
6	Southeast U.S. Continental Shelf	38	Indonesian Sea
7	Northeast U.S. Continental Shelf	39	North Australian Shelf
8	Scotian Shelf	40	Northeast Australian Shelf-Great Barrier Reef
9	Newfoundland-Labrador Shelf	41	East-Central Australian Shelf
10	Insular Pacific-Hawaiian	42	Southeast Australian Shelf
11	Pacific Central-American Coastal	43	Southwest Australian Shelf
12	Caribbean Sea	44	West-Central Australian Shelf
13	Humboldt Current	45	Northwest Australian Shelf
14	Patagonian Shelf	46	New Zealand Shelf
15	South Brazil Shelf	47	East China Sea
16	East Brazil Shelf	48	Yellow Sea
17	North Brazil Shelf	49	Kuroshio Current
18	West Greenland Shelf	50	Sea of Japan
19	East Greenland Shelf	51	Oyashio Current
20	Barents Sea	52	Okhotsk Sea
21	Norwegian Sea	53	West Bering Sea
22	North Sea	54	Chukchi Sea
23	Baltic Sea	55	Beaufort Sea
24	Celtic-Biscay Shelf	56	East Siberian Sea
25	Iberian Coastal	57	Laptev Sea
26	Mediterranean Sea	58	Kara Sea
27	Canary Current	59	Iceland Shelf
28	Guinea Current	60	Faroe Plateau
29	Benguela Current	61	Antarctic (not included in this analysis)
30	Agulhas Current	62	Black Sea
31	Somali Coastal Current	63	Hudson Bay
32	Arabian Sea	64	Arctic Ocean

DIN export from watersheds to LMEs varies globally across a large range of magnitudes (Figure 7). The smallest loads are exported to many polar and Australian LMEs, while the largest loads are exported to northern tropical and subtropical LMEs. Of particular note are the large loads exported to the Gulf of Mexico, South China Sea, East China Sea, and North Sea LMEs in which high anthropogenic activity occurs in their watersheds. The Caribbean Sea, Mediterranean Sea and Indonesian Sea LMEs, among others, also receive substantial DIN loads.

The NEWS model also predicts substantial DIN export from the North Brazil Shelf LME which has relatively low anthropogenic activity in its watersheds. Further investigation is underway to evaluate the NEWS model for these large and relatively pristine tropical river basins. The high DIN load may reflect a number of factors including the large role that high water runoff from tropical rivers plays in the export of DIN, high biological N_2-fixation, low denitrification, and model uncertainty.

Identification of Land-based Nutrient Sources to LMEs. DIN loading to each LME was attributed to diffuse and point sources including natural biological N_2-fixation, agricultural biological N_2-fixation, fertilizer, manure, atmospheric deposition and sewage. Dominant sources of DIN to LMEs were also identified which may be useful for the management of land-based nutrient loading to LMEs.

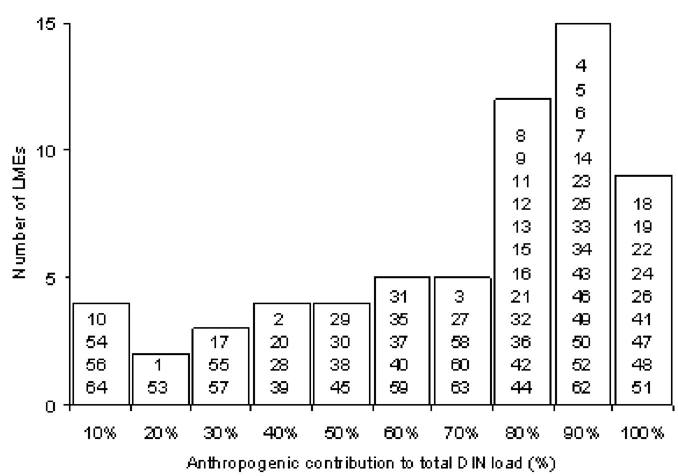

Figure 8. Histogram of anthropogenic contribution to total DIN load to LMEs. LME numbers are shown in each bar. See Table 2 for LME identification.

Land-based sources of DIN include natural sources (biological N_2-fixation in natural landscapes) and anthropogenic activities. In watersheds draining to LMEs, anthropogenic activities contribute to over half of the total DIN load in 73% of LMEs (Figure 8). These anthropogenic DIN dominant LMEs are distributed across most continents, except sub-Saharan Africa and most polar regions. Some of the highest proportions (> 90%) of anthropogenic DIN loads are to European LMEs, such as the North Sea and Mediterranean LMEs, and East Asian LMEs, such as the Yellow Sea and East China Sea LMEs.

Agriculture is a major source of the anthropogenic DIN export to LMEs. In 91% of the LMEs with agriculture occurring in their related watersheds, over half their anthropogenic export is due to agricultural sources such as agricultural biological fixation, manure, and fertilizer. Attribution of agricultural DIN export to these three sources reveals the predominance of fertilizer and manure over agricultural biological fixation. For example, LMEs with the largest agricultural loads have less than 20% of the total DIN load due to biological fixation and over 50% due to either fertilizer (e.g., in many northern temperate and Southeast Asian LMEs such as the Bay of Bengal, East China Sea and South China Sea LMEs), to manure (e.g., in most Central and South American LMEs such as the Caribbean and North Brazil Shelf LMEs) or to a combination of both (e.g., in the North Sea and Celtic-Biscay Shelf LMEs) due to local agricultural practices. There is no agricultural export to most polar LMEs.

Atmospheric deposition is important in regions where there are few other land-based inputs (e.g., in polar regions such as the West and East Greenland Shelf LMEs), where fossil fuel combustion from development is extreme (e.g., in the North- and Southeast U.S. Continental Shelf LMEs), or where extensive landscape burning occurs (e.g., in the Guinea Current LME which is fed by savannah fires in Western Central African watersheds; Barbosa et al. 1999). Sewage is an important source of DIN to only a few LMEs (as a primary source to the Kuroshio Current, Red Sea, West-Central Australian Shelf, and Faroe Plateau LMEs), while agricultural fixation plays an even lesser role as a primary source to only the Southwest Australian Shelf LME and a secondary source to the Benguela Current, North Australian Shelf, and West-Central Australian Shelf LMEs.

The variability in watershed DIN export and source attribution within individual LMEs exhibits comparably large differences as with across LMEs. Examples from different world regions including Asia, South America and the US-Latin America are presented below. Among the Yellow Sea, Humboldt Current and Gulf of Mexico LMEs, the DIN load from individual watersheds ranges over several orders of magnitude across both small and large watersheds (Figure 9). For example, similarly sized watersheds in both the Yellow Sea and Humboldt Current LMEs exhibit both the largest and smallest magnitudes of watershed DIN export. In contrast, the Mississippi watershed is the largest watershed contributing to the Gulf of Mexico LME and also exports the largest load of DIN to the Gulf of Mexico.

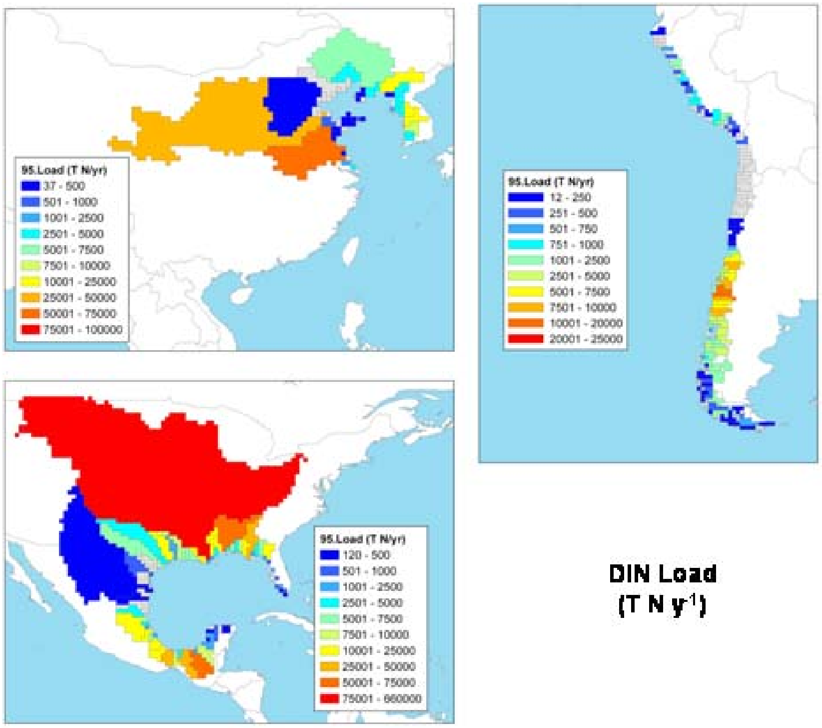

Figure 9. DIN export predicted by the NEWS DIN model from watersheds within the Yellow Sea, Humboldt Current and Gulf of Mexico LMEs. Units: Tons N/yr.

The relative importance of different watershed sources of DIN to LME loading also varies, e.g., among the Yellow Sea, Humboldt Current and Gulf of Mexico LMEs (Figure 10). Agricultural sources dominate the DIN export in all of these LMEs, but fertilizer contributes the most to export to the Yellow Sea and Gulf of Mexico LMEs while manure is relatively more important than fertilizer to the Humboldt Current LME. In the Yellow Sea LME, sewage is also a significant source (19%) to DIN export, while less so to the Humboldt Current and Gulf of Mexico LMEs. Nitrogen fixation occurring in natural landscapes is a significant source (28%) to the DIN export to only the Humboldt Current LME. Atmospheric deposition is a lesser source of DIN export to all three example LMEs, but contributes, relatively, the largest percentage (11%) to the Gulf of Mexico LME. The identification of dominant sources of DIN and their relative contribution at the individual LME level is essential for developing effective nutrient management strategies on an ecosystem level.

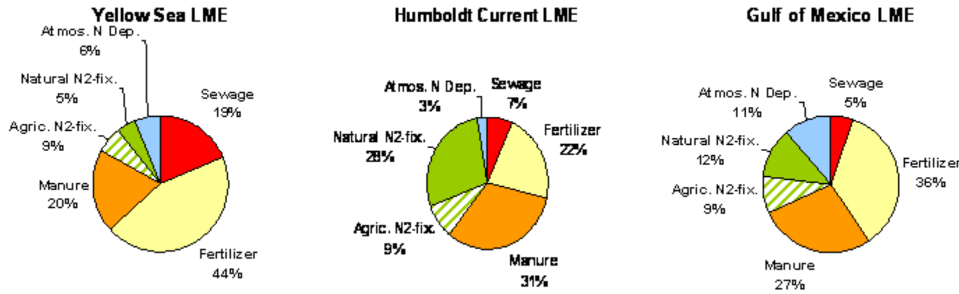

Figure 10. Source attribution of DIN export predicted by the NEWS DIN model to the Yellow Sea, Humboldt Current and Gulf of Mexico LMEs. Units: Tons N/yr.

Implications of Future Conditions in LME Watersheds

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

Based on a business-as-usual (BAU) scenario, inorganic N export to coastal systems is predicted to increase 3-fold by the year 2050 (relative to 1990) from Africa and South America (Figure 11) (Kroeze and Seitzinger, 1998; Seitzinger et al., 2002b). Substantial increases are predicted for Europe (primarily eastern Europe) and North America. Alarmingly large absolute increases are predicted for eastern and southern Asia; almost half of the total global increased N export is predicted for those regions alone.

The following scenario for 2050 was based on projections made from early 1990 trajectories and using a relatively simple DIN model (Seitzinger and Kroeze 1998).

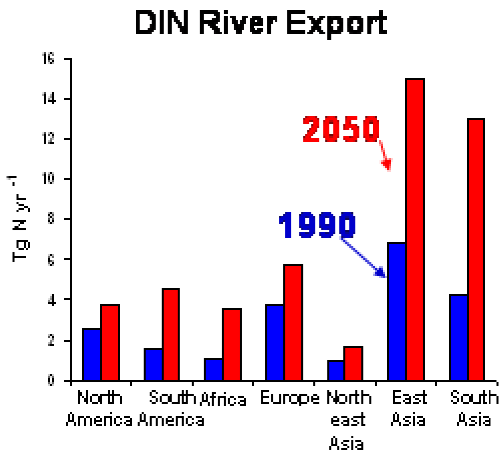

Figure 11. Predicted DIN export to coastal systems in 1990 and 2050 under a business-as-usual (BAU) scenario. Modified from Kroeze and Seitzinger (1998).

The NEWS model has more parameters and more detail behind the inputs (e.g., fertilizer use by crop type, level of sewage treatment, etc.) (Figure 2) thus facilitating more advanced scenario development and analyses. For example, it is now possible to explore the effects of a range of development strategies, effects of climate change, production of biofuels, increase in dams for hydropower, and consumptive water use (irrigation) on coastal nutrient loading. Using the NEWS model, we are currently analyzing a range of alternative scenarios for the years 2030 and 2050 based on the Millennium Ecosystem Assessment (www.millenniumassessment.org) to provide insights into how changes in technological, social, economic, policy and ecological considerations could alter future nutrient export to coastal systems around the world (Seitzinger et al. in prep.).

Coastal Ecosystem Effects

As noted at the beginning of this chapter, nutrient over-enrichment can lead to a wide range of coastal ecosystem effects. The most direct response of coastal ecosystems to increased nutrient loading is an increase in biomass (e.g., chlorophyll a) of primary producers or primary production rates (Nixon 1995). How might land-based DIN loading be affecting primary production in LMEs? As a preliminary examination, we compared land-based DIN loads predicted by the NEWS model to LME primary production (modeled SeaWiFS data; Sea Around Us Project 2007) (Figure 12). This analysis suggests that land-based DIN export supports a significant portion of primary production at the level of an entire LME. In areas with upwelling, nutrient-rich bottom waters support high rates of photosynthetic production. This is reflected in the generally higher primary productivity than predicted by the regression solely with land-based DIN inputs in LMEs characterized by upwelling (the Guinea Current, Arabian Sea, Pacific Central-American, Humboldt Current, California Current, Gulf of Alaska, Benguela Current, Canary Current, Northwest Australian, and Southwest Australian LMEs).

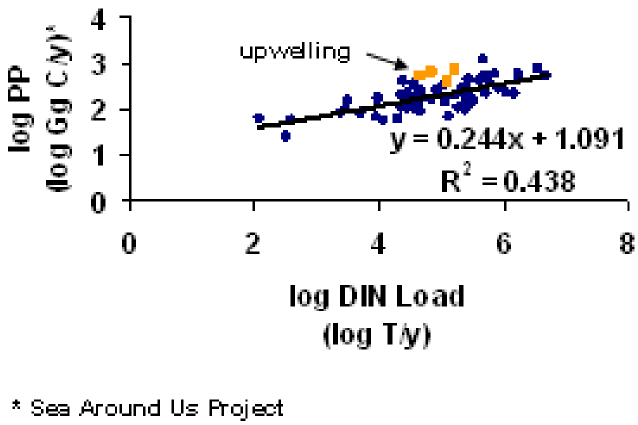

Figure 12. Phytoplankton production vs. DIN load to the 63 LMEs. Orange points are LMEs in upwelling regions. Phytoplankton production rates are from the Sea Around Us Project; DIN loads are from the NEWS model (Dumont et al. 2005). Figure from Lee and Seitzinger submitted.

The above analysis compares land-based N loading to average primary production for waters in the entire LME. In the near shore areas of LMEs, land-based N loading likely supports a much higher proportion of primary production than suggested by the overall relationship in Figure 12 and should be investigated. The additional effects of high nutrient loading to estuaries and near shore waters in LMEs on hypoxia, biodiversity, toxic and nuisance algal blooms, habitat quality, and fisheries yields also warrants further analysis.

Future Needs

We are beginning to make significant advances in understanding the relationship between human activities in watersheds and coastal nutrient loading at a range of scales (e.g., watershed, LME, and global) as illustrated by the application of the NEWS model. However, this is only a start. For example, to date the LME, regional, and global analyses have relied on input databases at the scale of 0.5 ^{o} latitude x 0.5^{o} longitude. The use of higher spatial resolution input databases based on local knowledge from specific LME regions could significantly improve the model predictions. Similarly, additional data for model validation is need. Development of scenarios based on local projections of population, agricultural production, biofuels, dam construction, and climate change, among others could provide information of use to policy makers.

Development of nutrient reduction policies and effective mitigation strategies also requires widely applicable, quantitative relationships between nutrient loading and coastal ecosystem effects. While there is considerable information on nutrient sources and coastal impacts, this information is often much dispersed and has not yet been compiled into a consistent database so that nutrient sources in specific LMEs can be linked to impacts in their associated coastal system. This is a critical next step in order for a toolbox to be developed so that effective policy measures can be formulated and measures taken, and for the outcomes of those policies and measures to be evaluated.

Many technical and political options are available to reduce fertilizer use, decrease nutrient runoff from livestock waste, decrease NOx emissions from fossil fuel burning, and enhance sewage treatment. The fact that many of these tools have not yet been implemented on a significant scale suggests that additional technological options and new policy approaches are needed. In addition, policy approaches to address non-point source pollution are often nonexistent or very limited. To ensure that the science used to develop these technologies and polices is sound and complete, existing data on nutrient sources, mobilisation, distribution, and effects need to be assessed. An approach is needed such as that being developed in GEF-sponsored LME programs and as promoted by the International Nitrogen Initiative (INI) (at INitrogen.org) where all stakeholders – including scientists, policy makers and private sector leaders – work together to develop a better understanding of the issues and to identify and implement workable solutions.

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Chapter 8

The Recovery and Sustainability of the Baltic Sea Large Marine Ecosystem*

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

Main characteristics of the Baltic Sea Large Marine Ecosystem

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

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

* Modified from *Sustaining the World's LMEs* (2009) pp 63-78. Reprinted with permission

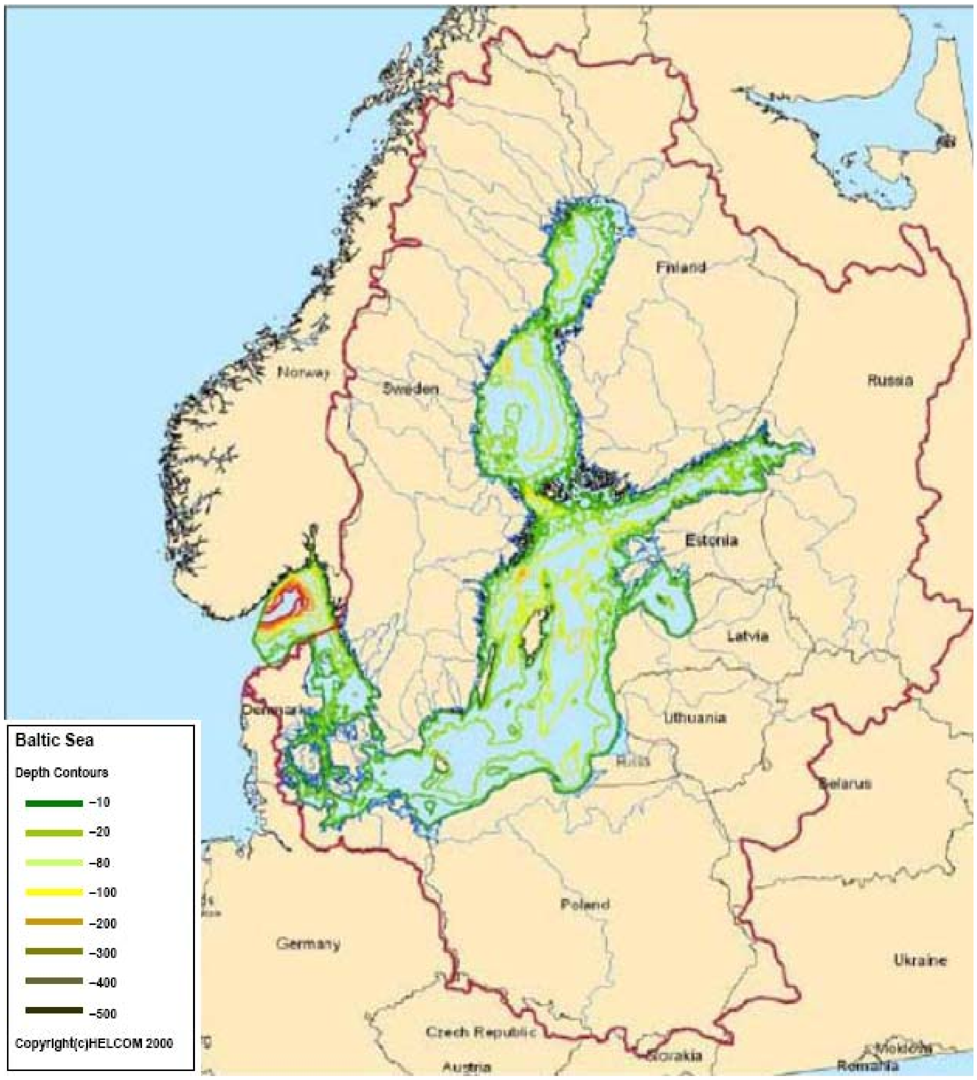

Figure 1. The Baltic Sea LME catchment area (outlined in dark red).

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

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

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

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

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

International Management and Advisory Systems

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

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

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

The Baltic Sea Regional Project

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

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

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

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

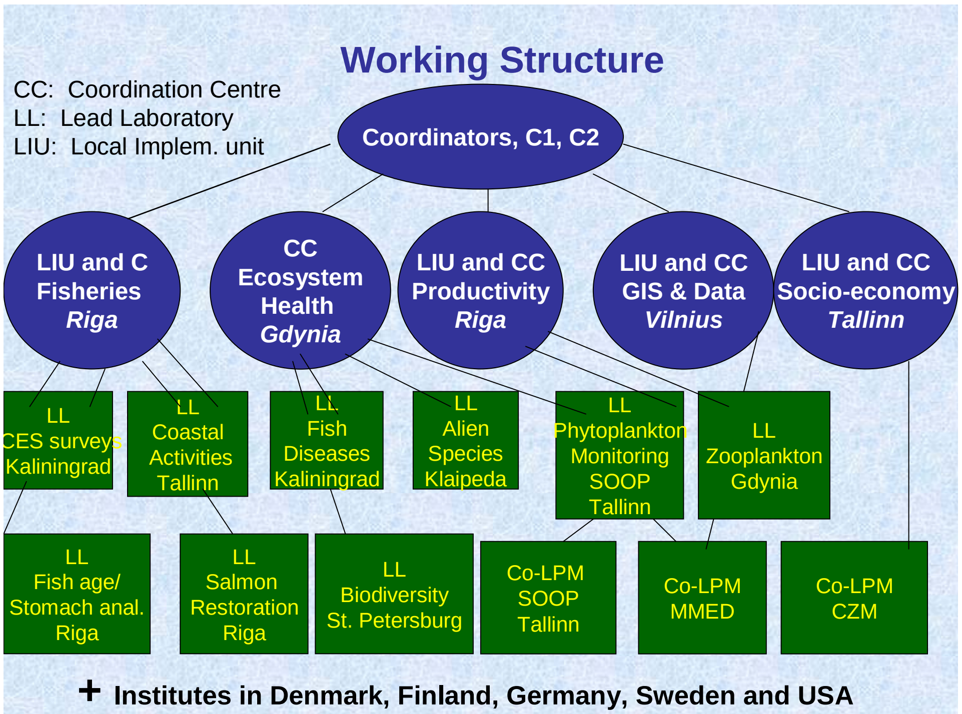

Figure 2. The working structure of the Baltic Sea Regional Project (BSRP), with Coordination Centers, Lead Laboratories and Local Implementation Units in different countries adjacent to the Baltic Sea LME.

Productivity and Ecosystem Health

It should be noted that, of the 64 LMEs around the globe, the Baltic Sea shows the highest temperature increase rate (1.35°C) between 1982 and 2006 (Sherman et al. this volume). Eutrophication, or nutrient over-enrichment, is the biggest problem facing the Baltic Sea. Increasing amounts of nutrients in the marine environment result in increased plant biomass and production, which in turn lead to elevated amounts of organic matter circulating in the ecosystem. The excess organic matter requires more oxygen, both when it is alive and when it is decaying. In the Baltic Sea LME, which experiences only rare major flushing events, eutrophication frequently leads to serious oxygen depletion and the formation of toxic hydrogen sulphide in the deeper regions. This has resulted in so-called dead bottom areas, nearly devoid of typical benthic animals and bottom living fish, covering nearly a third of the bottom area of the Baltic Sea LME. The input of nutrients to the Baltic Sea has increased greatly since about the 1940s, with nitrogen and phosphorous rising by about three to five times the 1940s level. The most important human-related source of these nutrients in the Baltic Sea is agriculture, where farmers use excessive manure and artificial fertilizers for the production of their crops, and the surplus runs into the sea via streams and rivers. This is especially true for the eastern Baltic countries, i.e. the BSRP recipient countries. Additionally, the situation is exacerbated by changes in land use and the loss of wetlands, as well as by the discharge of sewage from urban and industrial sources. Other complicating environmental factors affecting eutrophication trends are increased temperatures due to climate change in the Baltic Sea area.

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

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

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

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

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

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

Fish and Fisheries

The commercially most important fish species in the open Baltic Sea are cod, herring, sprat and Baltic salmon. The total annual catch of these fish stocks has increased 10-fold during the past 50 years. Until the 1930s, catches remained at about 120,000 tonnes, then increased to about 500,000 tonnes in the late 1950s and, after a steep rise in the mid 1960s, reached almost a million tonnes by the end of the 1970s. In the last 20-30 years however, overfishing and the failure of fisheries management to maintain sustainable fisheries and conserve commercial fish stocks have become increasingly more pronounced. Cod and wild salmon have been severely depleted and have been outside of safe biological limits due to decades of unsustainable fishing effort resulting from excessive fishing capacity and inappropriate fishing practices. Cod is the most important fish in the Baltic. From a maximum annual catch of cod in the mid 1980s of nearly 450,000 tonnes, the nominal catch steadily declined and has hovered between 50,000 and 100,000 tonnes since the early 1990s (**Figure 3**).

As a result of management failures due to the managing agencies setting cod total allowable catches (TACs) that have frequently exceeded the levels advised by ICES, the stock size of Baltic Sea cod reached its lowest level on record in 1991. Levels since then and up to 2007 have been close to this historic minimum.

Landings in Baltic Sea LME

Most recently, the largest cod stock in the eastern and central Baltic has shown signs of recovery as the biomass is increasing. Overfishing of larger fish-eating fish, e.g. cod, has allowed increased industrial fishing of sprat and herring. The economic yield per unit biomass of the fishery has declined, with a smaller proportion of the catch being directed for human consumption and food security.

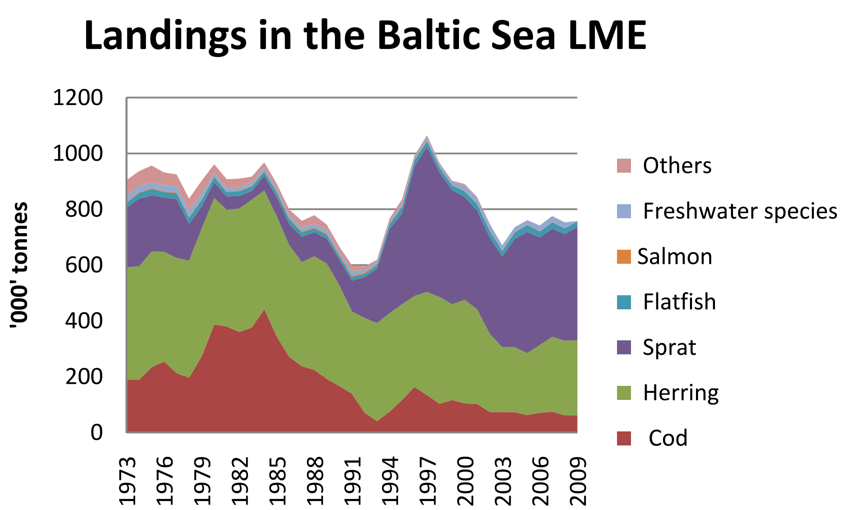

Figure 3. Fish catches in the Baltic Sea. Herring and cod are the most important fish species. (From ICES fish catch data.)

Unsustainable fishing has also caused further impacts on marine ecosystems through by-catch and the discarding of fish, and on bottom living animals, seabirds and marine mammals. Bottom trawling has degraded vulnerable habitats. This has had a negative impact on ecosystem structure and function. Fisheries enforcement has been ineffective against bad fishing practices. Fish in excess of the quotas have been landed outside legal channels, to the detriment of the stock, and to the detriment of official statistics on catches and landings. Fishing in closed areas has also been connected with unacceptable levels of discards. Where regional international regulatory commissions have agreed on remedial actions, there has often been a lack of political will at the national level to fully implement agreed actions to restore depleted fish stocks and protect marine ecosystems.

However, in the last two years, public awareness of the Baltic and its fish and fisheries, especially cod, has grown considerably in most of the Baltic riparian countries. The media has dealt in detail with the failure of the Common Fisheries Policy, and in Sweden, for example, the publication of the book "Tyst Hav" (Silent Sea) which in a popular way deals with the political, biological and economical issues of Baltic fisheries, received a strong reaction from the public (Lovin 2007). As a result, people started to boycott cod, fish dealers stopped selling cod, restaurants stopped serving it, and NGOs red-listed many Baltic Sea fish species. In Poland, fishermen and fisheries officials admitted to the heavy overfishing of TACs and high frequency of illegal fishing. Baltic Sea managers had long been aware of the situation and had already prepared a recovery plan for the Baltic cod. For the first time in years, ICES made a statement about the eastern Baltic cod population in 2008 indicating that "an increase in spawning stock biomass has been observed since 2005 although it is still at a historical low level" (Figure 4). ICES in 2008 classified the stock as being harvested sustainably (ICES 2008).

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

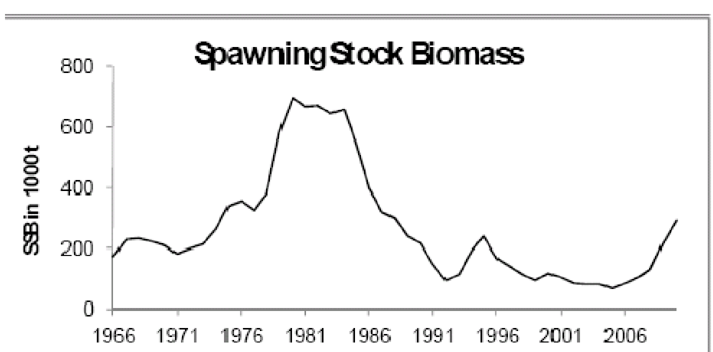

Figure 4. Spawning Stock Biomass of Baltic Cod from ICES Subdivisions 25-32 (From ICES 2010)

In a series of workshops, the BSRP Lead Laboratory (LL) for Coastal Fish has acted as co-chair and has cooperated with HELCOM, ICES and the Swedish National Board of Fisheries to improve the coastal fish monitoring programmes around the Baltic Sea with an aim to contribute to overall assessments of the Baltic Sea LME.

Present and Future

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

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

Through the BSRP and its LME activities, ICES became involved in an EU project called “BONUS for the Baltic Sea Science” – a Network of Funding Agencies” (BONUS ERA-NET). In 2005, this project was charged by the EU to produce a Baltic Sea science plan and implementation strategy. The task to accomplish this was given to BSRP/ ICES. This plan will convert research needs arising from management agencies into scientific questions to which the Baltic Sea science community can respond with research ideas. The Baltic Sea Science Plan is written in accordance with the LME concept and contains all its major elements (**Figure 5**) (Hopkins et al. 2006). The Science Plan served as the basis for the BONUS+ call for project proposals which was launched in September 2007. In June 2008, 16 projects were granted money for three years with a total budget of 22 million Euros. The Science Plan will also form the basis for future calls and activities during the implementation of the Joint Baltic Sea Research Programme, BONUS-169, under Article 185 (formerly 169) of the EC Treaty. This programme, which has an anticipated funding volume of 100 million Euros, will be implemented in two phases: a Strategic Phase during 2010-2011, followed by an Implementation Phase during 2012-2016. "By implementing a policy-driven, fully-integrated joint research programme, based on extensive and on-going stakeholder consultations, BONUS-169 will provide concrete scientific outputs facilitating the implementation of ecosystem-based management of environmental issues in the Baltic Sea area. BONUS thereby supports sustainable development of the region while strengthening research collaboration and facilitating the use of common resources and infrastructure in the region." (www.bonusportal.org.-2010).

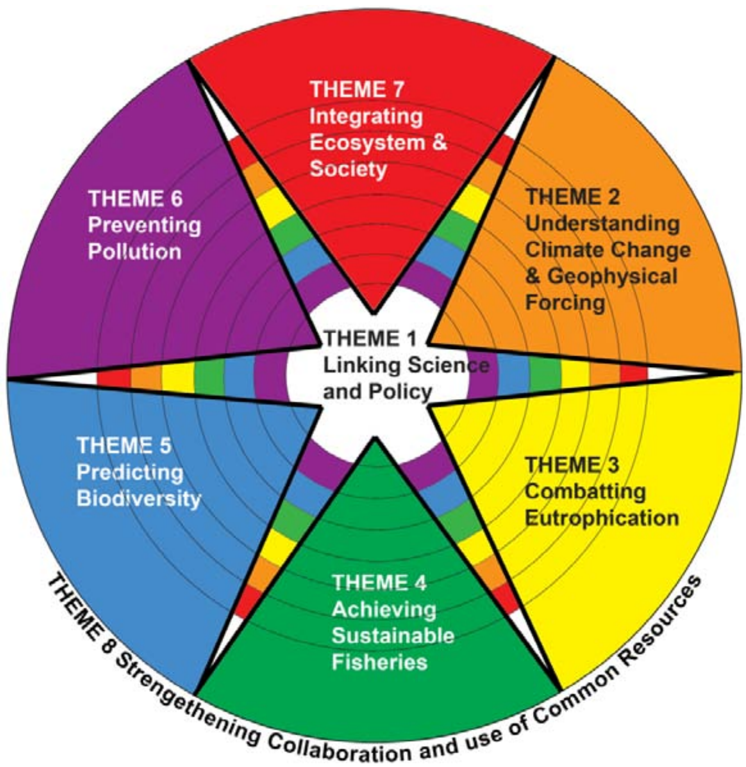

Figure 5 Illustration of the Baltic Sea Science Plan of the **BONUS** project.

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

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

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Chapter 9

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

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

PROJECT DESCRIPTION

The Benguela Current LME is one of the most productive upwelling regions of the world (**Figure 1**). It supports an important global reservoir of biodiversity and biomass of zooplankton, fish, sea birds, and marine mammals, while

* First published in Sherman et al., eds. *Sustaining the World's Large Marine Ecosystems* (2009) IUCN. 51-62. Reprinted with permission.

nearshore and offshore sediments hold rich deposits of precious minerals (particularly diamonds), as well as oil and gas reserves.

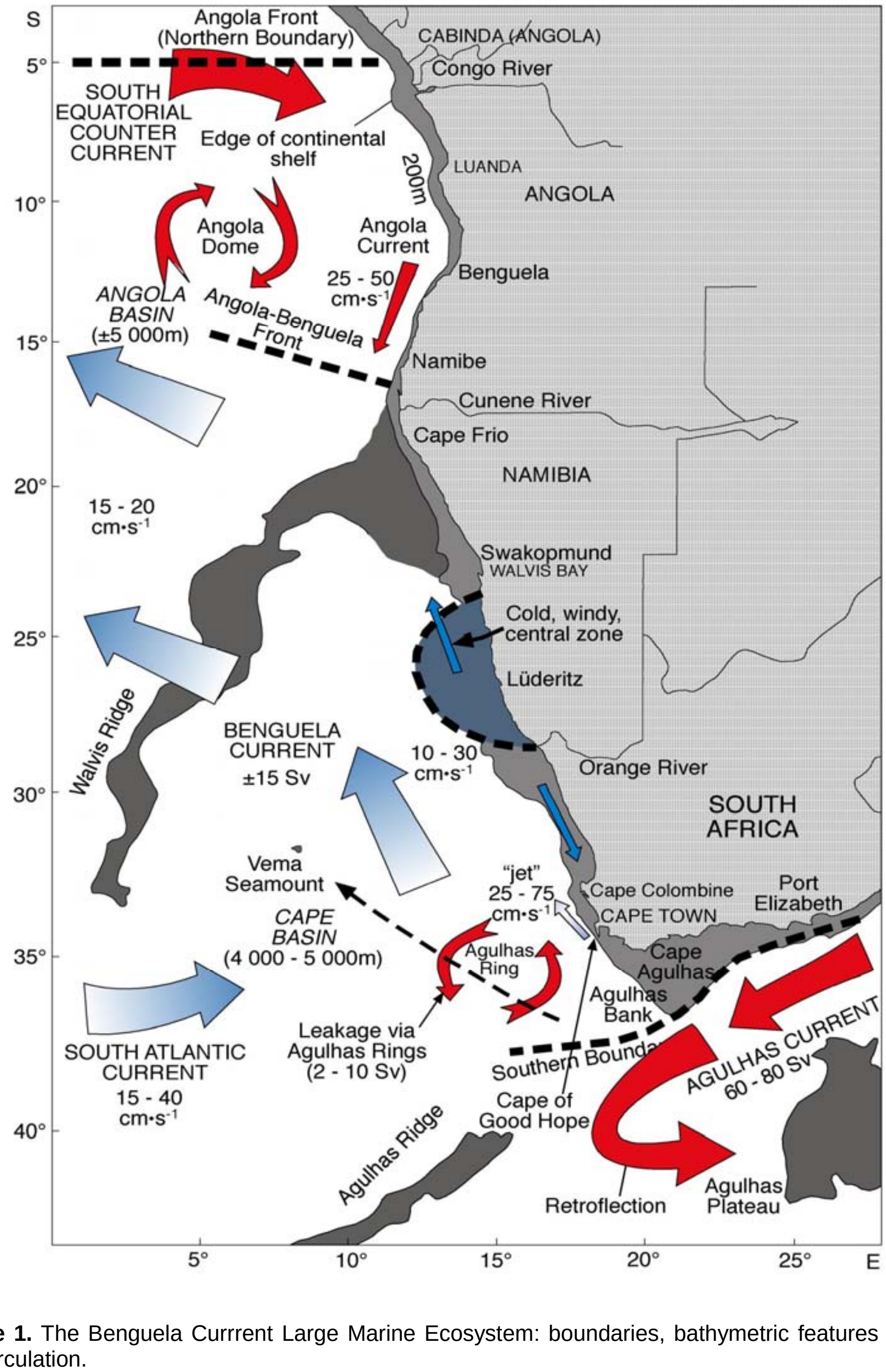

Figure 1. The Benguela Currrent Large Marine Ecosystem: boundaries, bathymetric features and circulation.

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

a) Synthesis and assessment of information on the BCLME

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

b) First Stakeholder Workshop – Broad Consultations

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

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

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

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

The workshop used a logic framework analysis process and focused on three main areas of programme activities: (a) resource use; (b) environmental variability; and (c) pollution and ecosystem health. The essential elements of the TDA were identified and prioritised by smaller working groups following the path (issues > problems > causes > impacts > risks > uncertainties > socio-economic consequences > transboundary consequences > activities/solutions > priorities > outputs > costs) outlined in **Figure 2**.

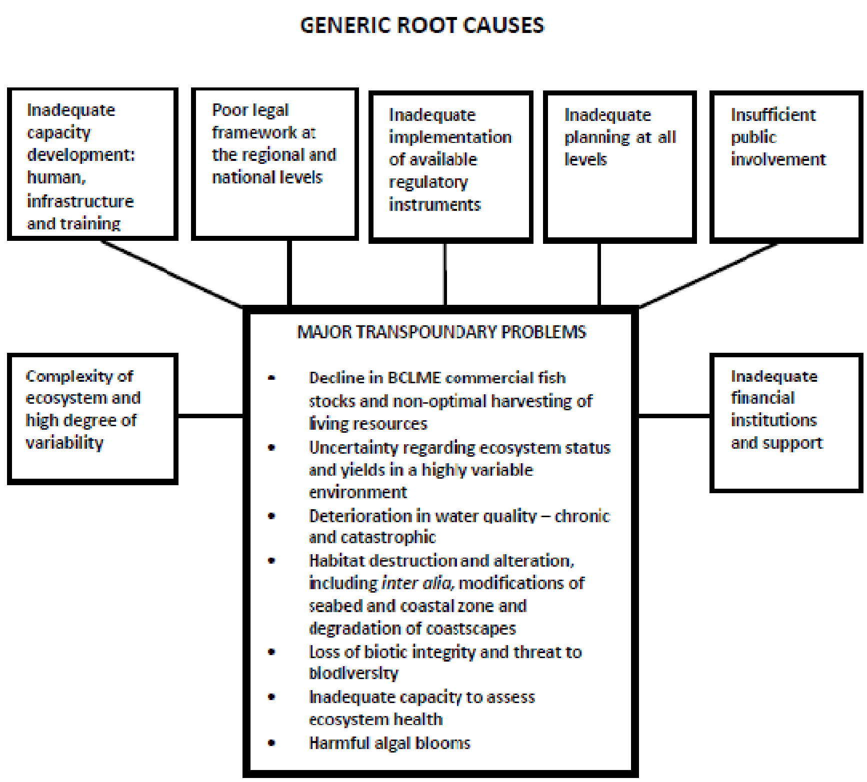

Figure 2. Major transboundary problems of the BCLME and generic root causes as determined by the TDA process.

What the working groups produced formed the basis for developing a comprehensive TDA report which led to the development of the SAP. A framework for the SAP was also defined by the stakeholders, for later development by a small group of experts into a more comprehensive document. The TDA workshop produced excellent results and generated a great spirit of cooperation and goodwill among the participants of the three countries.

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

The sustainable utilisation and management of resources

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

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

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

The maintenance of ecosystem health and the management of pollution

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

d) The Strategic Action Plan (SAP)

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

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

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

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

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

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

CHALLENGES AND EXPERIENCES

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

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

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

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

The Benguela Current Commission started to take form in 2004 when a feasibility study was commissioned to establish a regional organisation that would promote integrated management and the sustainable use of the

BCLME. This was followed by a second study focusing on economics which analysed the costs and benefits of cooperative research and management. Both reports recommended establishing a regional organisation that would implement an ecosystem approach to ocean governance in the Benguela Current LME.

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

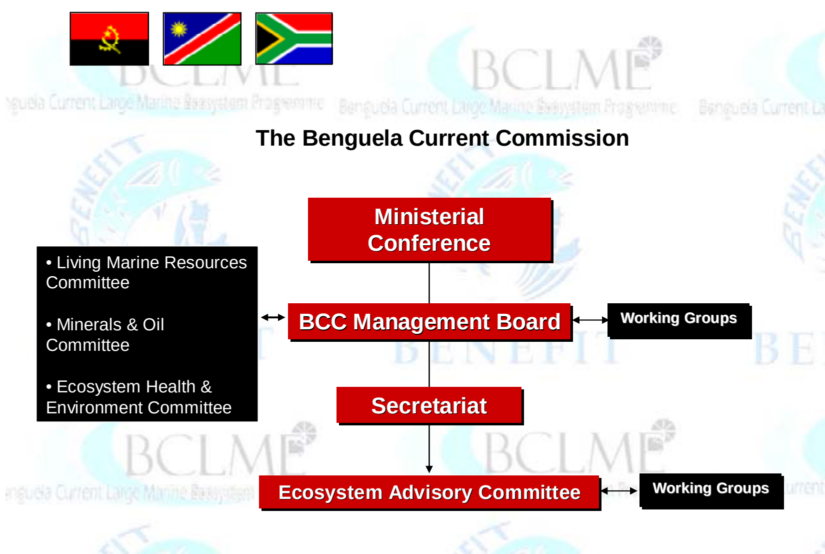

Figure 3. Structure and organization of the Benguela Current Commission.

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

The interim agreement of the BCC was formally signed in August 2006 by the Namibia ministers of Fisheries and Marine Resources, Environment and Tourism and Mines and Energy, and by the South Africa Minister for

Environmental Affairs and Tourism. The agreement was subsequently signed by the Angola ministers of Fisheries, Urbanism, the Environment and Petroleum in Luanda in January 2007. The first meeting of the Ministerial Conference of the BCC was held in Windhoek in July 2007.

LEARNING FROM EXPERIENCE

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

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

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

Close cooperation was also developed with the Global Ocean Observation System (GOOS) through GOOS-Africa, which led to strong partnerships in building capacity and training in operational oceanography and ocean monitoring systems particularly satellite remote sensing. A highlight of this cooperation was the Pan-African Forum on Large Marine Ecosystems held in Cape Town in November 2006. LMEs, GOOS, GEOSS and the UNEP Regional Seas Programme shared a common vision and identified the needs and areas of future collaboration, knowledge sharing, and the application of operational oceanographic skills.

REPLICATION

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

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

International linkages were successfully established with the GEF-supported Humboldt Current LME project and with the Implementation of the Strategic Action Programme (SAP) of the Pacific Small Island Developing States (SIDS) and other, more recent SIDS projects through collaborative workshops and exchange visits, some of which were sponsored by GEF IW:LEARN. These contacts led to the cooperation of scientists in the Benguela and in the Humboldt Current upwelling regions, with a sharing of knowledge on the ecosystems approach to fisheries management and the monitoring of top predators as a measure of ecosystem health.

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

SCOPE OF THE PROJECT AND COMMISSION

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

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

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

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

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BCLME Website: www.bclme.org

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

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Chapter 10

Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem: A Strategic Action Programme[*]

EXECUTIVE SUMMARY

Project objectives and activities

The objective of the UNDP/GEF Yellow Sea Large Marine Ecosystem (YSLME) Project is to facilitate the ecosystem-based management and environmentally-sustainable use of the Yellow Sea and its watershed by reducing development pressure and promoting sustainable development of this densely populated, heavily urbanised, and industrialized semi-enclosed shelf sea ecosystem. To achieve this objective, the YSLME Project prepared a Transboundary Diagnostic Analysis (TDA) and regional Strategic Action Programme (SAP). National Yellow Sea Action Plans (NSAPs) and demonstration activities of the SAP management actions were also prepared.

Transboundary environmental problems in the Yellow Sea

According to the TDA (2007) as well as to the new information reported since then, nine major transboundary environmental concerns have been identified:

- Pollution and Contaminants;
- Eutrophication;
- Harmful Algal Blooms (HABs)
- Fishing Effort Exceeding Ecosystem Carrying Capacity;
- Mariculture Facing Unsustainable Problems;
- Habitat Loss and Degradation;
- Change in Ecosystem Structure;
- Jellyfish Blooms; and
- Climate Change-related issues.

Purpose of SA for the Yellow Sea

To address these environmental issues, the YSLME SAP sets regional management targets for environmental quality of the Yellow Sea, and the required management actions to achieve these targets by 2020. Based on the concept of the "ecosystem carrying capacity" (ECC), the SAP proposes the targets and actions according to the services that the Yellow Sea ecosystem

[*] UNDP/GEF 2009. UNDP/GEF Project: *Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem. Strategic Action Programme*. 56 pages. ISBN:978-89-964543-0-4 93530

provides. The actions consist of both technical and institutional/legislative (governance) interventions.

Brief history of SAP development

To ensure the concerns of all stakeholders were addressed in the SAP, seven meetings with regional scientists, government officials, and other relevant stakeholders such as NGOs were organized in 2007 and 2008. Initially, a consultation meeting prepared a concept paper describing the objectives and central theme of the SAP. Next, two ad-hoc working group meetings identified the regional management targets and the management actions. The final two drafting group meetings prepared the draft SAP for the special Project Steering Committee (PSC) meeting, organized immediately after the third ad-hoc working group meeting. The PSC reviewed and approved the SAP as the final draft to be submitted to the participating governments for their consideration and endorsement.

This document was drafted by Mr. CHUNG Suh-Yong, Mr. ENDO Isao, Mr. JIANG Yihang, Mr. JIN Xianshi, Mr. WALTON Mark, Mr. WEN Quan, and Mr. YOO Sinjae with additional contributions from Mr. CHO Dong-Oh, Mr. FANG Jianguang, Mr. HUH Hyung-Tack, Mr. JANG In Kwon, Ms. KANG Young Shil, Mr. KWON Sukjae, Mr. LEE Jang-Uk, Mr. LEE Sang-Go, Mr. LEE Youn Ho, Mr. LI Haiquing, Ms. LI Jingmei, Mr. LIANG Fengkui, Mr. LIU Hongbin, Mr. PARK Gyung Soo, Mr. TOBAI Sadayosi, Mr. WANG Songlin, Mr. WANG Zongling, Mr. XU Xiangmin, Mr. YANG Dong Beom, Mr. YANG Yafeng, Ms. YU Ming, Mr. ZHANG Xuelei, Ms. ZHENG Wei, and Mr. ZHU Mingyuan.

Ecosystem-based approach

The YSLME SAP uses an innovative “ecosystem-based approach” to manage the complicated relationships between the environmental stresses and the resulting problems. The ecosystem-based approach uses scientific knowledge to guide appropriate management actions that preserve the ecosystem function of the YSLME. The goal of the YSLME SAP is to preserve the ECC which is defined as the capacity of the ecosystem to provide its ecosystem services. These services are vital for the welfare of communities surrounding the Yellow Sea. They include provisioning services (e.g.fisheries & mariculture), regulating services (e.g. regulation of climate change and water quality), cultural services (e.g. tourism), and supporting services (e.g. nutrient cycling & primary production). Traditionally, the management actions targeted problems by sector. However, this approach is of limited effectiveness as environmental problems are not normally the result of a single cause. The sector approach cannot address all the underlying causes. Based on this past experience, the ecosystem-based approach, advocated by the YSLME SAP, targets multiple ecosystem services holistically to sustain the ECC of the Yellow Sea.

Regional management targets and actions

The YSLME SAP proposes eleven regional management targets to sustain the ECC (Box 1). These targets primarily address a particular ecosystem service, with the understanding that achievement of a target will also benefit other ecosystem services. These targets are set using current scientific understanding and most are quantitatively measurable. Under ecosystem-based management, scientific monitoring is essential to assess the impact of the management actions and management must be adaptive to respond to new knowledge.

Technical actions

To achieve these regional targets, the SAP proposes associated technical management actions.

Governance Actions

The proposed management actions include not only technical actions as mentioned above, but also governance actions. Specifically, the SAP suggests the following actions as an implementation mechanism to enhance the environmental governance of the Yellow Sea: to improve the effectiveness of legal instruments; to promote participation of a wide range of stakeholders; and to create the YSLME Commission (Box 2).

Having devised the management actions, the SAP provides the means to secure economic justification of the actions and to monitor and evaluate their status and performance. Firstly, the SAP suggests the actions to integrate economic analyses into the ecosystem management of the Yellow Sea, providing the basic framework and a case study of the cost-benefit analyses of the management actions. Secondly, the SAP lists performance indicators (i.e. process, stress reduction, and environmental status) as well as the mechanism of monitoring and evaluation to determine the effectiveness of each action.

Future of ECC in the Yellow Sea

The current level of exploitation or stress placed on the Yellow Sea will result in a loss of economically important services; most noticeable will be the loss of provisioning services. Decision-makers are faced with a choice, whether or not to introduce the SAP management actions that will sustain the ecosystem services and preserve the Yellow Sea as a productive, useful commodity for future generations.

Box 1: Regional targets and technical actions proposed by the YSLME SAP

Provisioning Services

Target 1: 25-30% reduction in fishing effort
- Action 1-1: Control fishing boat numbers
- Action 1-2: Stop fishing in certain areas/seasons
- Action 1-3: Monitor and assess stock fluctuations

Target 2: Rebuilding of over-exploited marine living resource
- Action 2-1: Increase mesh size
- Action 2-2: Enhance stocks
- Action 2-3: Improve fisheries management

Target 3: Improvement of mariculture techniques to reduce environmental stress
- Action 3-1: Develop environment-friendly mariculture methods and technology
- Action 3-2: Reduce nutrient discharge
- Action 3-3: Control diseases effectively

Regulating Services

Target 4: Meeting international requirements on contaminants
- Action 4-1: Conduct intensive monitoring and assessment
- Action 4-2: Control contaminants discharge with reference to Codex alimentarius and Stockholm Convention
- Action 4-3: Implementing MARPOL 1973/78 effectively

Target 5: Reduction of total loading of nutrients from 2006 levels
- Action 5-1: Control total loading from point sources
- Action 5-2: Control total loading from non-point sources and sea-based sources
- Action 5-3: Apply new approaches for nutrient treatment

Cultural Services

Target 6: Reduced standing stock of marine litter from current level
- Action 6-1: Control source of litters and solid wastes
- Action 6-2: Improve removal of marine litter
- Action 6-3: Increase public awareness of marine litter

Target 7: Reduce contaminants, particularly in bathing beaches and other marine recreational waters, to nationally acceptable levels
- Action 7-1: Conduct regular monitoring, assessment and information dissemination particularly in bathing beaches and other recreational waters
- Action 7-2: Control pollution in bathing beaches and other marine recreational waters

Supporting Services

Target 8: Better understanding and prediction of ecosystem changes for adaptive management
- Action 8-1: Assess and monitor the impacts of N/P/Si ratio change
- Action 8-2: Assess and monitor the impacts of climate change
- Action 8-3: Forecast ecosystem changes in the long-term scale
- Action 8-4: Monitor the transboundary impact of jellyfish blooms
- Action 8-5: Monitor HAB occurrences

Target 9: Maintenance and improvement of current populations/distributions and genetic diversity of the living organisms including endangered and endemic species
- Action 9-1: Establish and implement regional conservation plan to preserve biodiversity

Target 10: Maintenance of habitats according to standards and regulations of 2007
- Action 10-1: Develop regional guidelines for coastal habitat management
- Action 10-2: Establish network of MPAs
- Action 10-3: Control new coastal reclamation
- Action 10-4: Promote public awareness of the benefits of biodiversity conservation

Target 11: Reduction of the risk of introduced species
- Action 11-1: Control and monitor ballast water discharge
- Action 11-2: Introduce precautionary approach and strict control of introduction of non-native species

Box 2: Outline of the YSLME Commission

Objectives
- To co-ordinate national efforts better
- To enhance the effectiveness of regional efforts

Nature
- Soft, non-legally binding and co-operation based institution

Institutional framework
- Steering Committee: serves as a supreme decision making body
- Secretariat: secures appropriate expertise to address the policy and research interests of the Steering Committee
- Sub-Commissions: mainly consist of experts, responsible for technical issues

Conclusions

To address the transboundary environmental problems in the Yellow Sea, the YSLME SAP develops an ecosystem-based approach to sustain the ECC holistically. The SAP not only sets regional management targets, but also devises the management actions to achieve the targets. The actions consist of both the technical and governance actions. With the implementation of these actions, the ECC of the Yellow Sea will improve and thereby continue to provide the ecosystem services.

Several characteristics make the YSLME SAP unique compared to other SAPs. Firstly, the YSLME SAP employs the ecosystem-based approach rather than the traditional sector approach. Secondly, the SAP provides the concrete and measurable targets and the comprehensive management actions to achieve them. Lastly, the SAP proposes mechanisms for regional co-ordination and co-operation, including the YSLME Commission.

The Yellow Sea ecosystem and its ECC will change in the future, for better or worse. If all the pressures exerted on the ecosystem continue, the Yellow Sea will degrade and its ECC will decline. However, if all the management actions proposed in this SAP are implemented and regional management targets met, the Yellow Sea will improve its capacity to supply its provisioning, regulating, cultural and supporting services and the Yellow Sea would remain a living, vital, productive, and healthy sea.

1. Environmental Challenges in the Yellow Sea: Environment status

The geographic area of Yellow Sea Large Marine Ecosystem (YSLME) for use in the project was defined in the UNDP/ GEF Project document [1] as the body of water bounded as follows: to the west by the Chinese coastline south of Penglai; to the north by a line from Penglai to Dalian; to the east by the Korean Peninsula and Jeju Island and a line drawn from Jindo Island off the south coast of the Korean mainland to the north coast of Jeju Island; and to the south by a line running from the north bank of the mouth of the Yangtze River (Chang Jiang) to the south-western coast of Jeju Island (Figure 1).

This shallow sea has an average depth of 44m [2]. The seafloor slopes gently from China and more steeply from Korea to a trough in the eastern portion that runs south to the Okinawa Trench [2]. It was carved by the ancient Yellow River (Huang He) when Yellow Sea was dry during the last glacial period [3]. The Yellow Sea region is under the influence of the Asian monsoon system, where seasonal winds prevail. The region is also located between the Siberian High and the subtropical Pacific Low, which results in cold-dry winters and warm-wet summers [4]. The bio-geochemistry of the sea is strongly influenced by fresh water and airborne (aeolian) material. Rivers discharge approximately 1.6 billion tonnes of sediment and 1,500 billion tonnes of freshwater into the Yellow Sea annually [5] with a further 460 billion tonnes of water from rainfall [3]. The huge freshwater inputs result in temperature and salinity differences that limit the water exchange between the Yellow Sea and the East China Sea [6], so that water is only exchanged every 7 years [7] making this sea vulnerable to pollution. There are two seasonal water circulation patterns (Fig 1) but water circulation is weak [7] meaning that coastal areas are susceptible to localised pollution discharges. Nevertheless, the Yellow Sea is very productive and supports substantial populations of fish, birds, mammals, invertebrates and a huge human coastal population. This population relies on the Yellow Sea LME for many services such as: provision of fisheries (2.3 million tonnes per year) [Yellow Sea Fisheries landings may include catch from adjacent areas, likewise catch from the Yellow Sea may be landed in elsewhere] & mariculture (6.2 million tonnes per year); the support of wildlife, provision of bathing beaches & tourism, and its capacity to absorb nutrients and other pollutants. The ability of the Yellow Sea to provide these services is defined here as “ecosystem carrying capacity.” Fisheries of the ten most important species landed in the Yellow Sea area1 have increased rapidly since 1986 from 400,000 tonnes to 2.3 million tonnes in 2004 [5]. However, this level of exploitation is not sustainable. In common with many other seas, over-exploitation of fisheries resources mean that fish catches in the Yellow Sea once mostly consisting of large, long-lived, valuable demersal fish such as hairtail and small yellow croaker are now dominated by short-lived, smaller, lower trophic level and less valuable species such as anchovy and sandlance [9].

The combination of the loss of wetlands, deterioration in coastal water quality and overexploitation of resources has reduced the ecosystem carrying capacity of the Yellow Sea. The loss of the capacity of the Yellow Sea to provide services such nutrient regulation combined with increased pollution is driving changes in the food chain that may not support the current productive ecosystem and are encouraging red tides and harmful algal blooms (HABs) currently experienced in the Yellow Sea [11, 12].

The loss of biodiversity reduces the ecosystem’s ability to respond to change [13]. Thus the loss of key fish species through over-fishing is thought to allow the blooms of flagellate and jellyfish [12] currently reported in the region [14-16]. These changes may signal the beginning of a shift towards an ecosystem dominated by worthless jellyfish, as has happened in various other areas including the Benguela Current Region [17, 18] and the Black Sea [19].

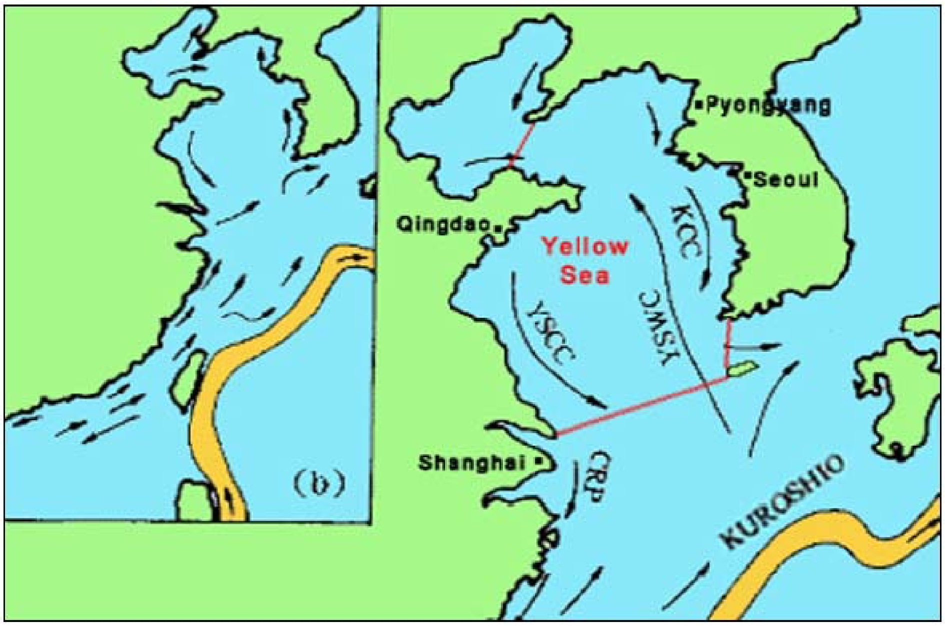

Figure 1: (a) Winter and (b) summer circulation features for the Yellow Sea, extracted from Su (1998) [10]. The identified currents include Yellow Sea Coastal Current (YSCC), Changjiang River Plume (CRP), Yellow Sea Warm Current (YSWC), Korean Coastal Current (KCC), and Kuroshio Current. The red line marks Yellow Sea LME boundary.

In order to ensure the future capacity of the Yellow Sea ecosystem to provide services such as the production of fish & shellfish, climate regulation, carbon sequestration and nutrient cycling, improved science-based management is required. The following document, the Strategic Action Programme of the YSLME, provides a roadmap for improving the ecosystem carrying capacity by the year 2020, through a combination of improvements in environmental legislation and enforcement, improved regional co-ordination and national co-operation between government agencies, elimination of environmentally damaging subsidies, enhanced public awareness and capacity building, and the use of regional monitoring networks. Once in place, these actions will help limit the loss of habitat, reduce environmental degradation and improve over-exploited fish stocks. Using the principles of ecosystem-based management and sustainable use we can ensure these ecosystem services for future generations.

Environmental impacts from an adjacent area, the Bohai Sea, are addressed by similar management actions identified in this document. China's "National Action Plan for the Blue Bohai Sea" has documented reductions of fishing efforts and pollution discharge. The GEF-funded PEMSEA Project developed the “Bohai Sea Declaration”, and Environment Management Strategy in the Bohai Sea, with participation of the provinces and cities around the Bohai Sea. These efforts are going on in the region. Relevant information and impact assessment of management actions will be provided by the PEMSEA Project and the appropriate governmental agencies in China.

2. Environmental Problems and Causes

The Transboundary Diagnostic Analysis (TDA) is part of the mechanism that the GEF recommends to ensure that nations sharing an large marine ecosystem (LME) begin to address coastal and marine issues by jointly analysing factual, scientific information on transboundary concerns [20]. The root causes and priorities for management actions to address those concerns are examined in the Causal Chain Analysis. The TDA process provides a useful mechanism to foster participation at all levels. This section set out the primary environmental concerns as expressed in TDA and new information reported since the TDA was published.

2.1 Pollution and Contaminants

Pollution is the introduction of contaminants into the environment that causes harm to organisms or damage to the environment [21]. These cover a range of compounds resulting from human activities due to discharges of industrial and domestic waste. These enter the marine environment through rivers, groundwater and through the atmosphere as wet or dry deposition. Some of these contaminants occur naturally and are essential for supporting life, while others have only been found since the industrialisation occurred. Most of these compounds have no detrimental effect until a certain critical concentration is reached either in food or in the environment. The Regional Working Group (RWG) on Pollution identified inorganic nitrogen and phosphate, faecal substances, heavy metals, persistent organic pollutants (POPs), polycyclic aromatic compounds (PAHs) and marine litter as the major contaminants in the Yellow Sea [1].

Inorganic nitrogen and phosphate are important nutrients that sustain phytoplankton (single celled algae) communities, which form the basis of the marine food chain. However, high concentrations stimulate excessive phytoplankton growth that cannot be consumed by zooplankton leading to eutrophication (see 2.2) and HABs (2.3). Faecal compounds from domestic waste disposal can result in contaminated water supplies or seafood, like mussels, oysters and scallops. The resulting illnesses vary from stomach ailments to dysentery or typhoid. Heavy metals, although possibly important locally around industrial areas, are not considered a transboundary problem. PAHs are also likely to be a more localised issue associated with certain industrial processes although this class of compound can be mutagenic or carcinogenic [1]. Incorporation of POPs in to the food chain is, however, part of a global problem and can lead to increased health risks in humans [1].

2.2 Eutrophication

The extensive and frequent over-use of chemical fertilizers and the increased discharges of partially treated industrial and domestic waste have raised the concentration of dissolved inorganic nitrogen in coastal waters. This nutrient enrichment acts as a fertilizer stimulating the growth of phytoplankton often to a problematic degree as evidenced by algal blooms and red tides. Few species are able to grow in this environment and feed on this productivity and therefore biodiversity is decreased. Normal food chains that support fish and shellfish are highly impacted, and production suffers[1]. The Yellow Sea is very vulnerable to eutrophication as it is isolated from the East China Sea by a strong thermohaline front [6] and internally, water circulation is weak [7]. This results in a flushing time of 7 years [7] meaning that contaminants like nitrogen can accumulate in the system.

2.3 Harmful Algal Blooms (HABs)

Frequently, the eutrophication 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, especially in mariculture establishments [1]. Silicate (Si) is the result of the erosion and weathering of rocks and is carried to the sea by rivers, ground water and by the wind as dust. As a result of changing freshwater flows due to irrigation and hydroelectric projects, much of the silicate is trapped before entering the sea. The decreased silicate inputs in combination with increased nitrogen (N) concentrations have changed the ratio. This Si:N ratio is vital in sustaining the growth of diatoms. Diatoms are the most important group of phytoplankton in economically productive systems, accounting for approximately 60% of primary production by biomass in the world oceans [22] However, when the ratio of Si:N falls beneath a ratio of 1:1 (Redfield ratio), the lack of silica prevents diatoms from forming their silica body walls and consequently flagellate species are favoured [23-25]. Since 1980, the Si concentration in the Yellow Sea has been close to the ecological threshold required for diatom growth [26]. The result is that organisms that are not dependent on this nutrient benefit most, such as flagellates. Some of these flagellates produce blooms (red tides and HABs) that are either toxic to higher organisms, such as human shellfish poisoning, or reduce palatability of seafood. Intense blooms can also reduce survival of fish and shellfish through gill clogging and reduced oxygen levels [1].

2.4 Unsustainable Fisheries

The rapid increase in Yellow Sea fisheries landings experienced since 1986 when catches were 400,000 tonnes to 2004 when almost 2.5 million tonnes of fish were caught is unsustainable [27, 28]. The over-exploitation is evidenced by the decrease in mean size at catch of some species over the same time period [29]. In addition the composition of fisheries catches have dramatically changed in the last decades: in the 1950's and '60's the catch was dominated by small yellow croaker, large hairtail and shrimp; in the '70's herring dominated the catch briefly and in the late 80's to the present day anchovy has been the dominant species, although recently even catches of anchovy have declined and a new fishery for sandlance has developed. In general large commercially valuable species have been replaced by smaller, lower trophic level, less valuable pelagic species [1, 9, 30, 31]. Furthermore, the mean trophic level of the main commercial species in the Yellow Sea has decreased due to dietary changes as a result of ontogenetic shifts in diet, climate change induced changes in availability of dietary items and over-fishing of the prey items of carnivorous fish e.g. anchovy [32].

2.5 Unsustainable Mariculture

The production from mariculture and freshwater aquaculture from China and Republic of Korea (ROK) has grown spectacularly and in 2005 these countries accounted for 44 million metric tonnes[33] or 70% of the world's total production, with China accounting for the bulk of the growth [1]. Mariculture accounted for approximately 14 million tones in 2004 of which the greatest increases were from mollusc culture. However there are signs that these increases are not sustainable, and recently the productivity per unit area has begun to fall as the area under cultivation grows [1, 5]. This fall in productivity maybe due to the fact that only unsuitable cultivation areas now remain, or that increased proximity of farms has resulted in: increased disease transmission between farms; raised concentrations of organic wastes; and competition for food resources amongst cultivated organisms [1]. These factors all increase stress and lower the growth and survival rates of the culture organisms, thus reducing productivity.

2.6 Habitat Loss and Degradation

Habitat has been lost at staggering rate with almost 40% of coastal wetlands being converted to other uses [8] and both countries have further development plans. Coastal construction has altered coastal habitats, and industrial, agricultural and domestic effluent, aggregate mining and dumping have further degraded the marine coastal environment. These coastal wetlands are important habitat for shellfish fisheries and culture, and many of the commercially important fish species use these areas as nursery or feeding grounds at some stage in their life cycle. Additionally many endangered bird species depend on these wetlands as feeding and breeding grounds on their migration routes [5]. Moreover these wetlands perform import biogeochemical functions such as sediment retention, carbon sequestration, nutrient cycling, prevention of saltwater intrusion and coastline stabilisation.

2.7 Change in Ecosystem Structure

Changes in the biomass and composition of phytoplankton and zooplankton communities could have serious consequences for fisheries productivity as these groups form the basis of the food chain. The national reports by the YSLME project indicated increases in the biomass of phytoplankton fraction > 77 μm, but decreases in the zooplankton > 500 μm on the Chinese side, while on the Korean side of the Yellow Sea increased biomass of zooplankton > 330 μm were recorded [1, 5, 27, 28]. The ratio of diatoms to dinoflagellates was reported to have decreased in recently years, possibly in response to the increasing eutrophication and decreased ratio of Si:N [1] as mentioned previously. Benthic biomass also appears to have decreased and the proportion of polychaetes seems to have increased [5], these changes are frequently associated with increasing eutrophication of the sediments. The reduced benthic community could have important consequences as it is an important food source for many commercial important fish species. As mentioned previously, there have also been changes in the composition of fisheries landings suggesting that community structure has altered as a result of overfishing and other anthropogenic impacts.

2.8 Jellyfish Blooms

The TDA reported that the abundance of jellyfish have increased in recent years leading to clogging of fishing nets and increased likelihood of bathers being stung [1]. Recently it was reported that the increase in marine litter and construction of concrete structures (e.g. jetties and wharfs) has expanded the habitat available for the asexual reproductive stage of jellyfish [34]. In addition, the reduction of plankton-eating fish stocks, brought about by over-fishing, has increased the food available to support the growth of jellyfish blooms [18, 35]. There appears to be a growing consensus that pollution, acidification of the sea and changing phytoplankton communities is leading to increased jellyfish densities [12, 17, 35-38]. Not only do these higher jellyfish densities impact the tourists and fishermen in the Yellow Sea, they also directly impact fish stocks through feeding on the fish larvae and reducing the availability of zooplankton which is an important food source for larval fish [37, 39-43].

2.9 Climate Change-related

Air temperatures over the Korean Peninsula have increased at a rate of 0.23°C/decade since the 1960's [44]. Although annual variation in sea temperatures appears to be connected with other major climate systems (e.g. El Nino/Southern Oscillation and the Aleutian Low) [44], mean sea temperatures have increased 0.38 – 0.94°C/decade in the Yellow Sea [26]. The warming trend has been accelerating in recent decades and there has been a northward movement of isothermals during the period [45]. Climate change will affect marine ecosystems in many ways [46]. Changes in global precipitation and temperature patterns could alter large-scale oceanic circulation patterns [47]. As a result, circulation in marginal seas such as the Yellow Sea will be affected as well. This will affect migration and dispersal of marine organisms. Intensified stratification can reduce the productivity in the upper layer as reported from offshore waters of California [48]. Diseases are more likely in the warming environment already the incidence of disease in many marine species is increasing around the world [49]. Most of the major commercial fish species over-winter in the bottom cold water mass located in the central southern portion of the Yellow Sea [28]. Shrinkage of cold water mass due to climate change could have serious consequences for these stocks. Already some cold-water species, such as Pacific cod and herring, are no longer found in commercial numbers due to over-fishing and/or warming of the water mass [44]. Climate change can cause the mistiming of the arrival of migratory birds and breeding season with food availability as evidenced in other seas [50, 51]. In addition, climate driven changes in sea level could have significant impacts of the food availability to wading birds [52].

The increase in carbon dioxide emissions due to anthropogenic activities that is driving climate change is also causing acidification of seawater. A decrease 0.7 pH units is expected by the time fossil fuels are depleted. Already the pH of the world oceans has decreased 0.1 pH units, representing a 30% increase the H+ ion concentration [53]. The speed of change is causing concern, as oceans are unlikely to be able to adapt so quickly [53]. Already links between jellyfish density and acidification have been reported [54].

3. Institutional and Legal Framework in Protection of Marine Environment and Sustainable Use of Marine and Coastal Resources: Current Status and Limitations.

3.1 Institutional Arrangements Status: Regional Co-operative institutions (e.g., YSLME, NOWPAP) exist, but the coordination among institutions could be improved to address environmental stresses in the region. Several international institutions exist in the region. While the YSLME Project is directly related to the regional governance in the Yellow Sea, other institutions such as Northwest Pacific Action Plan (NOWAPAP), Partnerships in Environmental Management for the Seas of East Asia (PEMSEA), and IOC/WESPAC also have some relevance to the Yellow Sea region [55]. There are also bilateral co-operative institutions including those between China and ROK based on two bilateral treaties on the environment and fisheries, i.e. the Joint Committee on the Environmental Co-operation and the Joint Fisheries Commission [55]. However, the level of co-ordination among the institutions to bring synergic effects and the efforts to avoid the duplication problem is low. For example, considering the serious impacts of the recent oil spill accident in 2007, better co-ordination between the YSLME Project and NOWPAP could have increased the effectiveness of regional efforts to deal with the problems.

Gaps: There is a need to improve regional co-ordination. Improved regional co-ordination will enhance overall effectiveness using limited resources in the Yellow Sea region. This can be achieved by a creation of a regional co-ordinating mechanism such as the YSLME Commission.

3.2 Legal standards

Status: There are several treaties and guidelines related to the environment of the Yellow Sea region, but the level of strictness and scope of coverage of these legal instruments varies. The United Nations Convention on the Law of the Sea, the London Convention and its 1996 Protocol, MARPOL, the Convention on Biologic Diversity, the Ramsar Convention and the FAO Code of Conduct for the Responsible Fisheries are examples of multilateral treaties and guidelines [55]. Bilateral treaties such as those between China and ROK on the environment and fisheries are also relevant to the environment in the Yellow Sea [55].

However, not all of the coastal countries in the Yellow Sea region are the members of the treaties including the 1996 Protocol to the London Convention and Annex VI of the MARPOL [55]. Furthermore some treaties such as the United Nations Convention on the Law of the Sea, and the Convention on Biologic diversity do not provide detailed legally binding standards to address the problems in the Yellow Sea to the coastal countries. The FAO Code of Conduct for the Responsible Fisheries, on the other hand, may not be effective due to its non-legally binding nature. At the national level, national laws and regulations of coastal countries in the region have not been sufficiently developed to implement regional standards [55]. There exist inconsistencies of existing laws and regulations. Limited enforcement of laws and regulations contribute to the problem of implementation of legal instruments.

Gaps: There is a need to improve the strictness, scope of coverage and enforcement mechanism of legal instruments. Improvement of the strictness and scope of coverage of legal instruments at the regional level will help enhance overall effectiveness of the legal instruments. Development of a regional mechanism to harmonise national legal institutions is also necessary in order to achieve equally effective implementation of legal instruments in each participating country.

3.3 Stakeholders' Involvement

Status: Several stakeholders are involved in the regional governance in the Yellow Sea region. However, the level of importance and participation varies. The government is the most important stakeholder. The role of the central governments of the participating countries has been critical. However, among the coastal countries in the Yellow Sea region, the Democratic People's Republic of Korea (DPRK) has not fully participated in the regional efforts. Several international organisations have participated in the regional governance. UNDP has actively participated in the regional governance while the UNEP and IMO are also related to the regional governance in the Yellow Sea. Other stakeholders such as NGOs and private sectors have participated in the regional governance less actively compared with other realms [55].

Gaps: Securing participation of all the coastal countries and relevant stakeholders in the regional governance is necessary. Capacity building of some stakeholders is also important before their full participation in the regional governance. Despite some progress in securing the participation of DPRK in regional efforts, full participation of the DPRK, which is important in terms of geographical completeness and effectiveness of regional governance in the Yellow Sea region, has not been achieved yet[55]. Enhanced co-ordination among the participating governments is also necessary to enhance the effectiveness. Further constructive participation of relevant international organisations needs to be sought. Capacity building of local governments and NGOs is necessary to encourage their full participation in regional governance. Finally a constructive participation of private sectors is also important to enhance overall effectiveness of regional governance in the Yellow Sea region.

4. Environmental and Scientific Basis for the Management Strategies: Ecosystem Carrying Capacity and Regional Management Targets

4.1 Ecosystem Services

The Yellow Sea provides many benefits that are crucial for the lives and wellbeing of people in the surrounding countries. The coastal population especially, relies on the Yellow Sea ecosystem for a large portion of their basic and economic requirements. These benefits obtained from ecosystems are called ecosystem services [56] and are generally classified into four categories: provisioning, regulating, cultural and supporting services [57]. Provisioning services provide ecosystem goods such as seafood (cultured as well as natural), fuels, bio-products, genetic resources and raw materials (e.g. sand & salt). Regulating services play a crucial role in the maintenance of environmental quality. These include water quality regulation, sewage treatment, waste disposal, and disease regulation. Cultural services provide non-material benefits such as spiritual, aesthetical, and recreational amenities. While some cultural services, like tourism, have market values [58], others, such as spiritual services might be difficult to be valued. Whether or not cultural services have market values, they have direct implications for human well-being. Therefore, provision-ing, regulating, and cultural services provide benefits directly usable by people.

There are other kinds of ecosystem services that human society needs, although they are not as visible as the above three service categories. For the three directly-usable services to be maintained, basic ecosystem functions and processes have to work. Physico-chemical and biological processes are involved in such basic ecosystem functions. For example, people eat fish and fish eat plankton, and therefore in order to sustain fish production, production of plankton communities should be maintained. Production of plankton is furthermore controlled by many physico-chemical factors. These functions that support the basic processes of ecosystems are called supporting services. Supporting services include primary production, nutrient cycling, and maintenance of biodiversity. Without supporting services, the other directly-usable services cannot be sustained.

4.2 Ecosystem Carrying Capacity

Not every ecosystem provides the same quantity and quality of ecosystem services. This is because ecosystem services are the result of many physico-chemical and biological processes within the ecosystem, and different ecosystems have different structures and processes. Therefore, it is obvious that there is a limit to the ecosystem services that an ecosystem can provide. Also, as an ecosystem changes, the ecosystem services that they provide will change. For example, if the environmental conditions deteriorate, fisheries resources decline and we get less fish for food. The factors that change the structure and productivity of ecosystems are called drivers of the ecosystem changes [56]. Most physico-chemical factors are called direct drivers as they immediately influence ecosystems. But it is the indirect drivers that are ultimately responsible for direct drivers. Urbanisation and population growth are good examples. These indirect drivers will increase the nutrient loads (a direct driver) which will lead to eutrophication. Figure 2 describes the relationship of ecosystem, ecosystem services, direct and indirect drivers, human societies, and climate system. These form a cycle which is driven by human societies and climate system.

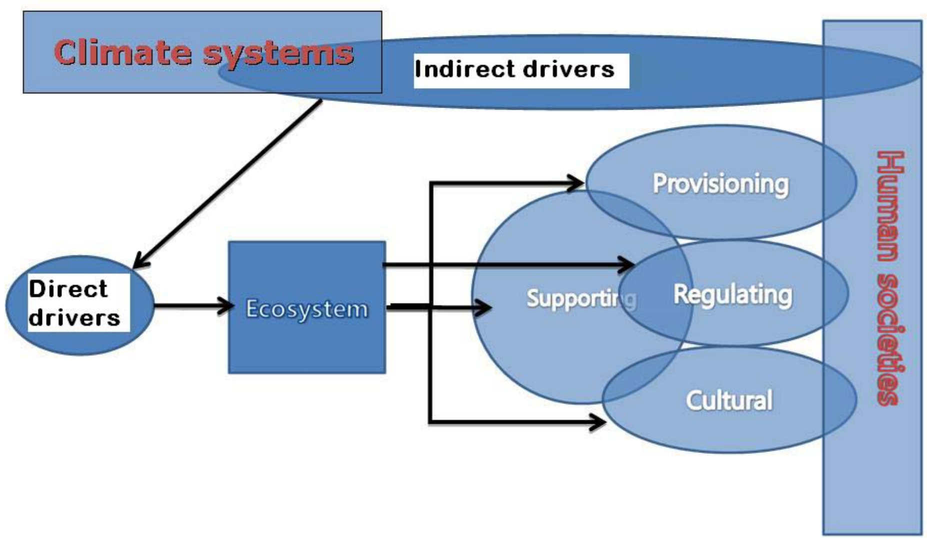

Figure 2: Relationship of ecosystem, ecosystem services, direct and indirect drivers, human societies, and climate system.

Thus, in the face of a changing world, the goal of ecosystem management will be to maximise and sustain ecosystem services. However, managing ecosystem services is a complicated issue as there are linkages and tradeoffs among services [57]. For instance, if aquaculture production (provisioning service) is unsustainably maximised, other services, such as regulating, cultural, and supporting, will be diminished in addition to reduction of wild fish catch. Because of linkages and trade-offs, we cannot manage each ecosystem service separately. This is why sectorial approaches have not been very successful. Another problem is that, not all the drivers of ecosystem changes are controllable (e.g., climate change). Climate change will further complicate the management issue as its effects will interact with anthropogenic drivers.

Therefore, there is a need for a comprehensive and holistic quantity that describes this fundamental capacity of ecosystem to provide its services. We define "ecosystem carrying capacity[1] (ECC)" as the capacity of an ecosystem to provide its services or the sum of all the ecosystem services it can provide. ECC will be determined by various ecological processes that are inter-dependent, which in turn are determined by ecosystem configuration and state. As such, ECC will change under different environmental conditions as the ecosystem structure and processes will change. The environmental conditions will change as societal requirements increase and climate change accelerates.

4.3 Future of ECC in the Yellow Sea

During the past decades, we have witnessed many signs of the deterioration of the Yellow Sea's ECC, such as the decline of commercially important fish landings, increase of algal blooms, and novel jellyfish blooms [1]. We have identified the major environmental threats to the health of the Yellow Sea ecosystem in section 1 and 2. The problems can be summarised into five broad categories: pollution, habitat modification, unsustainable mariculture, unsustainable fisheries, and climate change. These problems have impacted fundamental ecosystem properties, which in turn have been changing ECC of the Yellow Sea.

How the Yellow Sea ecosystem and its ECC will change in the future? If the trends identified in the TDA continues, we will experience further degradation of the Yellow Sea ecosystem and reduction of ECC. Moreover, global climate change will exacerbate the situation. Disturbances in the hydrological cycle, sea-level rise, ocean acidification, spread of diseases, rising temperature, and strengthened stratification among others will amplify the on-going problems [46, 62-68]. The impacts of climate change will be experienced throughout the whole basin. Such ecosystem changes are difficult to predict with certainty because of complicated interactions and un-controllable forcing. The future management of the Yellow Sea ecosystem therefore should be designed and executed as an adaptive, learning-based process that applies the principles of the scientific methods to the processes of management. The ultimate target of ecosystem based management should be to sustain ECC of the Yellow Sea

[*] "Carrying capacity" concept was originally proposed by Verhulst (1845)[59] to describe logistic growth of human population. The concept has been widely used in population ecology, e.g. Begon et al (2006) [60]. Recently, Olsen et al. (2006)[61] used the term as "ability of ecosystems to sustain fishery and other living resources"

ecosystem. This requires that the management actions should be based on long-term scientific research and adaptive strategies.

4.4 Regional Management Targets *

In this document, the Regional Management Targets are the regional management objectives to be achieved by 2020 through implementation of management actions. Each of the five major environmental problems mentioned above as major stresses changes ECC and affects multiple ecosystem services (Figure 3). The regional management targets should aim to the reduction of those stresses and the improvement of ECC as a whole through ecosystem-based approach. Improving ECC means improving all of its components: provisioning, regulating, cultural, and supporting services.

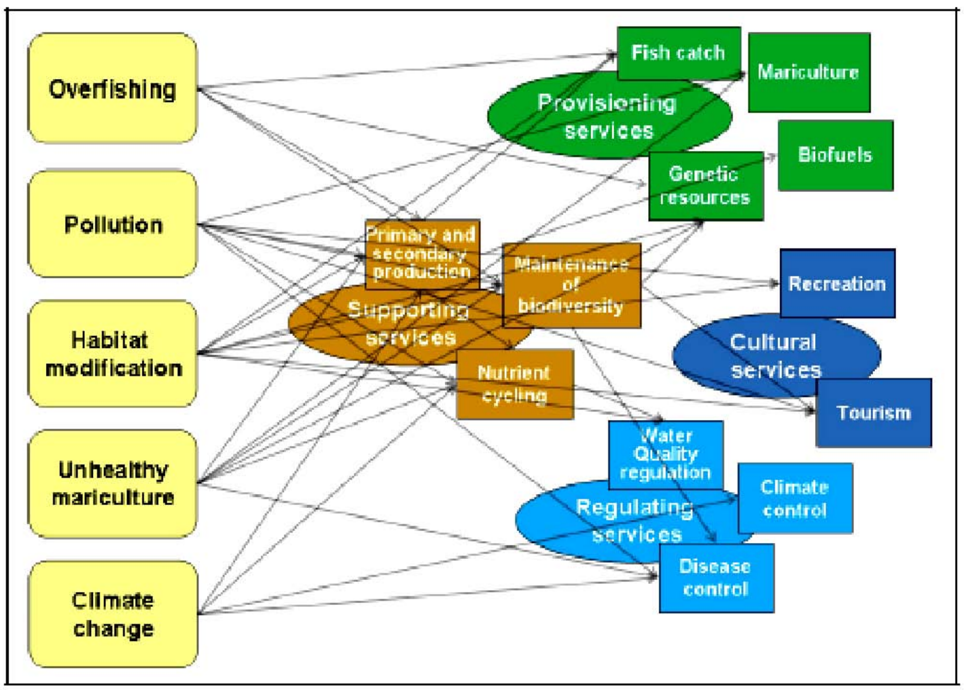

Figure 3: Relationship between major environmental problems and ecosystem services.

The Regional Management Targets for 2020 are:

A. The ECC should be improved for sustaining the provisioning services from YSLME to provide foods, genetic resources, new materials and bio-fuels, etc., to meet the requirements of human welfare. In this regard, the regional

* Regional Management Targets are equivalent to the Regional Ecosystem Quality Objectives from the GEF document

management targets should be to reduce the fishing effort, to rebuild the over-exploited fish stocks, to improve the sustainable mariculture techniques, and to keep the stock levels adequately high for reproduction to ensure the healthy condition of fisheries resources.

B. The ECC should be improved for maintaining the regulating services of YSLME for sewage treatment (water quality regulation), disease control and climate regulation, etc. to meet the requirements of environmental and human safety. In this regard, the regional management targets should be to keep the quality of seafood at safe levels, and to improve the seawater quality with reduction of pollutant discharge.

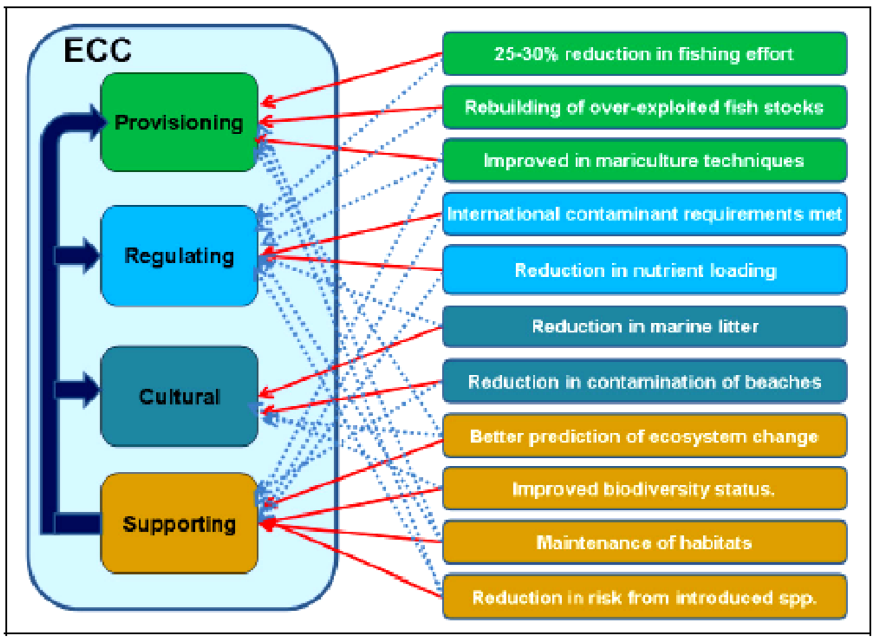

Figure 4: The relationship between Ecosystem Carrying Capacity (ECC), ecosystem services *(left) and the regional targets (right) that seek to maintain these services.*

C. The ECC should be improved for increasing the cultural services of YSLME for its, aesthetic values and cultural diversity and attractiveness for recreation and ecotourism as well as spiritual/religious values. In this regard, the regional management targets should be to conserve the landscape and/or seascape, and to reduce the standing stock of marine litter and contaminants particularly around bathing beaches and other marine recreational waters, to nationally acceptable levels.

D. The ECC should be improved for maintaining the supporting services of YSLME for nutrient cycling, primary and secondary production and their transfer, and maintenance of biodiversity, habitat preservation, etc. In this regard, the regional management targets should be to reduce the human impacts in order to maintain and improve current populations/distributions and genetic diversity of organisms including endangered and endemic species, to maintain the habitats according to standards and regulations of 2007, and to reduce the risks from introduced species and red tides. Also required is better understanding and prediction of ecosystem changes to ensure effective adaptive management.

5. Management Strategies: Interventions and Actions towards 2020

To improve ECC, or the ecosystem services as a whole, eleven regional targets have been selected (Figure 4). Appropriate management for these targets will improve physical, chemical, biological processes that sustain ecosystem services, and thereby will improve ECC eventually. In Figure 4, how these targets are related to ecosystem services are indicated by red arrows. These red arrows indicate the major links but achieving these targets will improve more than one service. Such additional effects are indicated by dotted arrows in blue. While the eleven targets are classified by the major linkages, their effects will be multiple and holistic. Also note that the targets mainly related to supporting services will promote other services. Although supporting services are not directly usable by humans, they support other directly usable services. To sustain or maximise ECC, not only the directly-usable services, i.e., provisioning, regulating, and cultural services, but also supporting services should be maintained. That is why targets seemingly having indirect relevance are included, such as monitoring and assessment of ecosystem structure and productivity. For example reducing fishing effort may not have the desired effect of rebuilding fish stocks, without a reduction in the pollutant discharge (Figure 5). This is because pollution is affecting the supporting services, degrades the environment, changing the composition of the phytoplankton (micro-algae) which in turn affects the zooplankton composition which affects the fish production. Figure 5 represents choices faced by decision makers, whether to introduce management actions to sustain ecosystem services and the resulting maintenance of fisheries catches, or take no action, with the result that by 2020 if trends continue fish catches will be significantly reduced and will consist of smaller less valuable fish.

Planning and implementation of comprehensive regional ecosystem quality objectives that address problems faced by all ecosystem services are fundamental for adaptive, scientific, ecosystem-based management.

5.1 Actions Primarily Addressing Provisioning Services

Decline in landings of many commercially important fish species and unsustainable mariculture practices have been identified as the major factors affecting the provisioning services of the Yellow Sea ecosystem. The following actions principally aim to make provisioning services of the Yellow Sea ecosystem sustainable. The first goal is to increase fisheries resources by reducing fishing pressure and rebuilding fish stocks. The second goal is to make mariculture sustainable by reducing its impacts on the environment and by controlling diseases effectively. Although these actions will primarily improve provisioning services, they will also have pervasive effects on regulating, cultural, and supporting services as well.

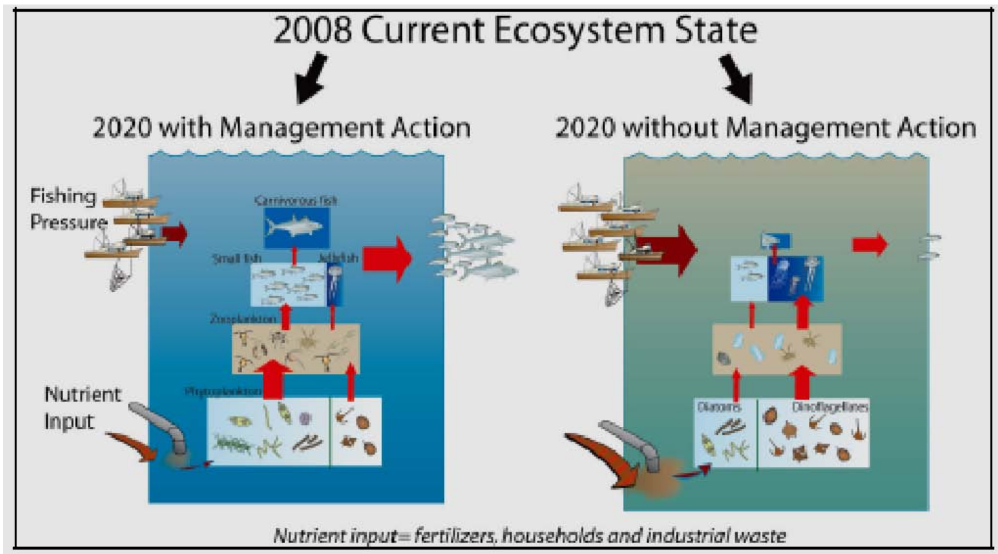

Figure 5: A simplified overview of the state of the ecosystem in 2020 with and without management actions.

5.1.1 Technical actions

Target 1：25-30% reduction in fishing effort*

Management Actions1-1: Control fishing boat numbers
Reduction in fishing effort already has been implemented in the region for several years. Optional buy-back of fishing boats from fishermen will continue, a reduction of 25-30% of total marine fishing boats is recommended during 2004-2020 based on the current stock level. In addition, new boat building should be strictly controlled.

Management Action 1-2: Stop fishing in certain areas/ seasons

Closed season and areas for fishing have been used for many years. Limitation of fishing is implemented in certain areas, such as spawning and nursery grounds in the coastal waters, and is a useful measure to conserve

* Estimation of reduction required to avoid over-exploitation explained and presented at the First Yellow Sea Regional Science Conference [69], the specification of management actions will be adjusted according to new regional knowledge, including the regional stock assessment organized under the project.

fisheries resource. Closed seasons and areas for fishing need to be continued based on improved scientific knowledge. In China, after 12 years in practice, the summer fishing ban has been demonstrated to efficiently conserve juvenile fish stock, and should be continued. Marine protected areas for fishery resources need to be established for conservation of the spawners and genetic resources of living resources.

Management Action 1-3: Monitor and assess stock fluctuations

There is a need to improve quality of data and of stock and/or individual-level biological parameters. Stock assessment is the basis of fisheries management, and should be based on scientifically monitored data and independent information. Joint monitoring and analysis of major stocks, compatible data and assessment methodology, need to be undertaken co-operatively as a demonstra-tion of the benefits to the individual country. Establishment of a regional database is recommended.

Target 2：**Rebuilding of over-exploited fish stocks**

Management Action 2-1: Increase mesh size

Yellow Sea is exploited by many different types of fisheries all using different gears. The main fishing method used in the YSLME is the bottom trawl which is a fairly unselective in what it catches. Increasing mesh-size can reduce the percentage of juveniles caught. More selective fishing gears and optimum mesh-size based on the studies of gear performance and fish behaviour are recommended to reduce by-catch.

Management Action 2-2: Enhance stocks

To rebuild over-exploited stocks, degraded habitats for fishery resources will be improved by transplanting sea-grass and by controlling pollution and construction. Estimation of reduction required to avoid over-exploitation explained and presented at the First Yellow Sea Regional Science Conference[69], the specification of management actions will be adjusted according to new regional knowledge, including the regional stock assessment organised under the project. Healthy, genetically diverse fry of high value fish and shellfish species will continue to be released into the sea in order to increase recruitment and help rebuild stocks. Designation of protected areas and building of artificial reefs in appropriate areas of the sea with suitable monitoring is encouraged to conserve and increase fishery resources and improve their environment. Impact of the release of hatchery-raised juveniles and construction of artificial reefs on the ecosystem should be monitored and assessed.

Management Action 2-3: Improve fisheries management

Ecosystem-based fisheries management (EBFM) has been widely discussed worldwide due to the failure of single species management. Introduction of EBFM is suggested based on improved knowledge. Establishment of a self-regulation system by fishermen and community-based management in the coastal areas are recommended. Use of Total Allowable Catch (TAC) and Individual Transfer Quota (ITQ) based on survey and assessment should be encouraged in fisheries management. Fish landings should be substantially reduced to optimal levels to keep biomass at biologically safe levels. Each participating country should implement the reduction in fishing efforts to nationally acceptable level, making efforts to ensure effectiveness in securing the sustainability of provisioning services.

Target 3： Improvement of mariculture techniques to reduce environmental stress

Management Action 3-1: Develop environment-friendly mariculture methods and technology

Yellow Sea region is one of the most productive areas in mariculture, many methods have been used. As an environment-friendly mariculture method, Integrated Multitrophic Aquaculture (IMTA) is recommended as it will also increase economic benefit. Standard offshore technologies to different conditions should be developed. Good Aquaculture Practice (GAP) should be demonstrated at commercial scales.

Management Action 3-2: Reduce nutrient discharge

The development of mariculture in the region is the fastest in the world, in order to reduce its negative impacts on the ecosystem, limited water exchange aquaculture systems, re-circulating systems are recommended to be established, and artificial diet improvement should be practiced on a commercial scale.

Management Action 3-3: Control diseases effectively

Mariculture diseases seriously affect the production. Diagnosis and control techniques for major diseases need to be developed and established. The network for an early warning and diagnosis system of diseases is suggested. New techniques and management measure to control disease should be introduced to the farmers.

5.1.2 Governance Actions

- Public awareness of the future benefits of a reduction of fishing boats, closed seasons/areas and improved regulations will bring, should be increased, especially among fishermen. A mechanism should be created to increase the public awareness of the benefits of IMTA, offshore aquaculture and limited-water exchange systems and artificial feeds.

- Alternative livelihoods should be provided until all ex-fishermen have new job opportunities, preferential taxation should be given to the fishermen who are engaged in non-fishing work, and subsidies for impoverished ex-fishermen are recommended [70].
- Training programmes should be encouraged to provide ex-fishermen with new techniques, information and skills.
- Incorporation of stakeholders into the various decision-making systems related to marine resource management, coastal zone management, pollution management etc. is encouraged. Co-ordination is also desirable between scientists, managers, fishermen, farmers, government departments and countries.
- Various management measures have already been implemented. However, with the development of fisheries industries and international ocean environment, the current laws and regulations for fisheries management need to be improved to meet the requirements of today.
- Illegal fishing and mariculture should be strictly controlled. Capacity building for enforcement of relevant regulations should be increased.
- Licenses that control both farm area and species are recommended. Standards and regulations for offshore mariculture are needed to as this industry develops. Improved regulations to control nutrient discharge and diseases in mariculture are needed, and policies to discourage use of trash fish should be encouraged.
- Establishment of a regional fishery scientific committee as a subsidiary body of the YSLME Commission is recommended, to conduct joint monitoring and assessment for trans-boundary fish stocks and ecosystem productivity, and to evaluate trans-boundary resources and to provide advice for fishery management.

5.1.3 Indicators of management actions

The following indicators are considered for management actions that address the
provisioning service function of YSLME:

- A 1/4 - 1/3 reduction in the number of motorized fishing boats by 2020 from 2004, and a harvesting level will meet the “surplus yield”, implying that the stocks are kept at biologically safe levels to ensure sufficient reproductive capacity to maintain fisheries resources in a healthy condition. Recovery of some over-exploited commercial fish stocks.
- The release of billions of fry into the sea for stock enhancement after necessary evaluation in accordance with ecosystem stability.
- The establishment of at least ten protected areas for fishery resources in the Yellow Sea.
- Reduced environmental stress as a result of the widespread adoption of environment-friendly mariculture and sustainable mariculture techniques.
- Efficient operation of a network of an early warning and a diagnosis system for mariculture diseases.

5.2 Actions Primarily Addressing Regulating Services

Problems for nutrient cycling, such as pollutant discharge, eutrophication, abnormal nutrient ratios and solid waste disposal were identified as major factors affecting regulating services of the Yellow Sea ecosystem. The following actions principally aim to improve regulating services of the Yellow sea ecosystem. The first goal is to control contaminant discharge according to the international standards. The second goal is to reduce eutrophication by diminishing nutrient loading. Although these actions will primarily improve regulating services, they will also have pervasive effects on provisioning, cultural, and supporting services as well.

5.2.1 Technical actions

Target 4. Meeting international requirements on contaminants

Management Action 4-1: Conduct intensive monitoring and assessment

Monitoring and assessment in the Yellow Sea from the coastal countries have been implemented for many years. A new mechanism for regional monitoring and assessment should be established. It is recommended that intensive and the regional routine monitoring and assessment on marine environmental pollution in the Yellow Sea should be conducted, and a regional workshop held every 5 years focused on monitoring technology and assessment methodology. It is also recommended that a diagnostic strategy for identifying sources and sinks of pollutants should be established. Regional methodologies for monitoring and assessment of status & trends of environment should be developed and the environmental status and trends report on YSLME be prepared and issued.

Management Action 4-2: Control contaminants discharge with reference to Codex alimentarius and Stockholm Convention

The coastal countries have taken measures to control the discharge of contaminants for many years. It is encouraged that a basin-wide strategy be developed to address the pollution in YSLME, and to update facilities/equipment to control or reduce discharge from industrial and municipal sources with the reference to the seafood safety and reducing health risks. Regional monitoring and assessment of contaminant sources and fates should be continued. The economic instruments to encourage reduced pollution loads should be introduced and a protocol to control dumping at sea be developed.

Management Action 4-3: Implementing MARPOL 1973/78 effectively

For control of oil pollution in Yellow Sea, effective implementation of MARPOL 1973/ 78 is encouraged with improvements in national and regional contingency strategies and plans for oil spills in YSLME, covering both vessels and offshore installations. The capacity for early warning and response to extreme pollution events on the sea should be strengthened. The necessary steps to fully exercise the enforcement powers should be taken. The co-operative research on measures to avoid any introductions of exotic species into the YSLME should be conducted.

Target 5. Reduction of total loading of nutrients from 2006 levels

Management Action 5-1: Control total loading from point sources

The total loading from point sources has been controlled in recent decades. The continuation of the strict control of pollution loading from point sources is encouraged. The routine monitoring of major input sources and loads should be enhanced with the exchange of data and information at a regional level. The total-quantity-control methodologies of pollutant discharge in combination with best available techniques should be adopted. The hot spot control should be conducted with the calculation of loads in hot spot areas. The recommendations for waste treatment capacity, including reviewing the current waste treatment facilities and for facility's future development every 5 years should be given. Clean production techniques, recycling, improvements in waste treatment systems and capacity and policies for the construction of new treatment plants should be promoted. The continuation of strict control of total nutrient loading control programme is encouraged through reduction of point and non-point pollution sources discharge, or increasing the portion of sewerage treatment. With those actions China planned to reduce total nutrient loading from point sources 10% from 2006-2010, and the reduction policy will be continued in the future.

Management Action 5-2: Control total loading from non-point sources and seabased sources

The atmospheric deposition and inputs from the watershed were considered important sources of Yellow Sea pollution [71, 72]. Therefore the research on atmospheric deposition, especially of nitrogen and toxic substances (heavy metals and POPs, etc.) should be expanded. Improved management of fertiliser use is needed, including the monitoring and assessment on fertiliser use, and technical recommendations on better fertiliser use. The management on sea-based sources should also be encouraged, including monitoring and assessment of sea based sources, practice of sustainable mariculture, and dredging to remove contaminated sediments. The development of storm water treatment systems is also recommended.

Management Action 5-3: Apply new approaches for nutrient treatment

The new approaches for treatment of pollutants have been developed rapidly and should be applied during the period of implementing SAP. The existing or constructing additional wetlands could be used to serve as nutrient sinks. Bio-technology for treatment of nutrients in wastewater and sewage could be applied. The cost-effective means of treating municipal wastewater should be investigated and the regional recommendations be produced.

5.2.2 Governance actions

- A mechanism for agreements and the methodology to share monitoring results, ecotoxicological data and relevant information should be established.
- An operational mechanism for a regional forum for integrated review of hot spots and to improve understanding of environmental capacity should be established.
- A mechanism to promote best available techniques and best environmental practices for related land and sea-based industries should be established
- A mechanism to encourage use of organic fertilisers, eco-agriculture and organic fertiliser use and sustainable utilisation of wetlands should be implemented.
- A mandatory review of environmental quality standards every 5 years should be conducted.
- Existing regulations, with international requirements, on clean production, recycling use, etc. should be improved.
- Participating countries are recommended to establish a total nutrient loading control programme in the context of their relevant development plans.

5.2.3 Indicators of management actions

The following indicators are considered for management actions that address the regulating service function of YSLME:

- Well-operated regional monitoring network;
- Provision of access to reliable monitoring information on environmental quality for state governance bodies and the public;
- Significant reduction of total loading of the pollutants;
- Significant improvement of seawater quality with reduction of human health risk.

5.3 Actions Primarily Addressing Cultural Services

Marine litter and the contamination of recreational waters have been identified as major problems threatening the cultural services of the Yellow Sea ecosystem. The following actions principally aim to improve cultural services of the Yellow Sea ecosystem. The goal is to reduce contaminants and litter around bathing beaches and other recreational marine areas. To achieve this, control and monitoring of contaminants as well as public participation is important. Although these actions will primarily improve cultural services, they will also have pervasive effects on provisioning, regulating, and supporting services as well.

5.3.1 Technical actions

Target 6. Reduced standing stock of marine litter from current level
Management Action 6-1: Control source of litters and solid wastes

Marine litter has become a global challenge [73]. Litter and solid waste has become a major issue in coastal areas. Management of waste from coastal cities, counties and watershed should be encouraged. The technologies for waste reduction, re-use, recovery, and disposal should be implemented and the clean production and development of re-cycling economy be promoted.

Management Action 6-2: Improve removal of marine litter

Litter on beaches and in coastal waters has impacted not only the aesthetics but also the lives of animals. Development and implementation of a monitoring programme for marine litter is encouraged, in conjunction with the assessment and dissemination of information, and exchange of data and information in the region. It is also recommended that the local governments and NGOs develop and implement programmes for cleaning marine litter in YSLME coastal waters.

Management Action 6-3: Increase public awareness of marine litter

Public awareness on the environmental protection for young generations are the key points for ensuring sustainable development of YSLME. The development and implementation of environmental awareness and education programmes, especially for primary, middle and high schools is recommended. The opportunities for NGOs participation should be created and/or provided. Educational information packages should be produced for use in schools.

Target 7. Reduce contaminants, particularly in bathing beaches and other marine recreational waters, to nationally acceptable levels

Management Action 7-1: Conduct regular monitoring, assessment and information dissemination particularly in bathing beaches and other recreational waters

Water quality in recreational waters will directly impact on the human health. To minimise health risks, agreed measurement techniques for bathing water quality should be developed with a common quality assurance support mechanism. The intensive monitoring, early-warning, assessment in the seasons and the information dissemination for bathing waters and other marine recreational waters should be conducted. The national acceptable criteria or guidelines on water quality for those areas should be developed and/or improved.

Management Action 7-2: Control pollution in bathing beaches and other marine recreational waters

Enhanced control of pollution discharge and impacts of accidents especially on bathing and other marine recreational waters is encouraged. The emergency response system for human health in these areas should be improved and/or developed.

5.3.2 Governance actions

- More funding opportunities for recycling enterprises should be provided.
- The operational approach or system for litter removal should be developed.
- The environmental awareness and education programmes should be mainstreamed into national plans.
- Network for government-issued public announcements on beach closures should be established. The reporting network, especially the public participation and reporting system should be established.
- More regular and stricter enforcement of marine litter laws should be carried out, and compliance with waste management laws and regulations be improved.
- Clear national & regional guidelines on marine litter monitoring and assessment should be established.
- Legislation of sub-standard recreational waters should be promoted.

5.3.3 Indicators of management actions

The following indicators are considered for the management actions that address the cultural services function of YSLME:

- Regional guidelines for marine litter monitoring and assessment;
- Establishment of operational mechanism for beach cleaning;
- Published educational information package ;
- Improved legislation on waste and litter management.

5.4 Actions Primarily Addressing Supporting Services

Improving provisioning, regulating, and cultural services is impossible without improving supporting services as well. This is because ecosystem functions rely on complex physical, chemical, and biological processes. Also climate change could alter overall ecosystem structure and productivity in the long run. Therefore, adaptive ecosystem management is crucial to improve the ECC of the Yellow Sea ecosystem. The following actions primarily aim to improve supporting services of the Yellow Sea ecosystem. These include maintaining habitats and biodiversity, and providing relevant information of current status and forecasts on the Yellow Sea ecosystem for adaptive, scientific, ecosystem-based management.

5.4.1 Technical actions

Target 8: Better understanding and prediction of ecosystem changes for adaptive management

Management action 8-1: Assess and monitor the impacts of N/P/Si ratio change

The basin-scale change of nutrient ratio has been observed in the Yellow Sea in the past decades [26]. Although such change could potentially impact the ecosystem structure and productivity, and ECC, the consequent changes in the ecosystem are not assessed well. The long-term trend in the nutrient ratio and its impacts on the ecosystem structure should be monitored and assessed. For this, existing national monitoring and assessment methodologies need to be reviewed and harmonised.

Management action 8-2: Assess and monitor the impacts of climate change

There are many signs of global climate changes on regional scales. Certainly these changes will continue in the coming decades and exacerbate anthropogenic problems. The Yellow Sea ecosystem is anticipated to undergo fundamental changes in the future and its ECC shall change. For better management of the Yellow Sea ecosystem, basin-scale monitoring and assessment of the ecosystem status is necessary. For this, existing national monitoring and assessment methodologies need to be reviewed and harmonised. If necessary, sampling and assessment schemes should be improved.

Management action 8-3: Forecast ecosystem changes in the long-term scale

Climate-induced long-term changes in ecosystems, despite its devastating nature, cannot be managed by humans. In such circumstances, forecasting the future changes and developing adaptive management scheme are the best strategy. Basic science and technologies exist for forecasting future changes of ecosystems, e.g., climateocean circulation models and ecosystem models. Regional efforts should be focused on integrating models and developing scenario-based projections for the future ecosystem changes.

Management action 8-4: Monitor the transboundary impact of jellyfish blooms

Recent outbreaks of jelly fish in the Northwest Pacific is truly a transboundary problem in that reproduction occurs in the Yellow Sea or East China Sea and medusa spread out to the East Sea/Sea of Japan. These novel outbreaks not only cause damage to the fisheries but also indicate fundamental ecosystem changes. International co-operation is required for proper monitoring and mitigation of jellyfish blooms on the regional scale. This includes developing national and regional monitoring methodologies for jellyfish blooms

Management action 8-5: Monitor HAB occurrences

Continued eutrophication in the coasts of the Yellow Sea for the past decades resulted in increases in algal blooms since late 1980's. Although the frequency of algal blooms has not increased in recent years, monitoring these nuisance blooms should be continued for potential impacts to aquaculture, fisheries and public health. In addition the regional capability for HAB monitoring and mitigation needs to be improved.

Target 9: Maintenance and improvement of current populations/distributions and genetic diversity of the living organisms including endangered and endemic species

Management Action 9-1: Establish and implement regional conservation plan to preserve biodiversity

As signatories to the Convention of Biological Diversity (CBD)[73], both countries already have national conservation strategies. The next logical step is to establish a regional conservation plan that would include: the establishment of new regional nature reserves/MPAs needed to maintain the population structure, distribution and genetic diversity of the living organisms and endangered and endemic species; regular regional biodiversity monitoring to assess the effectiveness of the conservation plan; and the promotion of the concept of sustainable use.

Target 10: Maintenance of habitats according to standards and regulations of 2007

**Management Action 10-1: Develop regional guidelines for coastal habitat
Management**

Under the CBD, signatories are obliged to identify areas that are important for biological diversity in combination with management plans for protecting these critical habitats through promotion of the sustainable use and creation of protected areas.

Management Action 10-2: Establish network of MPAs

Inter-linkage of MPAs is important to ensure that migration routes and genetic exchange are maintained. As required by CBD operational objective 3.1, a national and regional system of representative nature reserves/MPAs should be established. Moreover in order to improve effectiveness of these reserves/MPAs, enforcement should be strengthened and management improved through annual assessments.

Management Action 10-3: Control new coastal reclamation

Intertidal wetlands play a vital role in the provision of supporting services such as nutrient absorption, carbon sequestration, sediment deposition, shore line stability, and as habitat for many commercially important fish and shell fish species as well as birds and other animals. Therefore, governments should enforce strict limits on new coastal reclamation according to current government plans.

Management Action 10-4: Promote public awareness of the benefits of biodiversity conservation

The benefits of biodiversity preservation in terms of increased productivity from fisheries and mariculture and the ability of the ecosystem to adapt to change and continue providing the vital ecosystem services is not generally appreciated by the general public. To raise support for conservation measures increased public awareness of both the benefits of biodiversity preservation and the conservation regulations are required.

Target 11: Reduction of the risk of introduced species

Management Action 11-1: Control and monitor ballast water discharge

The introduction of non-native species through exchange of ballast water is a growing international problem that can reduce the productivity of native species in the existing ecosystem, such as the introduction of zebra mussel to the American Great Lakes and transfer of toxic dinoflagellates that cause human shellfish poisoning, from Asia to Australia[74]. Improved control and monitoring of ballast water discharge is needed following the International Convention for the Control and Management of Ships Ballast Water & Sediments.

Management Action 11-2: Introduce precautionary approach and strict control of introduction of non-native species

Aquaculture farmers frequently select non-native species for their growth performance, but these introductions can have serious consequences for native species. The precautionary principle should be employed when assessing the risk of introducing a non-native species [75], and once introduced strict monitoring of the organism should continue until the risk of ecosystem modification is negligible.

5.4.2 Governance Action

- For monitoring the impacts of nutrient ratio change and climate change, establishing a cross-basin monitoring network and implementing monitoring activities are crucial. For this, the following activities are necessary; to create regional committee to co-ordinate monitoring and assessment; to conduct routine monitoring; to hold annual meetings to conduct joint assessment.

- For ecosystem modeling activities and HAB assessment, the establishment of two regional science committees is necessary to co-ordinate these activities. These regional science committees will oversee further activities; to establish national science committees for integrative modeling activity; to hold regular regional science committee meetings; to co-ordinate HAB assessment activities.
- For monitoring jellyfish blooms, following actions are required; to establish an international monitoring network; to develop regional monitoring strategy; to implement regional monitoring.
- Development of a regional framework is needed to incorporate the assessment into management policies for climate change impacts, HAB, and jellyfish blooms. Activities to achieve this goal include; the review of monitoring strategies in national management policy; the review of the existing policy making framework; and incorporation of assessment activities in management policy.
- Development of a framework to incorporate the forecasts of ecosystem change into management policy is recommended. Activities to achieve this goal include; a review of national management policy regarding climate changes and a revision of the national framework to incorporate forecasts of ecosystem change.
- Creation of a regional mechanism for co-operation (such as the YSLME commission) is recommended and strengthened national mechanisms for interagency co-ordination and between government agencies and stakeholders to share information on biodiversity and biodiversity management are needed.
- Improved legislation and enforcement to ensure that vulnerable and endemic species and critical habitats are protected are required as recommended in the Convention on Biological Diversity;
- Regional and national mechanisms for raising awareness of environmental issues and legislation should be improved and public involvement through educational programmes and the promotion of eco-tourism and ecotourism livelihoods should be encouraged.
- A regional conservation plan and strengthened national legislation on coastal habitat management (including MPAs) as agreed under the Convention of Biological Diversity in addition to the creation of appropriate enforcement bodies should be established.
- Clear national and regional guidelines on biodiversity monitoring and assessments of the benefit of biodiversity to the local economy and the effectiveness of management should be identified.
- Improved enforcement of international regulations on the introduction of non-native species in combination with a strengthening of national legislation on species introductions and the use of risk assessment procedures is recommended.

5.4.3 Indicators of management actions

- Continuation of cross-basin monitoring of N/P/Si change, climate impacts, and HAB trends
- Working international monitoring network for jellyfish blooms,
- Regular status reports of N/P/Si change, climate impacts, jellyfish blooms, HAB trends
- Scenario-based long-term projection of ecosystem changes
- Development of adaptive management strategies using ecosystem status assessment and forecasting
- Policy making based on adaptive management strategies
- Species composition, species diversity indexes, and the density of vulnerable and endemic species at selected sites is maintained and improved compared to the 2007 situation.
- Area of current habitats is maintained according to standards and regulations of 2007.
- The incidence of disease/parasites and impacts endemic/vulnerable species caused by introduction of non-native species is reduced.

6. Economic Justification and Assessment

6.1 Economy of Management Actions

It may be difficult to gain public support for actions which are less likely to produce economic benefits even though the actions greatly contribute to maintaining and/or improving the ecosystem services. Therefore, the management actions, described in Section 5 in this document, should be economically beneficial. To examine the economy or efficiency of a management action(s), economic analysis, specifically Cost- Benefit Analysis (CBA), is used.* CBA compares the net benefits (i.e., the difference between "gross" benefits and costs) of management actions under two scenarios: with or without the actions. A research question that CBA addresses is: "What would happen if conservation measures [management actions] were implemented [compared] to what would have happened if they were not" [76]. The analysis then uses simple yet effective decision criteria: Comparing the gains (benefits) with the losses (costs) of an action, if the former exceeds the latter, support the action; otherwise, oppose it [77] i.e. the proposed actions are accepted if the net benefits are positive, or declined if the net benefits are negative. Figure 6 illustrates the concept of the CBA under with or without scenarios. Properly measured, the economic value of goods today may be illustrated as the leftmost column in the figure. Suppose that these benefits will decrease in the future because of environmental degradation; then, the benefits would be as shown in the next column to the right. The difference in the amount of the economic value between today and the future is the scale

* CBA is regarded as the most appropriate way to assess the economy of environmental management actions, although other methods such as the cost-effectiveness analysis and the economic impact analysis can be used alternatively, if necessary.

of predicted degradation. With management actions implemented, however, this degradation might be less (third column from the left). Comparing the results of the two scenarios, with or without management actions, would reveal the benefit of the actions.**

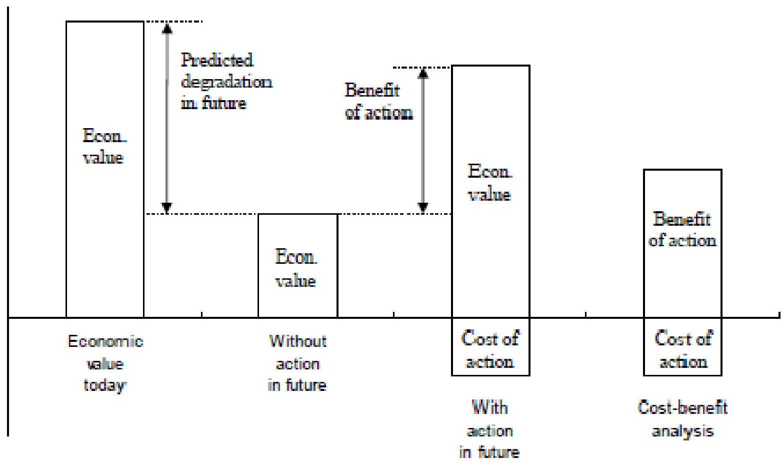

Figure 6: Cost-benefit analysis of environmental management actions (adapted from Pagiola et al., 2004 [76]*)*

In the subsequent cost-benefit analysis (the rightmost column), the benefit of implementing the management actions is compared with the cost of implementing them. The cost might consist of both direct costs and opportunity costs. If the benefits exceed the costs, it is reasonable to support the management actions.

To measure the value of ecosystem services, a number of economic techniques are used, including empirical technique, travel cost method, and contingent valuation method. The selection of techniques depends on the characteristics of services to be evaluated and on the availability of data to be collected and analysed under the constraints of limited research funds and time. If the services are traded in the market, one can use their market prices and trading volumes to estimate the value. The empirical technique takes this approach. If the services are not traded in the market, however, one should use either the market information of relevant services or the information collected by surveys about consumer preference for the services concerned. A typical example of the former approach is the travel cost method;

** The benefit, described in this document, is the "benefit of implementing management actions," that can be defined as the prevented future loss measured in economic value. The benefit of management actions is different from the "benefit of consuming ecosystem services." The former can be described as the difference in the amount of economic value between with- and without scenarios, while the latter can be described as the amount of the value itself. The benefit of ecosystem services can be gross or net depending on whether the cost of producing the services is included or not.

meanwhile, that of the latter is the contingent valuation method. For more information about valuation techniques, see UNDP/GEF (2008) [78].

6.2 A Case Study: Would Management Actions be Efficient?

Take management actions to reduce fishing efforts as an example to illustrate how CBA examines the efficiency of the actions. According to the study, the total catch of ten commercially-important species in China in 2004 is approximately 2 million tons [28]. The economic value of those species is estimated as approximately USD 2.8 billion with available market price data used (Annex 1)[79-84] * . Note that this estimation represents the value of eight species, not all species, in the Yellow Sea *. One of the major problems in fisheries in the Yellow Sea is the decline in landings of commercially-important species [1]. To address this problem, the SAP proposes management actions, including boat buy-back programme, seasonal/area fishing ban, and alternative livelihood provision, to reduce fishing efforts by 25-30% by 2020: Would those actions be efficient? Suppose that reducing fishing effort would increase fish stock; as a result, fish catch would remain constant *with* the management actions taken; in contrast, the catch would decrease *without* the actions taken. Figure 7 shows expected fish catch by 2020 under those two scenarios.* Note that fish catch under the with-scenario remains constant from 2010 through 2020, while that under the without-scenario decreases by 30% by 2020 in this figure.

* The economic value of the species is approximately 21.8 billion Chinese Yuan. It is assumed that USD 1 is equal to 7.85 Chinese Yuan (i.e. the average official exchange rate from July 2005 to December 2007[59]).

* This case study deals with the following eight species: Acetes, Anchovy, Chub Mackerel, Fleshy Prawn, Largehead Hairtail, Small Yellow Croaker, Spanish Mackerel, and Squid.

*It is assumed that (i) fish catch in 2010 would be the same amount as the average of fish catch from 2000 to 2004; (ii) without the management actions, fish catch would decrease by 10-30% by 2020 due to the depletion of fish stock; (iii) with the actions, fish catch would remain constant at the same level as the average of fish catch from 2000 to 2004; and (iv) fish prices would remain constant at the level in 2007.

Literature suggests using 2 to 4 percent as a social discount rate, although higher rates might have been applied to the analysis of fisheries conventionally with the high risk the industry faces considered. It is

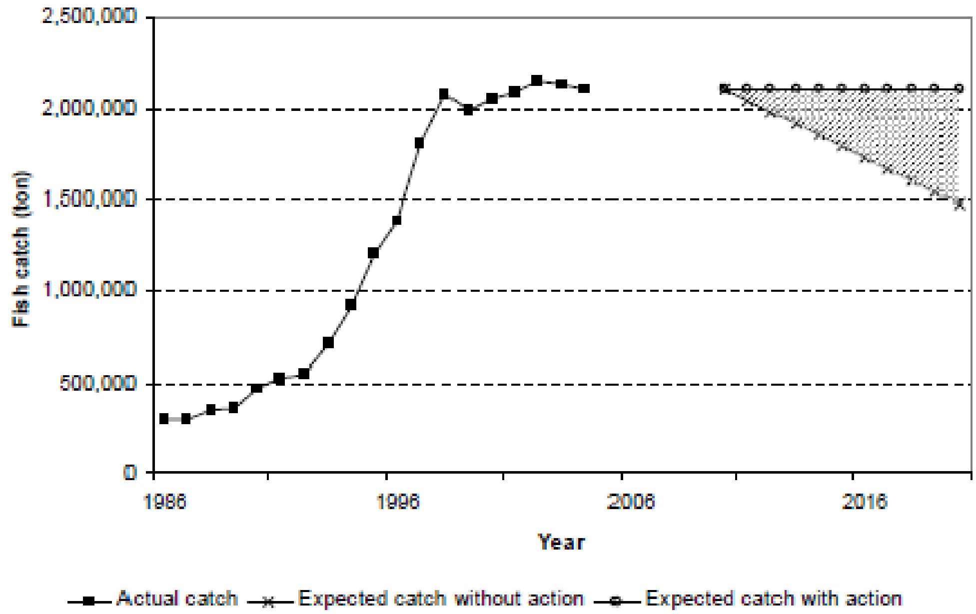

Figure 7: Expected fish catch by 2020 under with-and-without scenarios

The benefits of the management actions, shown as a shaded area in Figure 7, are the difference between the fish catch under the with-scenario and that under the without scenario. The benefits of the actions in terms of the monetary value are approximately USD 0.8 – 4.2 billion (Table 1: Row, “Benefit”). In order to compare future monetary benefits with cost of management actions put into effect at the current time, this example uses a social discount rate of between 0 - 7%. This rate equates future benefits to the present day value.

Table 1. Cost-benefit performance of management actions

		Social discount rate		
	Decrease in fish catch	0%	3.5%	7%
Benefit (1)	30%	4,232	3,226	2,498
	10%	1,411	1,075	833
Cost (2)		126	103	86
Net benefit (1) – (2)	30%	4,106	3,122	2,412
	10%	1,285	972	747

Unit: Million USD

The costs of actions in this case study include the direct cost of implementing boat buyback programme and creating alternative livelihood. It is estimated that the proposed actions would cost approximately USD 86 – 126 million

(Table 1: Row, *Cost”). The proposed actions would make sense economically as long as the costs of those actions are less than the benefits. In this case study, the benefits of the actions exceed their costs; the net benefits are approximately USD 0.7 – 4.1 billion (Table 1: Row, “Net benefit”). Therefore, one can conclude that implementing the actions is justified economically.

Figure 8 illustrates the result of the case study, employing the similar diagram used in Figure 6.* Note at the far right column that the benefit of the actions is greater than the cost of them: The net benefits are positive.

6.3 Integration of Economic Analysis into Ecosystem Management

In general, there is a lack of the economic considerations of ecosystem management in the region. Few analyses have been conducted on conservation activities from the perspective of cost-benefit performance. The CBA of major management actions should be conducted to provide more information. To integrate economic aspects into ecosystem management, it is recommended to take the following preparatory actions by 2020:

- Improve the regional guideline for economic analyses of environmental management actions;
- Conduct pilot CBA studies on selected demonstration activities of the actions;
- Organise technical trainings on CBA to build and/or strengthen the capacity of theparticipating countries;
- Integrate economic analyses into the workplan of relevant authorities to design and implement better conservation activities; and
- Review the results of all the above preparatory work to not only improve theregional guidelines, but also strengthen the national capacity.

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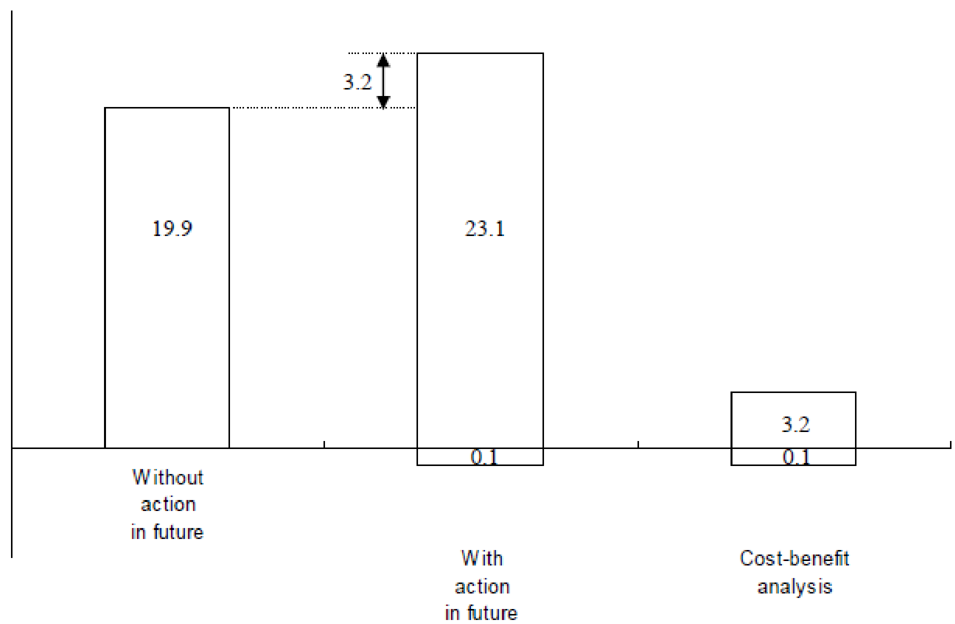
* recommended to conduct sensitivity analysis to check the robustness of analytical results. Using different rates, one can be confident about supporting the proposed management actions if net benefits still remain positive [78].

* Note that it is assumed in Figure 8 that (i) the fish catch under the without-scenario decreases by 30% by 2020 and (ii) the social discount rate is 3.5%. For illustrative purposes, the cost of the actions shown in this figure is bigger than the actual amount. (The actual cost is so small that it cannot be shown in the figure on the same scale as the benefit.)



Unit: Billion USD

7. Institutional & Legislative Actions and Financial Mechanism for Implementation of SAP

7.1 Governance

7.1.1 Institutional actions: creation of the YSLME Commission

It is desirable to establish the YSLME Commission as an institutional vehicle to continue and expand current efforts through the YSLME Project. The YSLME Commission will contribute not only to better co-ordination of national efforts but also to enhancing effectiveness of regional efforts.

Nature of the YSLME Commission

The YSLME Commission is to be a soft, non-legally binding and co-operation based institution. Considering complex geopolitical situation in the Yellow Sea region, it is not appropriate to have a legally binding treaty-based institution though it could be sought in the future. However, sufficient political wills among participating governments should be secured in the form of a joint declaration or an MOU [55].

Institutional framework

- YSLME Commission Steering Committee (YSLME CSC): YSLME Commission Steering Committee will serve as a supreme decision making body. YSLME CSC will include representatives of each participating government and the Secretariat.

- Secretariat: The establishment of a permanent secretariat will provide secretariat functions to the YSLME CSC. The secretariat should be small but secure appropriate expertise to address policy and research interests of the YSLME CSC.
- Sub-Commissions: Several Sub-Commissions will be created and responsible for technical issues in its own. Sub-Commissions will be mainly composed of experts.

Ensuring DPRK's full participation

DPRK's full participation is important in terms of geographical completeness and effectiveness of the work of the YSLME Commission. More efforts need to be made to ensure DPRK's full participation in the YSLME Commission.

7.1.2 Actions to improve effectiveness of legal instruments

Improving the implementation of international & regional treaties and guidelines

In order to improve the strictness, scope of coverage and enforcement of the legal instruments, actions need to be made including, but not limited to followings:

- Ensuring full ratification of the treaties;
- Strengthening co-ordination between the bilateral Fisheries Agreement between China and ROK in the YSLME Commission Context;
- Developing regional guidelines in order to incorporate suggested guidelines of the FAO Code of Conduct for Responsible Fisheries into the YSLME Commission's Context; and
- Developing guidelines on matters not covered in detail by the United Nations Convention on the Law of the Sea, Convention on Biologic Diversity and Ramsar Convention.

Developing guidelines for periodic review of the implementation of treaties by each of the participating countries

Exchange of information on relevant domestic legislation.

Developing projects to harmonise domestic legislation according to the regional standards and guidelines to be developed through YSLME Commission

7.1.3 Stakeholders' wide participation

Strengthening partnerships with existing regional co-operative institutions

In order to enhance overall effectiveness, strengthening partnership with existing regional co-operative institutions, strengthening partnership with these regional institutions is necessary including, but not limited to the followings:

- Strengthening co-ordination with bilateral co-operation mechanisms such as the Joint Committee on Environmental Co-operation, the Joint Fisheries Commission, China-Korea Joint Ocean Research Center, between the coastal countries
- Strengthening partnership with other regional co-operative mechanisms, especially with NOWPAP
- Further strengthening current Yellow Sea Partnership among related stakeholders
- Developing strong partnerships with relevant regional and international institutions to address the oil spill problems

Private sector's involvement

As private sector is an important stakeholder in the environmental and sustainable development in the Yellow Sea region, it is necessary to ensure private sector's involvement in the YSLME Commission process. Relevant private sectors include the related industries and research and education institutions.

Capacity building for NGOs and Local Governments

Capacity building for NGOs and local governments is important to help these stakeholders engaging in regional governance in the Yellow Sea region in constructive ways. Capacity building for NGOs and local governments include, but not limited to the followings:

- Increasing understanding of international/regional institutions
- Learning advanced management measures
- Developing co-operation abilities with related stakeholders in the regional governance

7.1.4 Guidelines for the improvement of national governance

- Ultimate implementation of regional policies in the Yellow Sea region is made at the national level. Therefore it is important that the actions for the national governance in each participating country are appropriately taken to implement regional measures effective at the national level. Actions for the national governance in each participating country include, but not limited to the followings: Enactment and modification of legislation in order to fully incorporate regional guidelines and standards into the national legislation
- Improvement of the enforcement mechanism of the policy measures
- Institutional reforms to ensure effective co-ordination among the relevant governmental bodies and other stakeholders
- Wider stakeholders' participation in the national governance

- Increasing public awareness

7.2 Upgrading National Capacity

Upgrading capacities of national institutions play important role in the implementation of the SAP. Based on the root cause(s) from YSLME TDA report, the weak capacities of national institutions were identified, such as the inadequate balance between development and environmental protection policy, the limited compliance assurance infrastructures, lack of co-ordination between public health sector and private sector, etc.. The actions should be taken to update the capacities of national institutions, which involve the effective management programmes, capacity-building programmes, formulation of projects eligible to be financed by international financial donors, the involvement of all identified stakeholders into the implementation of SAP, etc. The relevant actions should be detailed in the National Strategic Action Plan (NSAP).

7.3 Financial Mechanism for the Implementation of YSLME SAP

In order to establish a sustainable financial mechanism to support implementation of YSLME SAP, there is a need to identify the financial requirements; to identify relevant financial resources and establish effective financial mechanism for raising necessary funds from possible sources, managing financial resources, and reporting financial status.

- Financial requirements for implementation of SAP will be identified following the identification of actions and activities of SAP implementation.
- It is necessary to identify sources to meet the financial requirements for implementation of the SAP, including GEF financial support, contribution from the governments of the participating countries, and potential donors. It should be noted that the financial commitments from the governments of the participating countries will be critical source of funding to show political willingness of the countries.
- A Financial Mechanism will be established following the establishment of a YSLME Commission as the implementing mechanism for the SAP. Staged arrangements will be prepared:
    - For the first 5 years (2010-2014), GEF funding will be the major financial resources to cover the incremental costs of the project activities. In the meantime, the national co-financial resources will be used as substantive support to the project implementation.
    - For the second 6 years (2015-2020), the participating countries will establish a sustained financial mechanism to cover the costs of the implementation of project activities.

A fund-raising campaign will be established within the YSLME Commission to generate financial support from private sectors and other donors. The YSLME Commission will provide overall policy on the fund raising campaign. The Head of the secretariat of the YSLME Commission has principle responsibility for identifying the financial sources, and fund raising campaign. If necessary, special consideration should be given to this important element, including establishment of a special post within the secretariat dedicated to fund raising.

8. Monitoring and Evaluation

8.1 Indicators of Monitoring and Evaluation

Monitoring is a continuous or periodic function that uses systematic collection of data, qualitative and quantitative, for the purposes of keeping activities on track. It is first and foremost a management instrument [85]. This document is focused on the Project Indicator Monitoring as defined by the GEF.

8.1.1 Process Indicators

Process Indicators

The establishment of process indicators is essential to characterize the completion of institutional processes on the multi-country level or the single-country national level that will result in joint action on needed policy, legal, and institutional reforms and investments that aim to reduce environmental stress on transboundary water bodies [86].

- Regional Agreement on establishing the Yellow Sea Commission for implementing the Regional SAP;

Based on the results and recommendations made by the Regional Governance Analysis of the Project, it is recommended that a Yellow Sea Commission should be established in charge of the implementation of the SAP. As one of the most important indicators, the establishment and effective operation of the Yellow Sea Commission will be good “process indicator”. This indicator presents the regional mechanism for the implementation of the SAP. It is hoped that the DPRK would join the Commission in an appropriate stage.

- Established national mechanism for implementing the National SAPs;

The Inter-Ministry Co-ordinating Committee established within the project should be strengthened to take more responsibilities in implementing activities identified in the SAP, in particular those activities that are transboundary. The well-established and well-functioned national mechanism provides national institutional arrangements to protect the marine environment in the Yellow Sea.

- Establishment of cross-basin monitoring network & implementation of regional monitoring activities, (including scientific research);

As the project objective is to establish ecosystem-based management of the marine environment in the Yellow Sea, a basin-wide monitoring programme should be established to provide scientific knowledge and environmental information on the status of the marine environment. The regional monitoring network should cover all the elements relevant to the marine environment, and should have regular and effective monitoring activities and reports.

- Improved regulation and legislation and strengthened enforcement in the participating countries will cover following aspects:
    - To promote sustainable exploitation of fish stocks.
    - To control total loading of pollutants.
    - To establish regional conservation plan to protect endemic and vulnerable species.
    - To establish national and regional systems of representative nature reserves/MPAs and to integrate into a global network and as a contribution to globally agreed goals.
    - To establish environment-target-control mariculture practice.
- Established a sustainable financial mechanism for implementation of SAP.

8.1.2 Stress Reduction Indicators

Stress reduction indicators relate to the specific on-the-ground measures implemented by the collaborating countries. Often a combination of stress reduction indicators in several nations may be needed to produce detectable changes in transboundary waters.

- Reduced and controlled fishing effort, to reduce stress in over-fishing;
    - Reduced number of fishing boats.
    - Improved selectivity of fishing gear.
    - Scientific assessment of summer fishing-ban.
- Enhanced sustainable mariculture
    - Established carrying capacity guidelines for planning mariculture.
    - Enhanced integrated multi-trophic mariculture techniques to reduce pollutants to the marine environment.
- Established new MPAs and improved management effectiveness of existing nature reserves/MPAs to reduce stress in loss and modification of marine habitats
    - Improved effectiveness of management for MPAs including the quality of prepared management plans.
    - Restriction on new reclamation.
    - Increase public involvement in MPAs management.
- Controlled and/or reduced pollution discharge to reduce stress in marine environment pollution
    - Updated knowledge of current waste treatment facilities.

  - Improved treatment system and capacities, including established new treatment facilities.
  - Established regional regular monitoring system to better understand status and trends of pollutants in marine environment.

8.1.3 Environmental Status Indicators

For projects in damaged transboundary systems, years may go by before a sufficient number of countries have implemented sufficient stress reduction measures to enable a change to be detected in the transboundary water environment.

- Established cross-basin monitoring network and implementing monitoring activities to better understand the environment status in the Yellow Sea
  - Harmonised monitoring methodologies and assessment of impacts ecosystem.
  - Developed comprehensive models to predict change and its impact on fisheries.
- Better understanding of environment status in the Yellow Sea through established regional monitoring system;
  - Fish stock improvement after reduction of fishing efforts.
  - Reduced pollution load and concentration.
- Protected marine habitats, in particular coastal wetlands
  - Reduced rate of habitat loss.
  - Maintained ecological characters of critical habitats including species compositions, species diversity indexes.
  - Reduced number of endangered species.

8.2 Mechanism of Monitoring and Evaluation

The YSLME Commission is the overall responsible body for monitoring and evaluation of the implementation of the SAP.

8.2.1 Project Implementation Review (PIR)

The YSLME secretariat is responsible for preparation of annual Project Implementation Review (PIR) to be submitted for Commission to review and make decisions whenever deemed necessary. The PIR will also submit to UNDP and GEF.

The YSLME secretariat should prepare management responses to the comments and decisions made by the Commission.

8.2.2 Mid-Term Evaluation

Mid-term evaluation should be organised in the mid of first phase of the SAP implementation (first 5 years), and in the mid of the second phase of SAP implementation. The Mid-term evaluation should be carried out by the external/independent experts selected by the Commission, in consultation with UNDP and GEF, based on the indicators established for the monitoring and evaluation.

8.2.3 Final Evaluation

Final evaluation should be organised in the end of first phase of the SAP implementation (first 5 years), and in the end of the second phase of SAP implementation. The Final evaluation should be carried out by the external/independent experts selected by the Commission, in consultation with UNDP and GEF, based on the indicators established for the monitoring and evaluation.

9. Conclusions

The Yellow Sea ecosystem and its ECC are undergoing change. If all threats and the problems to the ecosystem continue as described in the TDA, the Yellow Sea would further become more degraded and reduced in its ECC, which means the Yellow Sea has diminished sustainable capacity to provide its services for human welfare. If all the management actions listed in this SAP will be taken with the regional targets, the Yellow Sea would improve its capacity for its provisioning, regulating, cultural and supporting services. By 2020, it could be seen that after all the management actions have been taken efficiently, the Yellow Sea would be a living sea, which is vital, productive and healthy. By 2020, it could be seen that after all the management actions have been taken with all coastal countries, the Yellow Sea would be a sea of co-operation, a sea of friendship, a sea of peace and a sea of safety.

Editor's Note: Endorsement of the YSLME SAP by senior officials of the People's Republic of China and the Republic of Korea was signed by both parties in November 2009 and is reproduced here as the SAP Annex.

10. References

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Annex

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: 張占海

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
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Date: 19 NOV 2009

Chapter 11

Managing Large Marine Ecosystems for Climate Change Mitigation

Jerker Tamelander[1], Dorothée Herr[2] and Dan Laffoley[3]

Introduction

Current global climate change is driven primarily by human activities leading to increased greenhouse gas (GHG) concentrations in the atmosphere (IPCC 2007). Impacts on ecosystems, economies and societies have already been recorded. This includes for example widespread coral bleaching and degradation, undermining coastal livelihoods (e.g. Wilkinson 2008), loss of coastal ecosystems and the fishery and shoreline protection services they provide, including saline intrusions on agricultural lands and drinking water supplies, and changing weather and rainfall patterns (IPCC 2007). Further, and in many cases accelerated change is predicted with high certainty.

This is challenging our efforts to reduce man-made climate change. Technological development and lifestyle changes that can make significant contributions to reducing GHG emissions to the atmosphere are by-and-large being rolled out at too slow a pace. These must be complemented by additional, effective and immediately implementable means to reducing GHG emissions to and increasing sequestration from the atmosphere. There is also a need to increasingly promote adaptation to changes that are unavoidable due to time lags in the earth's climate and ocean circulation system.

Coastal wetlands and marine ecosystems offer significant opportunities to this end. Similar to terrestrial forests, coastal wetlands, mangroves and seagrass beds sequester atmospheric carbon dioxide (CO_2) in biomass through primary production. A significant amount of carbon also accumulates in organic soils, partly from biomass produced in the systems and partly from sediments they trap (Laffoley and Grimsditsch 2009, Nellemann et al. 2009).

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An international policy foundation for nature-based mitigation is provided by the United Nation Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, which recognize the need to limit release of greenhouse gases from storage or the loss of possible sinks as a 'side effect' of land use and land use change. Much progress has been made in terrestrial environments, including through the development of the Reduced Emissions from Deforestation and Forest Degradation (REDD+) mechanism. However, until recently the role of coastal wetlands and marine ecosystems in regulating atmospheric carbon dioxide concentrations has not been the subject of research activities or policy development that would enable quantification of the potential and application of coastal and marine-based mitigation strategies.

Large Marine Ecosystems (LMEs) can through research and assessment further our understanding of the carbon cycle in coastal wetlands and marine ecosystems, in relation to how carbon pools degrade and how they can be enhanced. Being ecosystem-based by definition but addressing socioeconomic and governance processes both on regional and national levels, LMEs also offer a unique opportunity to develop and pilot practical approaches for ecosystem management and restoration for the purposes of increased carbon sequestration or avoided emissions. This makes LMEs uniquely placed to focus thinking and deliver actions that can strengthen climate change mitigation.

Carbon sinks and sources in coastal and marine ecosystems

The marine realm plays an important role in the global carbon cycle. The ocean is the worlds' largest reservoir of carbon dioxide, absorbing 25% of total human emissions to the atmosphere each year. This acts as a buffer, slowing climate change (however, it also leads to ocean acidification, a severe threat). Through primary productivity in the pelagic realm, carbon enters the marine food chain and is transported to oceanic sinks through sedimentation of organic matter and calcareous shells, a process known as the 'biological pump'. Coastal ecosystems also act as significant carbon sinks, holding vast stores of carbon in biomass as well as in continuously accumulating sediments. However, our level of understanding of these processes is not uniform, and different ecosystems offer different opportunities for mitigation.

Oceanic carbon sinks and sources

A significant gap remains in understanding oceanic carbon sinks, covering over 50% by area of the Earth's surface. Research has identified a number of ocean species and features that are particularly important.

Marine phytoplankton carbon uptake is estimated at between 0.6 and 1.8 gigatons of carbon per year, making up approximately 50% of the world's total biological uptake (Field et al. 1998, Arrigo 2007). Through the 'biological pump' some of this carbon is transported vertically to sediment in the pelagic ocean, constituting an important carbon sink. However, only a fraction of the total production is removed in this way (e.g. Lutz et al 2007, Busseler et al. 2007), and the efficiency of the biological pump varies considerably between areas and over time. However, it is clear that pelagic processes and food webs have been disrupted as a result of human impacts on the sea, with likely impacts also on the rates of final carbon disposal. On the one hand input of nitrate as well as carbon dioxide can have a fertilization effect on primary productivity (e.g. Riebesell et al. 2007). On the other, altered upwelling and reduced vertical mixing associated with climate change and in particular increases in global temperature are expected to decrease overall primary productivity in the ocean (Behrenfeld et al. 2006).

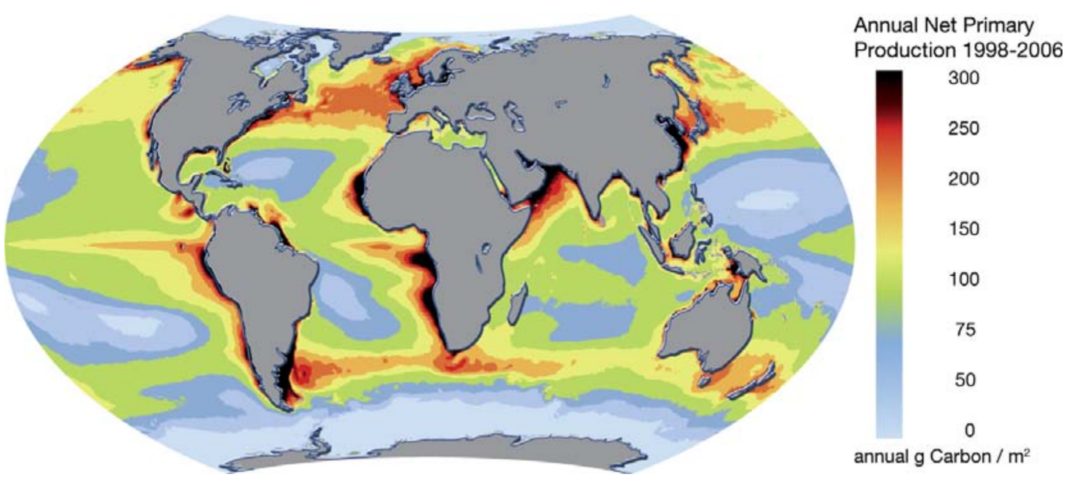

Figure 1. Net primary production in the surface ocean. Darker red areas denote higher production, blues lower [Source: UNEP/GRID-Arendal].

Larger pelagic biota also plays an important, if not yet fully understood role in carbon sequestration. Fish and whales are only a small portion of the ocean's overall biomass, but fishing and whaling have altered the ocean's ability to store and sequester carbon. For example, carbon dioxide is bound in standing biomass of fish and secreted as calcium carbonate via osmoregulation mechanisms ('gut rocks') (Kurita et al. 2008, Wilson et al. 2009). This contributes 2.7 to 15.4% of the estimated total global new calcium carbonate ($CaCO_{3)}$ production in the surface oceans. Fish carbonate production may rise in response to future environmental changes in carbon dioxide, and thus become an increasingly important component of the inorganic carbon cycle (Wilson et al. 2009). However, fish stocks have been heavily depleted especially during the latter part of the last century. Moreover, the associated reduction in average fish size also reduces fish carbonate production (Jennings and Wilson 2009). In other words, in addition to the many ecological implications of over-fishing, the global reduction in fish standing biomass as well as $CaCO_3$ production reduces the ability of the ocean to buffer climate change.

Similarly, the loss of megafauna also entails a loss of carbon dioxide bound in standing biomass, as well as transport to long-term sinks. Reduced megafaunal abundance and biomass through hunting and harvesting has led to an estimated biomass decline of >90% in many cetacean species in the last 100 years (e.g. Springer et al. 2003). Consequently, populations of large baleen whales now store 9.1 million tons less carbon than before whaling (Pershing et al. 2010). While some of this is offset by increases in smaller competitors (Essington 2006) a shift toward smaller animals could decrease the total community biomass by 30% or more (because a given amount of primary productivity can support a higher biomass of large individuals due to the increase in metabolic efficiency with increasing body size). Further, whales and other large marine vertebrates can efficiently export carbon from the surface waters to the deep sea through ‘whalefalls’. Pershing et al. (2010) estimate that rebuilding whale populations would remove 0.166 million tons of carbon each year through sinking whale carcasses. In addition, whaling may also have led to a reduction of primary productivity and thus carbon fixation in some iron-limited areas. According to one estimate, baleen whale faeces may have accounted for 12% of the iron in the surface of the Southern Ocean before commercial whaling began, supporting considerable primary production and carbon fixation (Nicol et al. 2010).

Benthic invertebrate communities also appear to provide an important carbon sink. Lebrato et al. (2009) estimate the standing stock of Echinoderms (starfish, sea urchins, brittle stars, sea cucumbers and sea lilies) on shelves, slopes and abyss at circa 2.11 giga tons (10^{15}g) $CaCO_3$.

Annual production contributes around 0.86 giga tons $CaCO_3$, more than 80% of it between 0 and 800 m, with the highest contribution attributed to the shelf and upper slope (Lebrato et al 2010). This is equivalent to 0.1 giga tons of inorganic carbon per year (by comparison, annual emissions from human activities are circa 5.5 giga tons of carbon). Although this production of calcite is less than the total biological production in the pelagic it delivers more carbon to permanent storage in sediments than, for example, foraminifera (Lebrato, M., et al. 2009). Other benthic organisms, including for example, polychaetes as well as microorganisms including archae and many bacteria, may also fill important roles, but less is known about these processes (e.g. Boetius and Wolf-Gladrow 2003, Lipp et al. 2008).

Carbon sequestration in coastal ecosystems

Two reports released in late 2009 (Laffoley and Grimsditsch 2009, Nelleman et al. 2009) presented an overview of the importance of coastal and marine ecosystems as carbon sinks, including mangroves, seagrass beds, salt marshes

and kelp forests. A further report (Crooks et al. in press) provides additional quantification of mitigation potential in particular focusing on coastal wetlands.
All coastal wetlands are net carbon sinks in the long-term through production of biomass and burial of organic matter in sediment, provided they are not degraded. This includes freshwater tidal wetlands, salt marshes, mudflats, mangroves and seagrass beds. While carbon stored in biomass is comparable to that in terrestrial systems, carbon burial in sediments can take place at rates up to 50 times those observed in terrestrial systems. Notably, this carbon sequestration can be maintained for centuries or more whereas terrestrial forest systems typically reach a steady-state equilibrium level of carbon in the soil within a few decades.

Carbon sequestration is particularly high in freshwater tidal marshes. However, this uptake is in the short term negated by methane production and release. Saline systems, on the other hand, produce only negligible amounts of methane, making e.g. salt marshes, sea grasses and most mangroves highly efficient carbon sinks (see Table 1). Over multi-century time scales all coastal wetlands are net sinks for GHGs (Crooks et al. in press).

Table 1: Summary of potential GHG reductions due to soil building in coastal wetlands [adapted from Crooks et al in press]. Carbon sequestration rates in ton carbon per square kilometre per year (tC km^{-2} a^{-1}) and ton CO_2 equivalents per square kilometer per year (tCO_2e km^{-2} a^{-1}); Methane production rates in ton methane per square kilometre per year (tCH_4 km^{-2} a^{-1}) and ton CO_2 equivalents per square kilometre per year (tCO_2e km^{-2} a^{-1}).

Wetland Type	**Carbon Sequestration Potential**			**Methane Production Potential**			**Net balance**
	Carbon	CO_2 equivalents^{+}	Rank	Methane	CO_2 equivalents^{+}	Rank	
Mudflat (saline)	<50	-183	Low	<2	<50	Low	Low
Salt Marsh	50-250	183-917	High	<2	<50	Low	High
Freshwater Tidal Marsh	500-1000	1,833-3,667	Very High	40-100+	1,000-2,500+	High - V. High	Neutral/ Variable
Estuarine Forest	100-250	367-917	High	<10	<10, 250	Low - High	High
Mangroves	50-450	184-917	High			Low – High*	Low-High*
Sea grass	45-190	165-697	High		<2, <50	Low	High

* Salinity dependent
$^{+}$ 1gC = 3.67 gCO_2e; 1gCH_4 = 25 gCO_2e

Carbon emissions from coastal marine ecosystem degradation

While carbon sequestered in coastal wetland sediment can remain stored for millennia in healthy ecosystems, degradation leads to decreased sequestration as well as emission of stored carbon. Drainage of coastal wetlands typically releases 0.25 million tons of CO_2 per square kilometer for every depth meter of soil lost (Crooks et al. in press), although this varies considerably depending on location and soil composition. Irrespective of their GHG balance in the natural state, degradation of these ecosystems turns them into strong net sources of GHG emissions (Crooks et al. in press).

Global trends for many of these ecosystems are negative. The current total area of mangroves as reported in the World Atlas on Mangroves (Spalding et al. 2010) is 150,000 km^2. This is a significant reduction from an original extent of well over 200,000. It has been estimated that clearance of 35,000 km^2 between 1980 and 2005 (Spalding et al. 2010) has resulted in a continuing annual release of 0.175 giga tons CO_2 per year. This is equivalent to CO_2 emissions of the Netherlands or Venezuela. Rapid conversion of coastal wetlands with peat-rich soil in parts of Southeast Asia, (e.g. for aquaculture and increasingly for palm oil plantations) releases higher-than-average amounts of carbon per unit area. The loss of the remaining 350,000 km^2 of mangroves and salt marshes would, it is estimated, result in the ongoing additional annual release of 1.75 giga tons CO_2 (Crooks et al. in press). Similarly, the rate of loss of seagrass meadows has increased by an order of magnitude over the last 40 years (Orth et al., 2006, Waycott et al. 2009). The total global seagrass area has been reduced by at least 29%, or 51,000 km^2, mainly after 1980, as a result of coastal development, dredging and declining water quality (Waycott et al. 2009). This is likely to cause considerable and ongoing emissions.

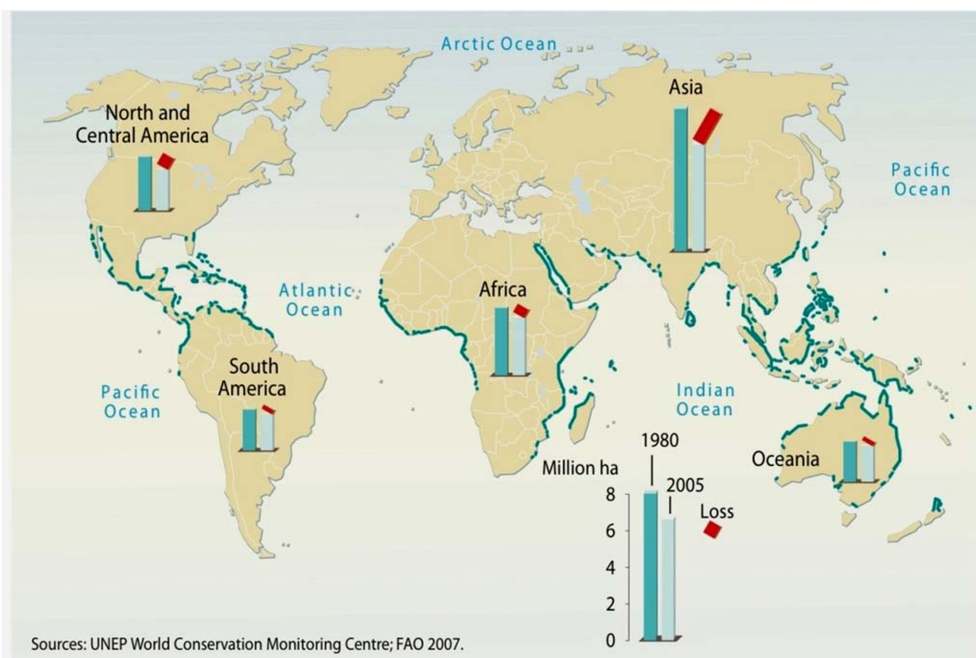

Figure 2. Estimated mangrove loss between 1980 and 2005 (Source: UNEP/Grid-Arendal)

Emissions arising from drainage of major river delta wetlands have been mapped with some accuracy. Release of CO_2 occurs when lowering of the water table allows oxygenation of sediments. The rate is most rapid during the first years to decade, but where soil organic content is high it can continue for a long time, creating depressions in the landscape. Drainage of 1,800 km^2 of wetland in the Sacramento - San Joaquin Delta in California has led to oxidation of peat soils, releasing circa 7,300 tons CO_2 per square kilometer per year over the past 100 years. Emissions to date, 2 giga tons CO_2, equal about half of the total above ground pool of carbon in Californian forests (Rojstazcer and Deverel 1993, 1995, Deverel and Leighton 2010).

Each year, between 10 and 15 million tons of CO_2 continue to be released from this Delta, equivalent to 2-3% of California's annual GHG emissions. Other large deltas that have released over 1 giga tons of CO_2 since the time of land use change include the Mekong Delta (4,7 $GtCO_2$), the Po (2,5), the Nile (1,4), the Wash (1,4), the Indus (1,2) and the Changjiang (1,1) (Crooks et al. in press).

These enormous and ongoing losses are currently not accounted for in national greenhouse gas (GHG) inventories under UNFCCC, nor mitigated through emission reduction strategies, and growing climate change impacts may further exacerbate the trends.

Opportunities for enhancing natural coastal and marine carbon pools

Knowledge of carbon sequestration and storage in different coastal and marine ecosystems and emissions arising from degradation or disturbance is not uniform. As a result mitigation opportunities and options vary considerably. However, it is clear that management of many coastal and marine ecosystems for increased carbon sequestration or avoided emission is immediately available using conventional management approaches. Moreover, in most cases this will have significant synergistic environmental effects, such as preventing shoreline erosion, promoting fishery productivity and protecting biodiversity. In some cases the effects on carbon pools, sequestration and emission rates are understood well enough to be quantified and incorporated in national GHG reporting as well as mitigation financing schemes. Establishment of carbon management in such areas is achievable in the near-term and could provide a bridge to future actions that draw upon the carbon sequestration potential of ecosystems more broadly.

Oceanic systems

The most obvious and legitimate opportunity for enhancing carbon sinking in the pelagic realm through management is promoting recovery of fish stocks and populations of large marine mammals. While it is presently difficult to quantify the mitigation potential it does lend weight to arguments for rebuilding the worlds depleted fishery resources.

Part and parcel of supporting recovery of and maintaining fish stocks is safeguarding functionality and productivity of pelagic ecosystems. Manipulation of productivity and geo-engineering of the biological pump, however, is fraught with problems. Due to dissolution and recycling only a fraction of pelagic production actually reaches the seabed. About 10% of the organic matter that leaves the euphotic zone (100m) reaches 1000m. Transfer efficiency ranges between 20 and 50% in the twilight zone, and only 1.1% (0.1-8.8%) of the primary production is transported as POC to depths greater than 1500m (Janssen et al 2002, Buesseler et al 2007, Lutz et al 2007). Thus promoting increased production e.g. through iron fertilization may not lead to a significant increase in transport of carbon to permanent sinks. Indeed, a recent study of an exceptionally large plankton bloom in the north Pacific, triggered and fertilized by volcanic ash, indicate only modest carbon sinking (Hamme et al 2010). In some cases sedimentation rates at seabed can be even counter indicative of pelagic production (Bishop and Wood 2009). Iron fertilization also entails a number of risks, such as reduced supply of macronutrients to surface waters downstream of fertilized regions, increased emissions of nitrous oxide and methane, both potent greenhouse gases, and changes in the extent or frequency of coastal hypoxia (e.g. Raven and Falkowski 1999, Buesseler et al 2008, Cullen and Boyd 2008). Finally, to secure a net reduction of atmospheric CO_2, once started these schemes would have to be maintained for ever.

Ensuring healthy pelagic ecosystems would, however, reinforce the pelagic to benthic linkages that sustain benthic dwelling fauna, including many echinoderms that provide an important mechanism for delivering carbon to sediment (Lebrato et al 2009, Smith et al 2009). Other actions that can protect and promote the role of benthic fauna in carbon sequestration is reducing negative impacts from activities such as bottom trawling and other fishing, oil, gas and mineral prospecting, and preventing the development of anoxic areas including through management of runoff.

While efforts to quantify oceanic carbon sinks and sources should be encouraged, practical application of such knowledge will in some instances present severe jurisdictional and governance challenges. The oceanic ecosystems and features that act as carbon sinks and sources cover vast areas that fall within the exclusive economic zones of numerous nations as well as in the high seas. This necessitates international and regional coordination and collaboration in management interventions. It also requires agreement on attribution of avoided emissions or increased sequestration arising from management actions, in particular when these are included in national GHG accounts or used to support decisions on mitigation financing.

Coastal Ecosystems

Our understanding of processes in tidal wetlands is sufficient to justify management and restoration for avoided emissions and increased sequestration. Existing guidance for estimating and reporting on GHG emissions by the Intergovernmental Panel on Climate Change (IPCC) can with relative ease be amended and expanded to also be applicable to coastal wetlands. In addition, carbon accounting methodologies and GHG offset protocols are under development by a variety of organizations, such as a US-based initiative to establish a GHG offset methodology for rewetting and conserving peat (VCS 2010), and the action plan released by the Restore America's Estuary National Blue Ribbon to establish an offsets protocol for temperate tidal wetlands (Crooks et al 2010) Some further examples are provided in an upcoming report by Crooks et al [in press], giving an overview of the considerable potential of nature-based mitigation using wetlands in particular, and presents pertinent data.

Similarly, knowledge of carbon dynamics in mangroves is adequate to warrant inclusion of mangrove management into the REDD mechanism. This offers opportunities for developing countries to finance mangrove management. However, REDD focuses on above and below ground biomass and does not at present consider carbon accretion in soil and sediment, which holds the largest pool of mangrove carbon and thus constitutes the largest sink and potential source of carbon dioxide. While this is mainly a result of methodological challenges, approaches for more comprehensive quantification of GHG budgets in mangroves can be adapted and refined from available methodologies for forests and wetlands. Guidance for management and restoration for enhanced carbon dioxide sequestration and avoided emissions can be established based on such approaches and available mangrove management and restoration manuals. A non-negligible opportunity for developing countries is including mangrove management activities in National Appropriate Mitigation Actions (NAMA). This could also encompass coastal wetlands management and restoration for avoided emissions and increased sequestration.

Estimates of the carbon burial capacity of seagrass meadows are limited in number, restricted to only some species and geographically biased. Available studies indicate that the rate of seagrass net production is of comparable magnitude to other coastal plants and higher than in most terrestrial ecosystems. (Duarte & Chiscano, 1999; Mateo et al., 2006). Especially in larger seagrass species below ground biomass development is considerable (Duarte & Chiscano, 1999). Reported carbon storage in sediment is highly variable both in the short and long term (Cebrian 2002, Duarte et al 2005). It seems likely that e.g. estuarine, high sedimentation seagrass beds will constitute more effective carbon sinks (and potentially lead to more significant emissions when degrading) than related reef seagrass beds. However, all seagrass beds are net sinks both in the short as well as long term under natural conditions (Kennedy and Björk 2009, Crooks et al in press). As such they offer immediate returns in terms of mitigation. With further research guidance and protocols can be developed that could, for example, enable trade in seagrass carbon credits.

The role of kelp beds is less well understood. While highly productive they do not accumulate significant amounts of organic rich sediment, and biomass turnover is very high. Possible long-term sequestration of carbon is through export of a fraction of kelp biomass to other (e.g. offshore) sinks. Further evaluation of the mitigation opportunities this offers is required (Reed and Brzezinski 2009).

Managing natural carbon sinks in the face of climate change

Climate change will itself have an impact on stability of carbon pools in coastal and marine ecosystems and their ability to sequester carbon. For example, while some coastal wetlands are expected to be able to accrete sediment at rates sufficient to keep up with present sea level rise of 3.1± 0.7 mm per year (IPCC 2007), accelerating sea level rise may in many cases outpace accretion rates (Harley et al 2006). Further, coastal profiles as well as man-made infrastructure will in many areas prevent wetland migration. Galbraith et al. (2002) estimate that intertidal habitat area may be reduced by 20–70% over the next 100 years in ecologically important North American bays, where steep topography and anthropogenic structures (e.g. sea walls) will prevent the inland migration of mudflats and sandy beaches.

Oceanic (and terrestrial) sinks that have lessened the rate of growth in atmospheric CO_2 until now may diminish as feedbacks between the carbon cycle and climate become more prominent (Houghton 2007). Current models indicate destabilization of carbon pools as a result of climate change will lead to a net increase in warming, but there is considerable variability as the uptake of CO_2 by land and ocean is poorly understood (The Royal Society 2010). Although increased temperature (and, at least in the case of terrestrial environments, increased carbon dioxide concentrations) can promote primary production, altered upwelling and reduced vertical mixing associated with climate change and in particular global warming are expected to decrease overall primary productivity in the ocean (Behrenfeld et al. 2006). The past 100 years have seen a decline in phytoplankton production in eight out of ten ocean regions, with the global rate of decline estimated at ~1% of the global median per year (Boyce et al. 2010). Increased temperature stratification also has implications for deep-ocean systems. Research has revealed large changes in deep-ocean ecosystems correlated to climate changes in the surface ocean, which can impact the global carbon cycle (Smith et al. 2009). Climate change effects will also lead to a number of changes in fish populations including considerable range shifts, with productivity increases in some areas and decreases in others (Cheung 2009). Therefore, maintaining the efficiency of natural ecosystems as carbon sinks rests, in addition to pursuing a range of mitigation strategies, on facilitating their adaptation to climate change through sound management.

Status and trends in natural coastal and marine carbon sinks in LMEs

Much of primary production in the ocean takes place within the world's 64 LMEs, and most if not all of the coastal ecosystems that lend themselves to nature-based mitigation fall within LMEs. The LME construct also makes it valuable to enhance these features. The 5-module LME strategy for measuring change and taking remedial actions (Sherman et al 2009) captures many of the processes important to management of carbon pools and fluxes in marine and coastal environments. Because LMEs are defined based on ecological criteria, including productivity and trophic relationships, their meaning and applicability for management purposes is strongly dependent on the ecological integrity of ecosystems that frequently span political boundaries.

However, the role of coastal and marine ecosystems in the carbon cycle in particular in the context of climate change and opportunities to reduce emissions from degradation or increased sequestration has by and large not been incorporated in LMEs, assessments and action plans. At the same time, many LMEs are centers of coastal ocean pollution, eutrophication, habitat degradation, overfishing, biodiversity loss, and climate change effects (Sherman et al 2009).

For example, coastal wetland loss is among the primary environmental problems in the Gulf of Mexico LME (rated poor) (Heileman and Rabalais 2009). Wetland loss along the Gulf of Mexico coast progresses at a long-term decadal rate of 2.5% as a result of coastal development, sea-level rise, subsidence, and interference with normal erosional/depositional processes. Within the last 70 years, Louisiana has lost c 5000 km^2 of coastal wetlands, and it has been predicted that up to 2000 km^2 will be lost in the next 50 years. Loss of these wetlands as natural protection from storms and hurricanes will have enormous consequences for people in the area, as well as for the energy security of the entire nation (EPA 2005). Loss of seagrasses over the last five decades ranges from 20% to 100% for most estuaries in the northern Gulf of Mexico, with only a few areas experiencing increases (Heileman and Rabalais 2009). Although only a fraction of the estuarine area in the Gulf Coast has high levels of sediment TOC (2% with TOC > 5%), the overall carbon emissions arising from wetland loss is likely to be significant.

Similarly, the UNEP LME Report (Sherman and Hempel 2009, individual chapters and references therein) states that:

- About 840 km^2 of coastal wetlands have been reclaimed in Shanghai since 1949, while 120 km^2 of coastal wetlands were converted to other uses from 1995 to 2000. China has planned to reclaim a further 45% of its mudflats.

- Approximately 30% of the surface area of wetland habitats in the Canary current LME has been permanently destroyed. Those that have not been destroyed are being modified largely because of continuing human activities.
- About 60%of Guinea's original mangroves and nearly 70% of the original mangrove vegetation of Liberia is estimated to be lost.
- Up to 70% of shrimp farms established on 10,000 km^2 of mainly mangrove forests allocated by the Indonesian government had by 2001 become unsustainable and were subsequently abandoned.
- The original area of mangroves in the South China Sea has decreased by about 70% during the last 70 years, with millions of hectares of land, mostly mangroves, having already been converted for shrimp mariculture, industrial development and tourist resorts. A continuation of the current trend would result in all mangroves being lost by the year 2030.
- There is evidence of widespread modification of seagrass habitats throughout the East Asian Seas region, with 20% to 50% of seagrass beds having been damaged. Vietnam has lost an estimated 40% to 50% over the past two decades.

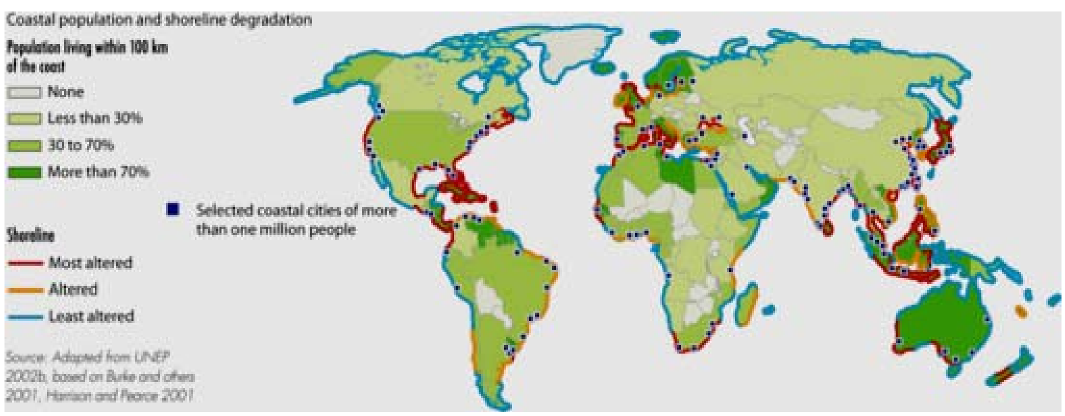

Figure 3. Coastal population and shoreline alteration. Areas in red are most altered through human impacts (Source: UNEP/GRID-Arendal).

These processes – widespread and covering a broad range of ecosystems – undoubtedly cause significant emissions of carbon dioxide from long-term sinks, as well as loss of sequestration capacity. However, as these emissions and losses of sinks are not quantified, they remain unreported and unmitigated. This is in part due to the fact that GHG accounting guidance specific to these ecosystems is by and large not available or only now being developed. More important from a governance perspective is that international policy frameworks do not explicitly obligate or encourage wetland management, as an activity under

Land Use Change and Forestry sections of the Kyoto Protocol. This reflects shortages in available scientific information about the processes of carbon storage in marine and coastal ecosystems. However, as mentioned above, available knowledge and methodologies provide a framework sufficient for quantifying GHG emissions and sequestration notably in coastal wetlands. Thus decisions regarding managing these systems for the purposes of climate change mitigation can already be made. Methods for management and restoration are also available and are, in many cases, both relatively straight-forward and cost-efficient. The same applies to mangroves, although estimating greenhouse budgets using presently available methodology does not capture fully soil carbon dynamics. In view of present status and trends of coastal and marine ecosystems, this adds impetus to further research into the factors influencing carbon sequestration in and carbon loss from seagrass beds and mangroves, as well as in the pelagic realm.

LMEs and nature-based mitigation

Current global climate change policies and governance mechanisms contain few incentives for restoration or disincentives to damage coastal ecosystems that hold large carbon pools and/or have considerable sequestration capacity. LME projects, supported by the Global Environment Facility, strive to sustainably manage these ecosystems for continued provision of a range of other ecosystem services and can thus also contribute to reducing emissions and increasing sequestration, but the exact contribution this makes to climate change mitigation is not being quantified. At the same time LMEs also offer opportunities to advance our understanding of how ecosystems act as carbon dioxide sinks or sources through assessment and research and, having established governance arrangements at national government levels, provide a sound platform for developing and testing management approaches that promote mitigation. This can directly inform national mitigation strategies and facilitate access to international carbon finance markets. It will also support international processes for identifying eligible mitigation activities for both developing and developed countries, as well as the inclusion of coastal and marine ecosystems in internationally adopted GHG accounting methodologies.

The Transboundary Diagnostic Analyses (TDA), conducted as part of LME planning processes, provide valuable overviews of status and trends in the marine and coastal environment of LMEs. Few if any TDAs have specifically addressed coastal and marine carbon pools, possible GHG emissions from them and carbon sequestration capacity. However, they do provide information on the ecosystems and features that may have particular value for nature-based mitigation and can thus to some extent serve as a baseline, while also identifying available data as well as critical gaps. It is important to bear in mind that the coastal systems that offer particular opportunities for nature-based mitigation are unevenly distributed. They may be of especially high value in certain regions or to certain countries, making up a significant part of national GHG budgets and offering opportunities to meet commitments as well as trade in offsets. Detailed assessment and mapping of GHG budgets can be carried out through LMEs.

Similarly, Strategic Action Programmes (SAP) that guide action both on national and regional levels to resolve threats to international waters, may in some cases provide implicit, if not explicit, mandates for managing coastal and marine ecosystems for the purposes of climate change mitigation. Most include provisions for environmental management and climate change adaptation actions that would be reinforced e.g. through activities that lead to avoided emissions from ecosystem degradation. Restoration of coastal ecosystems to enhance their carbon pools would also contribute to 'repairing' the nitrogen cycle and would reduce land-based marine pollution, frequently identified as a priority in SAPs. Similarly, improving the environmental sustainability of mariculture can also indirectly or directly reduce atmospheric CO_2, such as through development of integrated multi-trophic approaches and enhancing shellfish and seaweed culture (Zhang et al. 2005).

LME modules and indicators related to productivity and oceanography, fish and fisheries, as well as pollution and ecosystem health also capture many key aspects of carbon flux and storage. For example, sediment quality and coastal habitat indicators in the Pollution and Ecosystem Health Module, and assessment of multiple marine ecological disturbances (MMEDs) provide data on conditions of seagrass and mangrove habitat. This provides information on decline in ecosystem extent and health, and loss of essential services (Sherman et al. 2009). Wetland/delta soil organic content in combination with rates of loss (or accretion) provides an indication of carbon dioxide emissions (or storage in sinks). These assessments could be further extended to also measure change in carbon pools and sequestration capacity of other ecosystems.

Indicators of the productivity module, which already captures the key aspects of primary and secondary production in the surface ocean of LMEs, could support this further if extended to also encompass primary production in coastal systems such as tidal wetlands, mangroves and seagrass beds. These hold particularly large pools of carbon and exhibit high rates of carbon sequestration through primary production, which is also of importance to the pelagic realm and fisheries productivity through biomass and nutrient export. The fish and fisheries module obtains time-series information on changes in pelagic as well as benthic fish biodiversity and abundance. However, currently this does not entail particular attention to the transport of primary production to long-term or permanent sinks. Direct and/or proxy indicators for this may be possible to develop.

Through the LME socioeconomic module the value of coastal ecosystems for carbon management can be incorporated in planning. Direct economic benefits can be realized through trade in carbon credits. The opportunity costs of managing ecosystems for climate change mitigation will in some cases be considerable. However, the benefits of management and preservation of coastal wetlands may outweigh the opportunity costs of highly profitable but unsustainable wetland uses (such as intensive shrimp farming) if environmental externalities are accounted for, even at current carbon prices (Crooks et al. in press), or if the broader societal benefits of continuity in services that healthy coastal and marine environments provide are also considered. Through such analyses LMEs can enable nature-based mitigation and ensure it generates socioeconomic benefits. The regional collaboration fostered through LME can also address governance issues accounting for GHG sequestration in, and emissions from, ecosystems that span international borders.

Theoretical models have been derived for the carrying capacity of LMEs for fisheries (Christensen et al. 2009). Extending the carrying capacity to encompass coastal areas and processes will pose a significant challenge, technically as well as institutionally. But better understanding of the full range of benefits from maintaining coastal and ocean productivity and health, including increased CO_2 sequestration and reduced emissions, will provide both political and financial leverage for improved management.

Much work remains to be done before quantification of GHG emission reduction and sequestration in global and marine areas becomes sufficiently accurate to fully utilize all the opportunities offered. Simple but reliable approaches to measurement, reporting, and verification need to be developed. However, many coastal areas and especially wetlands, where available knowledge on carbon pools, emissions and sequestration rates is more complete, offer particular opportunities already to deploy, test and further develop nature-based mitigation of GHG sequestration and emissions within the world's LMEs.

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Chapter 12

Marine Spatial Planning as a Framework for Sustainably Managing Large Marine Ecosystems

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Introduction

For centuries, the sheer power and grandeur of the oceans made them seem impervious to human meddling. Today we face the stark accounting for our history of ocean use, where our appetites have directly shaped the ecosystems around us.

"The oceans have been like the Wild West, with the uses of any given area dependent on who gets there first," said Leon Panetta, former co-chairman of the U.S. Joint Oceans Commission Initiative and currently Director of the Central Intelligence Agency, in 2007. "Imagine if, on land, there were no rules on whether you could build a plant that produces hazardous waste next to an area that someone else wants to use for a housing development, school or public park. The group that wants to build the plant goes to the agency regulating plants that produce hazardous waste to get a permit, while the group that wants to build a housing development goes to the agency regulating housing developments, with little coordination between the two. Similarly along the shores, you can have inappropriate uses in a given place or incompatible uses sited right next to each other."

Marine spatial planning (MSP) brings a common sense approach to the oceans, and will help promote healthier seas and head off crises before they happen.

Coastal and marine spatial management is gaining considerable interest and momentum around the world as numerous countries have started to use MSP to achieve sustainable use and biodiversity conservation in large marine ecosystems (LMEs).

Beginning in the mid 1980s, Ken Sherman of the U.S. National Oceanic and Atmospheric Administration's National Marine Fisheries Service and Lew Alexander of the University of Rhode Island started to define the concept of LMEs as relatively large ocean spaces of approximately 200,000 km^2 or greater in the coastal waters adjacent to continents, where primary productivity is generally higher than in open ocean areas. At that time, the focus was primarily on collecting and analyzing bio-physical data at appropriate spatial and temporal scales to accommodate structured discussions about the biomass changes that were beginning to be observed in the oceans.

Today, LMEs are recognized as regional oceans of ecological continuity extending from the top of a river basin to the end of the adjacent continental shelf and seaward boundaries of coastal current systems. They are characterized by a combination of unique ecological criteria, bathymetry, hydrography, productivity and trophic relationships and generally account for 80 % of the total annual catch of global marine fisheries.

Currently, sixty-four LMEs have been identified around the world. Many are experiencing degradation as a result of over-fishing and destructive fishing, habitat modification and destruction, pollution, invasive species, and climate change. From its humble beginnings, focused on ecosystem dynamics at appropriate spatial and temporal scales, the LME approach has evolved into a 5-module strategy (productivity, fish and fisheries, pollution and ecosystem health, socioeconomic conditions, and governance) for improved management to protect and sustain ecosystem function and health.

The Need for Integrated Ocean Governance

Today, our oceans are in trouble. Experts estimate that more than a quarter of the world's major fisheries are struggling with depleted stocks. Our ocean and coastal waters are being polluted by agricultural run-off and other harmful toxins, which are threatening marine life and habitats. Consumers now worry about mercury levels whenever they reach for a fish at the supermarket or order it at a restaurant.

As the world's population grows by 2 – 3 billion people in the next 50 years, and people continue to settle along coasts and inland, the needs and pressures upon the marine environment will continue to grow. Without proactive marine spatial planning, use conflicts in LMEs will get worse—we already see competition between fishing grounds, wave energy facilities, protected areas and many others. Under our current fragmented management scheme, there is no way to address the impact of each activity on ecosystem services, the interactions of these activities on each other, and the cumulative impacts of these activities on the health of the ecosystem. Marine spatial planning's strength comes from focusing on and addressing the impacts of the *entire* suite of activities occurring in a specific place, so that LMEs can be resilient and productive into the future.

Increasingly, LMEs are being called upon to provide economic and social benefits in support of human well-being. For example, LMEs have emerged as the next frontier for renewable energy, home to potential wave, wind, and tidal power. But renewable energy facilities are just one of many important ocean uses that are competing for limited, and often sensitive, space. In order to sustain wealth from a variety of these uses, from fisheries to tourism, as well as to preserve the fundamental ecological structure and function that supports them, marine managers have started to think about new ways to manage proactively and wisely.

Marine Spatial Planning: A Framework

According to UNESCO, "marine spatial planning is a practical way to create and establish a more rational organization of the use of marine space and the interactions between its uses, to balance demands for development with the need to protect marine ecosystems, and to achieve social and economic objectives in an open and planned way. Marine spatial planning is a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process."

Marine spatial planning is not an end in itself, but a practical way to create and establish a more rational use of marine space and the interactions between its uses, to balance demands for development with the need to protect the environment, and to achieve social and economic objectives in an open and planned way" (www.unesco-ioc-marinesp.be/marine_spatial_planning_msp).

In contrast, traditional ocean management is marked by use-by-use management, with multiple agencies responsible for overlapping uses and areas of LMEs. For example, one agency may oversee fishing regulations, another aquaculture, and another enforcement of shipping rules. With uncoordinated management, LMEs have continued to be degraded in the face of multiple, cumulative stressors, reducing their ability to provide desired ecosystem goods and services. Marine scientists have called for ecosystem-based approaches to ocean management to protect ecosystem structure, function, and processes (McLeod et al., 2005. *Scientific Consensus Statement on Marine Ecosystem-Based Management*) (http://compassonline.org/?q=EBM). Marine spatial planning is an innovative way to put ecosystem-based management into practice.

An MSP process usually begins with collection, synthesis, and mapping of baseline physical, biological, and social characteristics of a given ocean space. The process brings people together to find common ground to develop ecological, economic and social objectives for that defined space. Then, by evaluating all the potential uses of the marine environment together with their positive and negative impacts on each other as well as the integrity of the oceans that is required to support these uses, MSP reduces user conflict while protecting areas critical to ecosystems and species, ensuring that ecosystem services are sustained.

The result of a good MSP process is a science-based and multi-stakeholder management plan that implements sustainable use. Marine spatial planning may build upon the current management regime, with mechanisms for coordination, instead of creating an entirely new jurisdictional structure. As in land use planning, a comprehensive MSP plan may be followed by a zoning scheme to separate incompatible uses, performance standards and regulations for different areas, guidelines for tradeoffs in decision making, and mechanisms for coordination, monitoring, and enforcement (Intergovernmental Oceanographic Commission, 2007. *Visions for a Sea Change: Report of the First International Workshop on Marine Spatial Planning*).

In practice, MSP:

- Enables managers to tackle large, system-level problems;
- Promotes appropriate, compatible, sustainable uses;
- Increases management efficiency through improved information exchange and interagency coordination;
- Ensures opportunities for appropriate development space;
- Advances stakeholder involvement via a transparent and structured process; and
- Creates ability to maximize benefits to humanity from an appropriate portfolio of uses.

The newly emerging field of ecosystem services may contribute to decision-making in an MSP process. Managers and stakeholders could evaluate the possible portfolio of ecosystem services that would be derived from various zoning arrays, based upon their environmental, ecological, and social objectives, in order to maximize the provision of desired services. Marine spatial planning also goes beyond the conservation tool of Marine Protected Areas. Protecting sensitive areas is one critical component of MSP, but by planning for and managing *all* uses around those sensitive areas, MSP will result in more resilient and productive ecosystems into the future.

The Framework in Action

Comprehensive MSP processes are now being implemented around the world in places like Belgium, the Netherlands, Canada, Germany, Australia, and China (Gopnik, 2008)[*]. In the United States, the state of Massachusetts was the first state to develop a comprehensive plan for its coastal waters. This process was largely driven by a new surge of development pressures, including proposals for wind farms, liquefied natural gas terminals, and pipelines. As in other places where MSP has been started, managers, scientists, and other ocean users were concerned about the lack of a long-term view in the face of these individual project proposals. There was no one single agency taking an integrated look at where these facilities should best be sited, relative to all of the important aspects of Massachusetts' coastal resources. Rather, proposals were being dealt with on a case-by-case basis by multiple agencies. In 2004, the Massachusetts Ocean Management Task Force, convened by the governor, identified ways to improve the manage-

[*] **Gopnik, Morgan**. Marine Spatial Planning in U.S. Waters: The Path Forward. The Gordon and Betty Moore Foundation, 2008.

ment and long-term health of the state's ocean. The Task Force's primary recommendation was a comprehensive ocean management plan.

The state legislature responded to the Task Force's recommendation and its constituents' desire to sustain fisheries, tourism, and conservation, and to be a leader in renewable energy, by passing the Oceans Act of 2008. Under the Oceans Act, the state's Executive Office of Energy and Environmental Affairs led a multi-agency, science-based planning process to operationalize object-tives for the plan, synthesize baseline data, assess cumulative human impacts, define various marine spatial plan options that would meet stated objectives (including the protection of special, sensitive, and unique habitats and renewable energy development), and decide upon a final plan.

The state included stakeholders in collaborative public meetings and advisory bodies throughout the process. Here, a public-private partnership called the Massachusetts Ocean Partnership, which includes leaders from the fishing, environmental, academic, shipping, government, and business communities, provided critical thought leadership and funding for scientific research and stakeholder involvement to bolster the state process. An ocean management plan was released on January 4, 2009. This plan was a leap forward for ocean management in the state because it included spatial and regulatory measures, performance standards for use and protection areas, and an adaptive process for revisiting the plan over time. In contrast to the status quo, this MSP process provided for a balanced, forward-looking plan for use of the oceans and clarity for ocean users. It provided transparent mechanisms for making tradeoffs, coordination between agencies, and ways to adaptively incorporate new information and needs.

Marine spatial planning has been implemented in more than a dozen countries globally, but the EU countries have been early pioneers in this approach. The MSP schemes in Germany, the Netherlands, and Belgium effectively cover their territorial sea as well as exclusive economic zones. Similar approaches have been started in the UK and Sweden, while in other Member States formal MSP processes are still in the early stages of development.

The Obama Administration as well as leaders in California, Rhode Island, Maine, Hawaii, and others are learning from the Massachusetts plan and process. In British Columbia, the Pacific North Coast Integrated Management Initiative is poised to build on the significant accomplishment of the First Nations marine spatial plans that were completed in March 2010. In July 2010, President Obama committed all regions of the United States to developing integrated ocean and coastal management systems based on MSP by creating a National Policy for the Stewardship of the Ocean, Coasts, and the Great Lakes. The national ocean policy calls for the development of coastal and marine spatial plans (CMS plans) based on the White House Interagency Ocean Policy Task Force's *Framework for Effective Coastal and Marine Spatial Planning* (19 July 2010), a framework that outlines a comprehensive, integrated, and ecosystem-based strategy to manage the conservation, economic activity, user conflict, and sustainable use of ocean, coastal, and Great Lakes resources.

Benefits of MSP

Successful MSP includes clear objectives for ecological and social goals, including economic, recreational, historic and ceremonial values. It requires a public participation process, an information portal to inform planning, and standards for determining where uses should go and how to evaluate trade-offs. Critically, comprehensive planning requires that we finally bring together the disparate sets of information that each sector collects but doesn't share with others. In essence, here is finally both an opportunity and a mandate to comprehensively consider what we know about a particular part of the ocean.

According to UNESCO, while many examples of marine spatial planning are in early stages, a number of potential important economic, ecological and social benefits have been identified. The biggest benefit for industries using large marine ecosystem resources is certainty. Planning coordinates and identifies which industries are compatible, in which ocean and coastal areas, and anticipates what conflicts may arise. This allows efforts to be made to reduce conflicts in advance among various industries, as well as reduce conflicts between industrial uses and sensitive ecosystems. Marine spatial planning frequently results in a streamlined permitting process. For states and countries that rely on LMEs as economic engines, MSP offers the most advanced way to plan for efficient use of resources and space.

Ecologically, MSP does a number of things to keep LMEs resilient. First, it prioritizes the identification of areas that are biologically or ecologically important. Then it incorporates any biological objectives, like protecting sensitive habitat or sustaining a key ecosystem service into the plan. This may result in identifying areas that will be used for nature conservation or recommended for a network of marine protected areas to protect biodiversity. Ultimately, MSP offers a sound way to reduce the cumulative impacts of human uses on LMEs.

In addition to economic and ecological benefits, MSP offers a number of social benefits. For one, it involves communities and citizens in the planning. Public voices and concerns are considered as ocean space is allocated for specific use or non-use and the economic and quality of life impacts are taken into consideration. This participation leads to improved protection of cultural heritage. It also ensures that social and spiritual considerations are included in potential use. This inclusive process creates greater buy-in to the planning process for those most impacted.

Momentum Behind MSP

Human use of ocean space is rapidly expanding – a trend driven by the quest for cleaner energy, food security, and increasing numbers of proposals for use of ocean space within LMEs. At the same time, climate change is confounding the expansion of human uses and our ability to manage ocean resources sustainably. Decision makers realize that threats to LMEs and growing conflicts over uses of the ocean are merely biophysical symptoms of fragmented and mismatched governance, and are turning their attention to diagnosing and treating the real problems that lie in the human dimension.

The main objective and consequently the main challenge of integrated ocean and coastal management is to maintain *ecosystem services* in an LME where user activities will continue increasing and space will be increasingly limited. To support continued momentum, the following needs to happen.

- **Effective monitoring and data sharing** – We need to find new ways to monitor and integrate the necessary data, the graphical output and modeling approaches that allow people to look at tradeoffs, and the social data tools, including stakeholder involvement methods and models.

- **Comprehensive stakeholder involvement** – Stakeholder input is a crucial component for an integrated management effort to be successful. Efforts must highlight the need for an aggressive stakeholder input process from all sectors. Furthermore, the importance of including all sectors in spatial planning efforts will need to be clearly articulated.

- **Transboundary issues** – Addressing ocean and coastal management issues between neighboring states and neighboring countries is key. Coordination across jurisdictions is therefore an important issue to consider in integrated ocean and coastal management.

- **Measuring cumulative impacts** – Marine spatial planners need to determine how to measure and account for cumulative impacts, ecosystem services, and emerging issues.

- **Identification of clear authority** – Identification of a clear authority for effective coordination is crucial to a successful integrated management process, especially for coastal and marine spatial planning.

- **Mechanisms to allow focus on the future** – An integrated ocean management plan should be dynamic by design and focused on the future to account for new and emerging sectors. Ensuring that integrated marine planning efforts include mechanisms that allow the incorporation of changes in economies, climates, and unforeseen issues is a difficult, but necessary task.

Moving Forward

No amount of marine life management can reverse the cumulative impact of humans on LMEs. We can only react to the coming changes—mitigate them, and adapt. Our best hope lies in protecting ecosystems to weather the storms ahead, securing the relationships that keep the systems running and painting a picture of what the future sea will look like if we act now, and what it will look like if we do not. Marine spatial planning offers us a way to tackle this challenge by managing for function, protecting the ocean qualities that sustain humans and ultimately life on earth.

For our own well-being and that of our children and future generations, we must design systems that balance conservation and use in a common sense manner. That is just what MSP does. It offers the opportunity to integrate human use and conservation, both of which should complement each other. Within a single framework, and with all parties involved, MSP will capture the entire suite of possible marine uses and activities – spanning the spectrum from extraction to conservation – and examine their impacts and benefits, together and at one time. It uses the best available science, and offers an approach that anticipates potential conflicts and mitigates them before they become reality.

If human use is well-planned and managed, ecosystems can be resilient and productive, but we need well-designed systems in place to help us navigate those waters. Marine spatial planning offers us an effective way to do this.

Commemorative Commentary: Sustaining Shark Populations*

"Shark finning is not only cruel, it is irresponsible and unsustainable fishing at its highest degree. In spite of this, it has been close to impossible to attain any international binding management and conservation measures to curtail this practice." –Randall Arauz 2010

Randall Arauz of Costa Rica is a 2010 Göteborg laureate in recognition of his campaign to focus international attention to halt the practice of shark finning.

Sharks in Decline

The eastern Pacific Ocean has historically been home to significant populations of sharks, with more than 18 different species identified in Costa Rica's waters alone. However, many species of sharks are now critically endangered. Over the last 50 years, global shark populations have declined by 90% as a result of overfishing, which has been exacerbated during the last decades by the growing demand for shark fins, specifically to be used as the key ingredient in shark fin soup. In China and in Chinese restaurants around the world, shark fin soup is a delicacy that was once considered a luxury consumed only on special occasions. Today, as China's economy booms and the growing middle class increases demand for the soup, shark finning has decimated the once-thriving stocks. As many as 100 million sharks are slaughtered annually to feed global demand. This unprecedented change in shark populations significantly threatens the sensitive balance required for healthy marine ecosystems, thus endangering the fisheries and economic livelihoods of fishing communities around the world.

The practice of shark finning has been widely criticized as wasteful by conservationists and brutal by animal rights activists. International fishing fleets targeting sharks specifically for their fins tow miles of hook-covered lines, catching thousands of sharks and other marine life in what is known as long-line fishing. The sharks are then hoisted aboard, where workers slice the fins from live animals before tossing the fin-less bodies back into the ocean to die. Because shark fins command $70 per kilo while shark meat yields only about $.50 per kilo, it has not made economic sense for ships to fill valuable hold space with a commodity worth so little. A single expedition can yield millions of dollars in profits when only fins are kept and shipped to market.

The potential for huge short-term profits has led many governments throughout the world to relax existing fisheries laws or simply turn a blind eye to shark finning. In 2004, Costa Rica was the world's third largest exporter of

* Commentary downloaded from www.goldmanprize.org/2010/southcentralamerica

shark products, including 800 tons of fins. Vessels from Taiwan, China, Indonesia and elsewhere travel to shark-rich waters, pay duties to local governments to land on their docks, and then bring their catches to market in Hong Kong, where the majority of the trade in shark fins takes place.

Steps Toward Permanent Protection

Arauz, a conservationist who founded the Association for the Restoration of Sea Turtles (PRETOMA) in 1997, has emerged as one of the world's leading voices working to ban shark finning. As a turtle biologist and conservationist, he worked with the shrimp industry in Costa Rica to reduce the sea turtle casualties associated with trawling. After some success in introducing new trawling technology to the industry, he learned that long-line fishing boats were also to blame for sea turtle deaths. When Arauz's friend got a job as a cook on a long-line shark fishing boat, Arauz sent along a video camera so that he could learn more about exactly how the fishing technique worked. The footage he received completely shocked him. He had not previously been aware of shark finning, and seeing the brutal practice in full color sparked his subsequent commitment to stop shark finning in Costa Rica.

In 2003, Arauz exposed a Taiwanese ship illegally landing 30 tons of shark fins, amounting to the deaths of 30,000 sharks, late at night at a private dock in Puntarenas, using a secretly filmed videotape. He released the footage to the media, and the resulting shock and outrage from the Costa Rican public and international community galvanized support for Arauz's ensuing campaign to enforce the country's existing laws against shark finning. He mobilized the support of 80,000 citizens and 35 deputies of the Legislative Assembly to sign a petition calling on Costa Rica's president to halt the practice and close private docks to the landing of international ships, as dictated by existing customs legislation. The petition and media attention garnered by the public outcry led to a decision by the customs department in November 2004 to halt all landings of fishery products by international vessels on privately-owned docks until they complied with the law. Unfortunately, the closure lasted only a few weeks.

Following this interim move, a new national fisheries law went into effect in February 2005 that specifically prohibits shark finning and mandates all sharks to be landed with their fins attached. The new law also calls for fines and jail terms for those caught landing shark fins at Costa Rican ports.

However, the industry soon identified loopholes in the legislation that enabled them to continue shark finning. The law still allowed for the landing of whole sharks with their fins "attached," so fleets began tying large fins to tiny sharks to get around the finning ban. In August 2006, Arauz succeeded in closing this loophole.

Arauz also filed suit against the Fisheries Institute and the Customs and Public Transportation Ministries at the Constitutional Court, Costa Rica's highest court, for failing to abide by current customs law. In 2006, the court ruled in PRETOMA's favor.

Throughout his campaign in Costa Rica, Arauz has worked closely with the Ministry of Foreign Affairs and the Congress to urge the UN to ban shark finning and to stop all long-line fishing in the eastern Pacific's international waters. He viewed a complete ban as a clear deterrent for shark finning vessels and as a means for reducing the negative impact on the other marine life unintentionally caught by the lines. In 2007, the UN General Assembly approved language calling on nations to mandate that all shark fins be landed attached to the body of the shark, marking a major shift in policy and a huge victory for Arauz and other activists working to protect sharks globally.

Since the UN recommendation was issued, Arauz has represented Costa Rica at several UN meetings and has called for a complete ban on shark finning. In 2007, he participated in a UN Convention of Migratory Species meeting as an official Costa Rican delegate and was instrumental in the election of Costa Rica as a member of a five-country commission tasked with drafting language for international cooperation for the protection of sharks.

It is inevitable that the 6,876,471,888 people inhabiting the planet as of 21 October 2010 leave their marks there.

From the points of view of the authors in this book, it is still possible for us to make individual and collective choices that will result in restoring and sustainably develop-ing our planet's full potential for present and future generations.