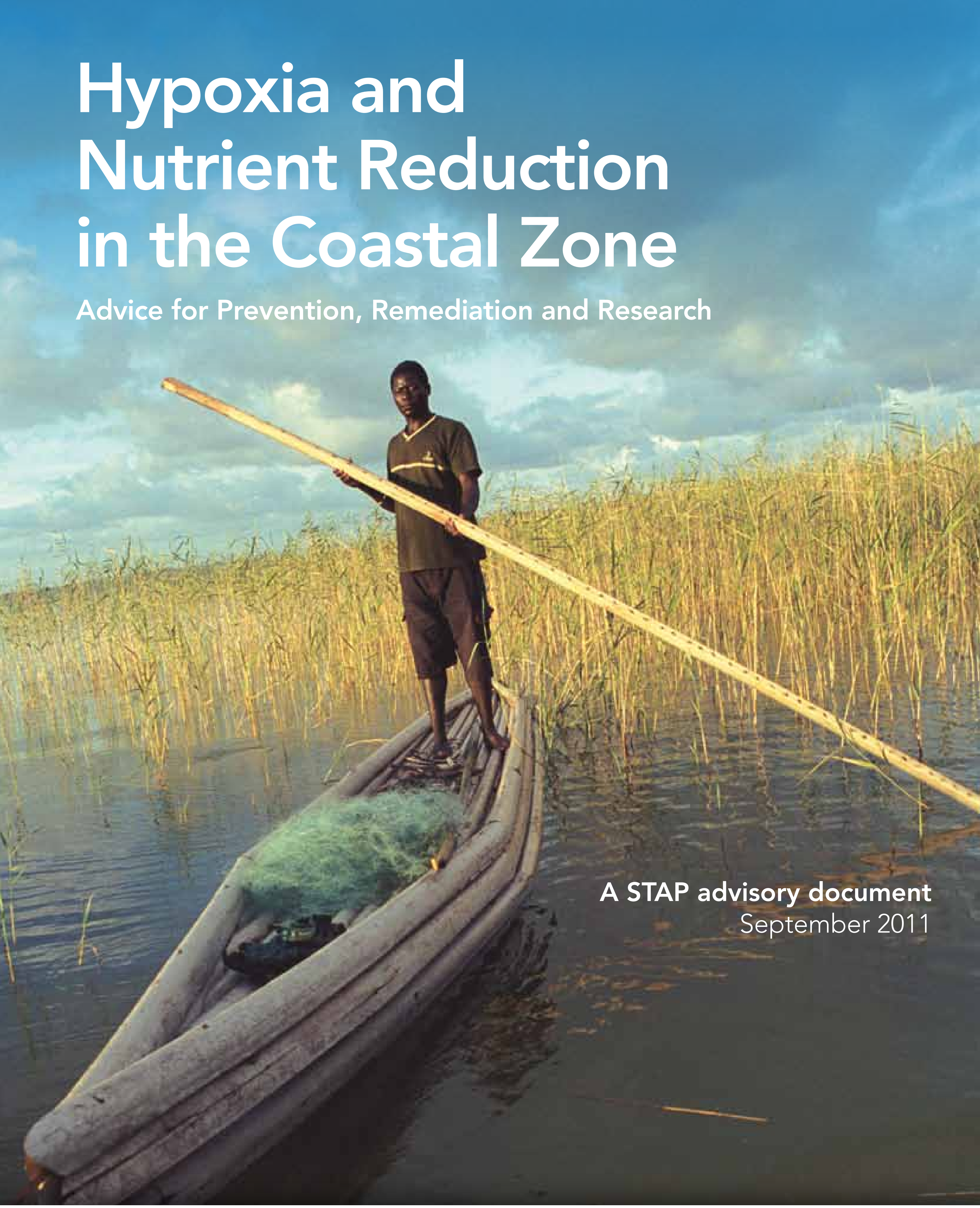

Hypoxia and Nutrient Reduction in the Coastal Zone

Advice for Prevention, Remediation and Research

A STAP advisory document
September 2011

Scientific and Technical Advisory Panel

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Hypoxia and Nutrient Reduction in the Coastal Zone
Advice for Prevention, Remediation and Research: A STAP advisory document

Prepared on behalf of the Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF) by

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Details of contributions are on pages 6-7.

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Disclaimers
The contents of this publication are believed, at the time of publication, to accurately reflect the state of the science regarding hypoxia and nutrient reduction in the coastal zone, nevertheless STAP accepts responsibility for any errors remaining.

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About STAP
The Scientific and Technical Advisory Panel comprises six expert advisers supported by a Secretariat, which are together responsible for connecting the Global Environment Facility to the most up to date, authoritative, and globally representative science.

http://www.unep.org/stap

Foreword

Reported cases of coastal hypoxia or low oxygen areas have doubled in each of the last four decades, threatening global environment benefits in most of the Large Marine Ecosystems (LMEs) in which GEF supports programs. GEF requested STAP to review the scientific evidence on coastal hypoxia and advise how to address the issue, beyond current actions. This STAP Advisory Document is based on a review of the scientific evidence, and scientific and management expert consultations. It has been reviewed by subject matter experts, the GEF Secretariat, the GEF International Waters Task Force and GEF agencies.

STAP concludes that the growing problem of coastal hypoxia requires accelerated GEF attention. Hypoxia is caused by eutrophication, i.e., the overloading of waters with nutrients, especially nitrogen, phosphorous and silicon and/or organic matter. Coastal areas are suffering from accelerating nutrient pollution from multiple sources including agriculture and livestock production, sewage and industrial waste, plus additional complex temperature and water exchange impacts from climate change. Nutrient effects on water oxygen levels are exacerbated when local water bodies become stratified and mixing, and thus oxygenation, of layers is prevented.

Hypoxia remediation is possible by reducing eutrophication through systematically reducing nutrient pollution from the most significant local sources. Nutrient reduction also brings multiple ecosystem benefits such as improved water quality, biodiversity, healthier fish stocks, aquaculture improvement and fewer algal blooms. The GEF and its development partners have already invested in substantial nutrient reduction efforts, with measurable success in the longer running European projects. To address accelerating coastal hypoxia, **GEF and its development partners should urgently increase their support to nutrient reduction projects, building on GEF's experience and leadership.** Coastal hypoxia and its causes are multi-focal area issues. GEF-International Waters is the lead focal area but hypoxia also concerns Biodiversity, Land Degradation and Climate Change and is an issue in which most GEF agencies have a role. This Advisory Document describes the need for integrated approaches and the specific roles for each GEF agency, and for international, national and local governments and industries.

Not all cases of coastal hypoxia are amenable to easy remediation. Where hypoxia originates primarily from the combined effects of larger scale ocean circulation events and climate change, local land based interventions will have limited impact. Intervention areas should be selected based on their expected potential for prevention or remediation and progress should be monitored. **GEF should establish principles for supporting priority systems in which to test management responses to permanent and seasonal hypoxic systems.** Priority should be given to east and south Asia where the largest increase in the number of hypoxic areas is expected.

Most of the GEF LME projects in advanced stages of implementation have reported coastal hypoxic areas matching those in the most comprehensive scientific database.[1] To assist projects, **GEF guidance for International Waters Transboundary Diagnostic Analysis and Strategic Action Programs should include new tools on how to address hypoxia and nutrient reduction. Existing LME projects should examine the current knowledge on coastal hypoxia and establish monitoring, prevention and remediation programs if these are not already underway. To assist new projects, GEF should support the development of a Hypoxia Toolkit, similar to the Persistent Organic Pollutants Toolkit (www.popstoolkit.com), and integrate into the project screening process a hypoxia screening tool that should be made available on the GEF IW:Learn project website.**

Coastal hypoxia is a complex problem and, although research has made great strides in understanding its causes and remedies, more knowledge is needed to fill critical gaps that impede action. **Prevention and remediation of hypoxia must be based on realistic expectations for success.** We recommend that **GEF agencies develop proposals along with selected targeted research initiatives to fill critical action and knowledge gaps and to guide GEF LME projects, within the overarching framework of global nitrogen cycle disruption.**

Thomas E. Lovejoy
Chair, Scientific and Technical Advisory Panel

Meryl J Williams
Panel Member for International Waters

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[1] Prof. R. Diaz, Virginia Institute of Marine Science, The College of William and Mary, Gloucester Point, VA, USA.

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Brief for the GEF - Coastal Hypoxia and Nutrient Reduction in the Coastal Zone

Rapid economic development and population growth, much of it along the world's coasts, plus increasing agriculture and livestock production, have placed huge environmental pressures on coastal ecosystems from direct resource use and the rising influx of nutrients and other pollutants from the land and atmosphere. A major symptom of the environmental pressures is the exponential rise in the number of coastal areas suffering from low oxygen or hypoxia. In each of the last five decades, the number of hypoxic coastal and estuarine areas has doubled. More than 500 hypoxic zones now threaten critical ecological areas, including the majority of the world's large marine ecosystems supported by the Global Environment Facility (GEF). Recognizing the increasing threats from hypoxia, the GEF tasked its Scientific and Technical Advisory Panel (GEF-STAP) to review the current knowledge of coastal hypoxia, its causes, lessons learned from GEF investments and other cases, and develop recommendations on how to prevent and remediate the growing problem. The present STAP Advisory Document addresses GEF's request. It was developed from reviewing the latest scientific literature and opinion, along with input from two expert consultations, the first in October 2009, in Shanghai, China covering the scientific basis and the second in June 2010 in Washington DC, USA covering local to international management options.

A review of the evidence for coastal hypoxia

The incidence, intensity, size and duration of coastal hypoxic areas are increasing, threatening GEF investments in global environmental benefits in large marine ecosystems (LMEs). Coastal hypoxia reduces fisheries production, kills and impairs fish and other marine life populations (changing their diversity and health), threatens human health, and reduces coastal amenities. Hypoxic areas also emit the most potent greenhouse gases, especially nitrous oxide and methane. Scientific evidence conclusively shows that coastal hypoxia is caused by eutrophication - that is, the overloading of waters with nutrients, especially nitrogen, phosphorous and silicon and/or organic matter. The effects of added nutrients on oxygen levels are exacerbated by local water body conditions, particularly strong stratification that prevents mixing and oxygenation of water body layers. Coastal areas, particularly but not only in newly industrializing countries, are suffering from accelerating nutrient pollution from multiple sources, including agriculture and livestock production, sewage and industrial waste, plus additional complex temperature and water exchange impacts from climate change. Hypoxia is often accompanied by increased harmful and obstructive algal blooms that harm human health, and may cause or contribute to severe economic losses. In areas such as the Yellow Sea, the Oregon Coast and in the eastern Arabian Sea, naturally low oxygen water from oxygen minimum zones in the deep ocean intrudes on the coastal shelves and interacts with, and exacerbates, human-induced hypoxic events.

Experience, including through GEF interventions, shows that remediation of hypoxia is possible. Eutrophication must be reduced systematically by reducing nutrient pollution from the most significant local sources, such as municipal sewage, agricultural fertilizers, and livestock waste. Beyond reducing the areal extent and severity of hypoxia, nutrient reduction also will bring multiple ecosystem benefits, such as improved water quality, biodiversity, healthier fish stocks, aquaculture improvement for filter feeders such as oysters, fewer algal blooms, and reduced biochemical oxygen demand. However, not all cases of coastal hypoxia are amenable to easy remediation. In cases where hypoxia originates primarily from the combined effects of larger scale ocean circulation or climate events, e.g., upwellings of low oxygen water from the deep, decadal climate patterns, and climate change, local land based interventions will have limited impact or responses may be delayed. Intervention areas should be selected based on their expected potential for prevention, or remediation, and progress should be monitored. To support sustained action, realistic expectations of the time needed for recovery should be established. Even for areas that can be remediated, 10-30 years may be needed to return to acceptable conditions, although improvements usually manifest after the first few years. Left unremediated, coastal hypoxia leads to serious and mounting social, economic and ecological costs as has been experienced by some OECD countries.

Indicators for coastal hypoxia and nutrient reduction

The most important indicator for stress reduction is the annual nutrient load entering the coastal areas through rivers and streams. In measuring progress towards reduced eutrophication, dissolved oxygen in the water column is a critical measure. Other indicators include turbidity, nutrients such as nitrogen, phosphorous and silicon and their compounds, temperature, salinity and depth. Totally anoxic (zero oxygen) conditions are marked by the accumulation of hydrogen sulphide, which also should be measured as an indicator in severe cases. Harmful algal blooms (HABs) also serve as an example of a bioindicator of a potential hypoxic area, although HABs do not necessarily lead to hypoxia. Once diagnosed, hypoxic conditions should be drawn to the attention of policy makers and their management responses directed towards solving eutrophication problems. Biogeochemical indicators should be complemented by socio-economic indicators.

The initial step towards reducing nutrient emissions should be an inventory of point source discharges and agricultural activities. If no hypoxia problems are evident, this would be followed by a carefully designed monitoring program on point source and diffuse nutrient concentrations and run-off, adjusted to a "standard run-off situation" or baseline for each location. Atmospheric sources must also be assessed especially in heavily industrialized regions where they can be a significant source of nutrient inputs. Indicators of nutrient reduction should be measured on monthly to annual scales, according to the rates at which changes manifest. When hypoxia from land-based sources of pollution is documented, a careful program of pollution reduction from sources of nutrients and oxygen depleting substances is warranted, accompanied by a water quality and biological monitoring program to document future conditions in the area of hypoxia. Non-point sources of nutrient pollution are the most difficult to measure and reduce. To date, most successful reductions have been from point sources.

Hypoxia in GEF LME projects

Large Marine Ecosystems are the GEF organizing units for transboundary coastal projects. GEF supports projects in 17 of the 64 LMEs. Using the GEF project IW:Science[2] document database, GEF LME project references to hypoxia were compared with those in the global scientific hypoxia database of Prof. R. Diaz.[3] For six LMEs (Gulf of Mexico, Mediterranean Sea, Black Sea, Guinea Current, Red Sea and Yellow Sea), GEF project reports closely matched information in the global database; six LME projects are still in early stages of development and have not yet provided relevant information (Agulhas and Somali Current, Canary Current, Baltic Sea, Gulf of Thailand and Indonesian Sea). Project documents from the remaining five LME projects (Bay of Bengal, Benguela Current, Caribbean Sea, Caspian Sea, Humboldt Current and South China Sea) reported hypoxia information that was not able to be matched directly with those in the global database. In some cases, the GEF LME reports were more precise and in others less. Overall, GEF LME projects are aware of hypoxia. To improve further how GEF projects address hypoxia, hypoxia management and nutrient reduction measures need to be explicitly embedded in GEF Transboundary Diagnostic Analyses (TDAs), and Strategic Action Programs (SAPs). Since new hypoxic areas are expected to emerge, all LME projects should monitor for hypoxia. To illustrate successes and challenges, five selected GEF case studies of hypoxia in LMEs are reviewed; Danube River/Black Sea, Baltic Sea, Yellow Sea, Gulf of Mexico and Guinea Current, plus two non-GEF case studies; Chesapeake Bay (United States of America) and the Mersey River (United Kingdom).

Preventing and remediating coastal hypoxia requires integrated actions

Experience with successful remediation efforts shows that management actions will need to be coordinated across sectors and scales as needed, and that fully integrated efforts can be built sequentially. The GEF-IW approach offers essential elements for integration. For example, the LMEs and freshwater transboundary surface water projects support collaborative platforms for joint cross-country and cross-sector identification of issues (TDAs), and commitments to action (SAPs). Ultimately, integrated coastal management (ICM) and basin-scale integrated water resources management (IWRM) usually will need to be combined and emphasize nutrient pollution reduction to deal effectively with coastal eutrophication, and hypoxia. Coastal managers will need to work with land-based agencies to make the case for and stimulate behavioral and practice changes.

Comprehensive nutrient reduction models are valuable for integrated and single sector management such as in coordinating and ranking the sectoral and spatial priorities for interventions and comparing the cost effectiveness of different pollution reduction options. Since coastal hypoxia typically involves large geographical areas and a variety of sources of nutrients whose rates change over time, stress reduction requires an iterative, long-term approach, shared long term vision, and coordinated and agreed intermediate steps. To overcome financial barriers for interventions such as waste water treatment plants, local governments and coastal area managers will need support from national and regional authorities.

Existing integrated management and nutrient reductions tools from Partnerships in Environmental Management for the Seas of East Asia (PEMSEA), Food and Agriculture Organization (FAO), the United Nations Environment Programme's Global Programme

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2. Enhancing the Use of Science in International Waters Projects to Improve Project Results, UNU-INWEH, see: http://www.inweh.unu.edu/River/IWScience.htm
3. Virginia Institute of Marine Science, The College of William and Mary, Gloucester Point, VA, USA.

of Action for the Protection of the Marine Environment from Land-based Activities (UNEP-GPA) and others and models from the Danube (MONERIS) and Intergovernmental Oceanographic Commission can be adapted, used and further developed. This Advisory Document provides a guide to key tools and materials.

Implications for the GEF

For GEF, coastal hypoxia and its causes are multi-focal area issues. Most GEF agencies have a stake and capacity to contribute. GEF-International Waters (IW) is the lead focal area but hypoxia also impacts global environment benefits in Biodiversity (BD), Land Degradation (LD) and Climate Change (CC). For example, near marine protected areas it can impact (referring to GEF-5 Focal Area Strategies) BD Objective 1 (to improve sustainability of protected area systems). Similarly when linked to fisheries, forestry and tourism, hypoxia affects Objective 2 (mainstreaming protection in production landscapes). CC Objective 5 (conserve and enhance carbon stocks through sustainable management of land use, land-use change) is affected because hypoxia changes coastal carbon sequestration and leads to increased emissions. In LD all objectives are affected, or alternatively can play a remediation role. The GEF cross-focal area objective of contributing to sustainable forest management also would positively contribute to preventing and remediating hypoxia because good forest management improves water quality and nutrient retention.

The GEF, along with development partners, has already invested in substantial nutrient reduction efforts, having supported the UNEP-Global Plan of Action on Land Based Sources of Pollution and the Global Nutrient Management Programme, and invested more than USD120 million in projects over 15 years in Southeastern Europe and Asia, with measurable success in the longer running European projects. Asian nutrient reduction projects are still underway and results are not yet expected. Technologies and approaches have included standard primary and secondary sewage treatments, construction and reconstruction of wetlands, improved on-farm livestock manure management and governance reforms. The compelling scientific and technical evidence is that GEF and investment partners should urgently escalate support to nutrient reduction.

GEF should establish principles for supporting priority systems in which to test management responses to permanent and seasonal hypoxic systems, considering the following factors:

- Priority should be given to east and south Asia where the largest increase in the number of hypoxic coastal areas is expected.
- Smaller systems with existing hypoxic conditions are more amenable to hypoxia remediation than larger systems and serve as a good entry point to larger scale efforts. Larger systems more open to ocean circulatory patterns are more likely to be strongly influenced by global climate and climate change impacts, which may not be "controllable" in the short- to medium term.

STAP advice is given for seven different groups of stakeholders.

- Intergovernmental bodies – must facilitate multinational, regional agreements on strategic action, normative instruments and create partnerships to bring nutrient reduction and hypoxia remediation to the fore of national pollution reduction agendas.
- National governments and agencies – should establish, implement and maintain sound scientific monitoring strategies, management strategies and supporting regulatory and legislative framework for pollution reduction, including especially for farm fertilizer use, livestock waste and sewage discharges as key sources of nutrients and oxygen demanding pollutants. Unless international bodies and national government sector ministries act, countries will not achieve the Millennium Development Goals in the coastal zone, such as reversing the loss of environmental resources.
- Industrial sectors – need to actively engage as stakeholders in policy-decision making and change their practices to reduce nutrient pollution.
- Scientific research community – must emphasize sound scientific input, which is crucial in every step of hypoxia management and communication of science to decision makers.

- Coastal zone managers, local governments – are central to hypoxia prevention and remediation through reforming municipal utilities for water and sewage pollution reduction and engaging local stakeholders. Complex institutional arrangements and infrastructure will be too much of a burden for most local governments and coastal managers. National governments need to assist local governments to overcome financial barriers and coordinate projects that cross political boundaries and involve multiple public and private sector stakeholders.
- NGOs – should be involved actively in integrated hypoxia management advocacy and actions.
- Communities and civil society – play an important role as environmental stewards and should show a vested interest in the health of their coastal marine and watershed environments and in continued flows of economic and social benefits of the goods and services they provide.

Specific roles are outlined for GEF partners, the GEF Secretariat, GEF Agencies (Multilateral development banks, UNEP, UNDP, UNIDO, FAO), three tiers of government in countries and key industrial sectors. Key roles and responsibilities are described for coordination, long term monitoring, new technological efficiencies, reforms and investments in reducing human sewage pollution and agricultural pollution, shared responsibilities, community involvement and integration in terms of management, scale, discipline and stakeholders. Based on critical knowledge gaps currently slowing progress, four research needs are proposed:

- Move towards an ecosystem-based management approach that includes the larger issue of global nitrogen cycle disruption.
- Synthesize the large body of knowledge on hypoxia and eutrophication across sectors and alternative remediation options to provide practical guidance on avoiding future areas of coastal pollution leading to hypoxia.
- Identify locations for focused research projects; and
- Look at future scenarios and contextual issues relating to hypoxia.

Although scientific understanding of the conditions that cause and remediate coastal hypoxia have become much better understood in the last decade, only a few long-term studies have yet been done to show how coastal ecosystems respond to decreases in nutrient loading and recover from hypoxia. While this is a critical knowledge gap, the STAP workshops clearly illustrated that the science community supports pollution reduction actions and that those actions are associated with improvements in coastal hypoxia where action has already been taken.

Recommendations to GEF to prevent and remediate coastal hypoxia

The growing problem of coastal hypoxia now requires heightened GEF attention. The following actions are recommended. More details of suggested implementation are contained on page 53, "What actions can the GEF take to prevent and remediate coastal hypoxia?"

- GEF and development partners should urgently increase their support to nutrient reduction projects, building on GEF's experience and leadership.
- Establish principles for supporting priority systems in which to test management responses to permanent and seasonal hypoxic systems.
- Develop a Hypoxia Toolkit similar to the Persistent Organic Pollutants Toolkit (www.popstoolkit.com), integrating into the screening process for new projects a hypoxia screening tool that should be made available on the GEF IW:Learn project website.
- GEF guidance materials for International Waters Transboundary Diagnostic Analysis and Strategic Action Programs should incorporate the tools developed for LME projects to address hypoxia and nutrient reduction.
- All existing LME projects should examine the current knowledge on coastal hypoxia and establish monitoring, prevention and remediation programs if these are not already in place.
- Prevention and remediation of hypoxia should be based on realistic expectations for success.
- GEF agencies should develop hypoxia research proposal(s) to fill critical coastal hypoxia knowledge gaps to guide action in GEF LME projects while at the same time addressing the associated concern of global nitrogen cycle disruption.

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Acronyms

BAPs	Best Agricultural Practices
BCLME Programme	Benguela Current Large Marine Ecosystem Programme
BD	Biodiversity
BMPs	Best Management Practices
BOD	Biological Oxygen Demand
C	Carbon
CH_4	Methane
CO_2	Carbon Dioxide
CAFOs	Concentrated Animal Feeding Operations
CBD	Convention on Biological Diversity
CC	Climate Change
CEE	Central and Eastern Europe
CSO	Combined sewer overflows
DIN	Inorganic nitrogen nutrients (NO_3-N + NO_2-N + NH_4-N)
DO	Dissolved oxygen
DRP	Danube Regional Project
EECCA	Eastern Europe, Caucasus and Central Asia
ENSO	El Nino-Southern Oscillation
EPA	Environmental Protection Agency
ESTs	Environmentally Sound/Sensible Technologies
EU (MS)	European Union (Member States)
FAO	Food and Agriculture Organization
Fe	Iron
FWS	Free water surface system (for wetlands)
GCLME	Guinea Current Large Marine Ecosystem
GDP	Gross Domestic Product
GEB	Global Environmental Benefit
GEF	Global Environment Facility
GOMLME	Gulf of Mexico Large Marine Ecosystem
GPA	Global Programme of Action
GPNM	Global Partnership on Nutrient Management
H_2S	Hydrogen Sulfide
HABs	Harmful Algal Blooms
HELCOM	Convention on the Protection of the Baltic Marine Environment
HPLC	High Performance Liquid Chromatography
Hrs	Hours
ICARM	Integrated Costal Area and River Basin Management
ICM	Integrated Coastal Management
ICPDR	International Commission for the Protection of the Danube River
IGO	Inter Governmental Organization
IM	Integrated management
IOC	Intergovernmental Oceanographic Commission
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IW	International Waters
IWRM	Integrated Water Resource Management
IWTF	International Waters Task Force
km	Kilometers
KTSE	Knowledge Translation, Synthesis and Exchange
L	Liter
LD	Land Degradation
LMIC	Low and Middle Income Countries

Acronyms

LME	Large Marine Ecosystem
m	Meters
μmol, μM	Micro-Moles
mg	Milligram
$mg\ l^{-1}$	Milligrams per liter (equivalent to PPM)
Mn	Manganese
MONERIS	Modeling Nutrient Emissions in River Systems
N	Nitrogen
N_2	Nitrites
N_2O	Nitrous Oxide
NAO	North Atlantic Oscillation
NBMPs	Nutrient Best Management Practices
NEWS-DIN	Nutrient Export from WaterSheds (inorganic nitrogen nutrients)
NGO	Non Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NR	Nutrient Reduction
ODA	Official Development Assistance
OECD	Organization for Economic Co-operation and Development
OMZ	Oxygen Minimum Zones
OSPAR	Oslo and Paris Commissions (Convention for the Protection of the Marine Environment of the North-East Atlantic)
P	Phosphorous
p.e.	Person equivalents
PEMSEA	Partnerships in Environmental Management for the Seas of East Asia
PES	Payment for Environmental Services
pH	Power of Hydrogen (measure of acidity)
PPM	Parts per million (equivalent to mg l-1)
PPP	Public-Private Partnerships
PRTR	Pollutant Release and Transfer Register
RENDR	Reduction of Enterprise Nutrient Discharges Project
SAP	Strategic Action Plan
SCOR	Supply Chain Operations Reference
SFS	Sub-surface flow system (for wetlands)
Si	Silicon
STAP	Scientific and Technical Advisory Panel
TDA	Transboundary Diagnostic Analysis
Tg	Teragrams (1012 grams, equivalent to a megatonne)
TEST	Transfer of Environmentally Sound Technologies
TMDL	Total Maximum Daily Load
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Programme
UN-ECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
UNU-INWEH	United Nations University Institute for Water, Environment and Health
UWWT	Urban Waste Water Treatment
WFD	Water Framework Directive
WWT	Waste Water Treatment
yr	Year
YSLME	Yellow Sea Large Marine Ecosystem

Definition of Terms

Coastal hypoxia	A state in the oceans where oxygen levels are depleted to less than 2 - 3 ppm (Committee on Environment and Natural Resources (CENR), 2000); Mississippi River Basin Watershed Nutrient Task Force, (2010).
Anoxia	Total lack of oxygen (similar to anaerobic) (U.S. Geological Survey, 2011. URL: http://toxics.usgs.gov/definitions/anoxic.html)
Dead zone	A lay term to describe an anoxic zone
Oxygen minimum zone	The zone of the ocean in which oxygen saturation is at its lowest. The OMZ occurs between 200 and 1,000 m depth in areas determined by ocean circulation, mixing with upper more oxygenated layers and depletion of oxygen by bacteria. Upper and lower ocean depths are higher in oxygen (based on Wikipedia entry. URL: http://en.wikipedia.org/wiki/Oxygen_minimum_zone).
Nutrient	Elements and compounds required for plant and animal growth e.g. U.S. Environmental Protection Agency, 2010; Mueller and Helsel, 1996. (URL: http://toxics.usgs.gov/definitions/nutrients.html)
Eutrophication	An increase in nutrient concentration (Art, 1993; National Academy of Science, 1967) (URL: http://toxics.usgs.gov/definitions/eutrophication.html)

Hypoxia-related sources

Art, H.W. (1993); CENR (2000); Mississippi River Basin Watershed Nutrient Task Force. (2010); National Academy of Sciences. (1969); U.S. Environmental Protection Agency. (2010); U.S. Geological Survey. (2011).

The rivers of northeast China spill sediment into the Bo Hai, a bay off the Yellow Sea.

1. Introduction

Rapid economic and population growth, much of it coastal, combined with increasing commodity production, processing, consumption and trade of food, fiber and energy have placed huge environmental pressures on coastal ecosystems. Human actions directly exploit coastal space and resources, alter and destroy natural habitats, reduce their capacity to absorb nutrients and increase the influxes of nutrients and other pollutants from the land and atmosphere. As a result, coastal water quality has deteriorated and estuarine and marine food webs changed. However, among these effects, the intensification of hypoxia has been the most fundamental environmental change in estuarine and coastal marine systems (Diaz and Rosenberg, 1995). The number of reported hypoxic areas related to human activity is rising, both in coastal and inshore waters. Diaz and Rosenberg (2008) documented the expanse of over 400 hypoxic areas in the world's coastal areas covering more than 245,000 km^2 of the sea bottom. Subsequently, the global database of reported events has risen to over 500 areas (Dr R. Diaz, personal communication and World Resources Institute[4]). These areas now threaten critical ecological and climate goods and services in most large marine ecosystems, including most of those in which GEF supports transboundary programs.

Scientific studies have indicated that human-caused eutrophication i.e., nutrient over-enrichment, is the main driver behind the expansion, intensity and duration of coastal hypoxic conditions (Rabalais et al., 2010). Until recently, hypoxic areas were found mainly on coasts and in estuaries of developed countries but the largest future increases in the number of hypoxic systems are expected in southern and eastern Asia (Seitzinger *et al*., 2002). Evidence is growing that open ocean oxygen concentrations are also declining. Based on the analysis of all available data from the global oceans, Gilbert *et al*. (2010) determined that for the last three decades, oxygen concentrations have been declining faster within 30 km of the coast between and 0 to 300 m water depth than in the open ocean. Overall the declines are related to global climate change, but the higher rate of decline near the coast is linked to land derived nutrient loads and possible interactions between warming and nutrients.

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4. http://www.wri.org/project/eutrophication/map

Through a combination of land runoff and, in some areas, atmospheric deposition, inland and oceanic aquatic ecosystems are becoming eutrophic from increased nutrient loading. The quantity of nutrients reaching the coastal ocean is determined not only by their original source strengths (e.g. the quantity of fertilizers used in agriculture, municipal sewage discharges), but also by the pathways through which these nutrients are cycled through watersheds. Cycling varies greatly from one watershed to another. For example, in South Asia, where roughly one-fifth of global synthetic nitrogen fertilizer is applied, nutrients released to the environment build-up in soils, groundwater and small aquatic bodies such as ponds and lakes, which then become strongly eutrophic. Significant transport by rivers only occurs during the wet season, but even then nutrient concentrations in most estuaries are not very high.

The efforts to remediate hypoxia should target eutrophication drivers. Coastal hypoxia is only one of the manifestations of eutrophication which also causes problems such as algal blooms, changes in water quality and food web structure (Cloern 2001). Reversing eutrophication, especially in hypoxia-prone areas, thus will have multiple ecosystem benefits beyond reducing the extent and severity of hypoxia. Especially where fish kills occur, the occurrence of hypoxia can be a strong argument attracting political support to reduce eutrophication drivers. Political support is critical to address the most challenging management issue in dealing with coastal eutrophication and hypoxia, namely how to integrate management actions across catchments and the coastal zone. The concepts and practices of integrated management will be elaborated in this Advisory Document.

Recognizing the increasing threats from hypoxia and the rapid recent advances in scientific evidence, GEF tasked its-Scientific and Technical Advisory Panel (GEF-STAP) to review the current knowledge, its causes, lessons learned from GEF investments and other cases and develop recommendations on


Aerial view near Dili, Timor-Leste (East Timor).

Water pollution due to dairy farming in the Wairarapa in New Zealand.

how to prevent and remediate the growing problem. The present STAP Advisory Document addresses GEF's request. It was developed from reviewing the latest scientific literature and opinion, and from two expert consultations, the first in October 2009, at the State Key Laboratory of Estuarine and Coastal Research, East China Normal University in Shanghai, China covering the scientific basis and the second in June 2010 in Washington DC, USA covering local to international management options. More than 35 experts participated; the final draft document was reviewed by all GEF agencies.

The GEF is the world's largest financial mechanism for projects to improve the global environment including transboundary freshwater and marine ecosystems. Using a partnership approach, the GEF is able to mobilize significant financial resources and know-how globally for dealing with complex issues such as coastal hypoxia. GEF has supported work in many of the known large marine ecosystems (LME) in which hypoxia has been detected, including the Humboldt Current LME, Gulf of Mexico LME, Benguela LME, Yellow Sea LME, South China Sea and Gulf of Thailand LME, Bay of Bengal LME, Baltic and Black Seas. Many of the GEF-supported actions have included significant support for nutrient reduction or broad eutrophication reduction measures. The most ambitious nutrient management project in GEF history has been the support for the Black Sea and Danube Basin, including the establishment of the Investment Fund for Nutrient Reduction with the goal of reducing hypoxia on the northwestern shelf of the Black Sea.

This Advisory Document is comprised of several complementary sections. Section 2 provides an overview of the scientific evidence for the causes, impacts and remedies for coastal hypoxia. The overview concludes that coastal hypoxia is human-induced and results from over-enrichment of coastal waters, often compounded by local water body flow characteristics, climate and climate change. This causality and empirical experience from well-documented cases show that remediation and prevention are possible. Section 3 contains basic advice for measuring and monitoring the biochemical aspects of eutrophication and hypoxia, including the frequency of monitoring. In Section 4, we investigate GEF's experience with coastal hypoxia in projects in 17 LMEs, in nutrient reduction investments and GEF's and others' experiences in hypoxia case studies. Recognizing the scale and range of responsible actors that need to be engaged to prevent and remediate hypoxia, Section 5 presents a short guide to existing hypoxia and nutrient reduction resources from FAO, PEMSEA, UNEP and others. It also provides in depth advice for seven classes of actors, namely international bodies, countries, coastal zone managers and local government, industry and the private sector, scientific researchers, non-government organizations and communities and civil society. The specific roles of GEF agencies are also covered. Section 6 touches briefly on targeted research that would help GEF refine its hypoxia approaches to great effect. The Advisory Document concludes with recommendations to GEF.

Aerial view of the district of Plateau in Abidjan, Côte d'Ivoire.

2. Coastal Hypoxia: An Evidence-Based Review

What is Hypoxia? The term "hypoxia" means insufficient supply of oxygen. In marine and coastal waters, the term is primarily used when water contains lower than normal oxygen concentrations to the extent that local organisms react to the low oxygen levels. To date, the scientific literature has not adopted consistent terms for specific levels of oxygen to express different conditions or even anoxic conditions (no oxygen). In this Advisory Document, we adopt the use agreed by the Scientific Committee on Oceanic Research (SCOR) Working Group 128 on coastal hypoxia. This defines the upper threshold of hypoxia as a state of the water column with dissolved oxygen concentrations of 2 mg L^{-1} (1.4 ml L^{-1} or 63 µmol L^{-1}) or 30% of oxygen saturation (Rabalais *et al.*, 2010). This value is particularly relevant as a threshold for coastal waters and organisms that have evolved under normal dissolved oxygen conditions and became exposed to hypoxia as a recent stressor. In contrast, hypoxia is a natural component of many freshwater habitats and much of the fauna has evolved tolerance to hypoxia. However, caution should be exercised in applying the 2 mg L^{-1} definition at the level of organisms or even ecosystems because different bottom dwelling marine organisms have lethal and sublethal responses to hypoxia that can vary by an order of magnitude (Vaquer-Sunyer and Duarte, 2008).

This paper does not use the term "dead zones", coined in the media, because the term is scientifically incorrect when applied to coastal hypoxic areas, the large naturally occurring open ocean oxygen minimum zones (OMZ) and upwelling areas along the coasts or truly anoxic waters. In these environments, different and highly diverse forms of microbial life thrive, especially sulphide-using bacteria when oxygen is very low and persists (Levin *et al.*, 2009).

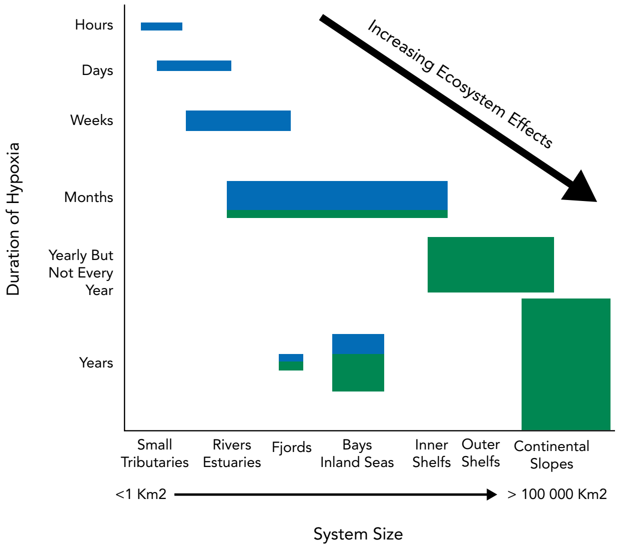
Hypoxia occurs when oxygen is being used up faster than it is re-supplied by ventilation of the water column from the atmosphere, through horizontal water movement, or by in situ photosynthetic production. Even in relatively well-mixed systems, hypoxic conditions may develop if the supply of organic matter is large enough to off-set oxygen diffusion and water movement. Sources of human-origin wastes rich in organic matter are human and animal sewage, effluent from food-processing plants, pulp and paper mills and fish-farms. For anoxic systems (with dissolved oxygen levels below the detection limit), stratification of the water column by waters of different densities is the main controlling factor.

The size and duration of existing coastal hypoxic areas vary by orders of magnitude. According to their duration, hypoxic systems can be classified into four main categories: permanent (years to decades to centuries), persistent seasonal (months), episodic (weeks), and diel (24 hrs or daily) (Diaz and Rosenberg, 2008). The spatial scales of hypoxic systems range from inshore estuaries to coastal shelves and open ocean areas and span depths of 1-2 m up to 600-700 m. Over these varied time and space scales, human influence varies. Humans have had the most negative impacts at smaller scales of space and time while natural processes dominate larger scales (Fig. 1). The current Advisory Document deals with coastal hypoxia which is predominately affected by human effects, i.e., the red in Fig. 1.

Although upwelling and OMZ are primarily marked as systems with natural hypoxia, evidence is increasing that at least some of them (for example the expanding OMZ along the west coast of India, the expansion of anoxia in the Baltic Sea, and possible shoaling of the oxic/anoxic interface in the Black Sea) are caused by the increased load of human generated nutrients. Global climate change, when considered as a human impact, affects all existing hypoxic systems at the outer shelf and continental slopes and is leading to a higher proportion of waters with declining oxygen concentrations (Bakun *et al.*, 2010; Gilbert *et al.*, 2010; Stramma *et al.*, 2010). Some projections based on climate change scenarios suggest about a 50% increase in OMZs by 2100 with their declining oxygen concentrations and expansion towards coasts (Riebesell *et al.*, 2007). Apart from a few examples of mixed natural and human influences on the outer shelf and continental slope hypoxic systems, most of OMZ and coastal upwelling areas cannot be *effectively* managed in the near-to-medium term. Only systems shown to the left from the vertical red line in Fig. 1 might be amenable to effective and direct management of hypoxia given the policy-relevant time interval (from several years to a couple of decades).

Diel, or daily hypoxia, is least studied compared to other types and is usually associated with highly carbon-productive tributaries, lagoons, and bays with restricted horizontal and vertical water flows.

FIGURE 1 - A synthesis of the variability of temporal, and spatial and typological categories for environments with hypoxia



The blue and green colors represent the relative ratio of human vs. natural influences, respectively (Rabalais et al., 2010). The vertical line marks the relative scale of systems that will best respond to management efforts to reduce hypoxia. Systems to the right of the line are directly manageable.

The emerging ability to continuously monitor oxygen and other water quality parameters with relatively inexpensive equipment will likely lead to the discovery that many systems undergo some form of daily cycling of oxygen. Episodic hypoxia (weeks to decades) usually occurs in similar systems, but is also typical in microtidal coastal systems. In such systems hypoxia can be stimulated by freshwater discharge creating layers in the water column. Daily and episodic hypoxia, however, have only mild impacts relative to those of seasonal and permanent hypoxia (Kemp *et al.*, 2009; Rabalais *et al.*, 2010). Permanent and seasonal hypoxia areas are the best studied and are of greatest importance for GEF projects in terms of human influence and their social and economic significance.

OMZs are the largest hypoxic areas in the world and cover about 30 000 000 km^2 (equivalent to about 8% of the total oceanic surface area) of open ocean mostly beyond continental margins and 764 000 km^2 of the continental margin sea floor (Paulmier and

Ruiz-Pino, 2009). The drivers for their formation are high surface and photic (light) zone productivity, old water masses, and limited circulation (Levin *et al.*, 2090; Rabalais *et al.*, 2010). OMZs occur at depths between 100 and 1200 m in the south-and north-eastern Pacific, off Western Africa, in the South and North Atlantic, and in the Arabian Sea. OMZs usually occur below upwelling regions fueled by high primary production associated with the latter. When nutrient rich OMZ water is upwelled onto the continental shelf, coastal hypoxia can be exacerbated in intensity and spatial scale (Keeling *et al.*, 2010).

Examples of hypoxic areas on the continental margins below 100 to 200 m in depth are along the eastern boundary currents associated with major upwelling areas (California, Humboldt, and Benguela currents). A notable exception to this general rule is hypoxia observed in the Bay of Bengal at water depths from 150 to 500-600 m, where the rate of exchange between coastal and open water masses and the highly nutrient enriched river discharge from catchment areas result in persistent hypoxia. However, Rabalais *et al*. (2010) speculate that even in rather open water circulation systems (like the Bay of Bengal), with increasing eutrophication, hypoxia might become a common phenomenon in coastal areas. The balance between upwelling and hypoxia can also change for the worse as a result of overfishing that alters the system's trophic pathways (food webs). This has been documented in the Benguela upwelling system on the southwest coast of Africa (Utne-Palm *et al.*, 2010).

The linkage between human influence and hypoxia is best established for estuarine and shelf systems. The most notable examples of such hypoxic systems include fjords (Drammensfjord and Mariager Fjords in Norway; Himmerfjarden, Sweden); estuaries (Chesapeake Bay and Perdido Bay, USA; Venice Lagoon, Italy; Wilson Inlet, Australia; Pearl River, China); and shelf areas such as in the northern Adriatic Sea, East China Sea (off Yangtze River), Yellow Sea (off Yellow River); northwestern shelf of the Black Sea (off Danube River); and northern Gulf of Mexico (off Mississippi River). Meanwhile, the Baltic Sea represents the largest enclosed seas dominated by human driven hypoxia and anoxia.

Drivers of coastal hypoxia, eutrophication and the disrupted global nitrogen cycle

Nutrient inputs from the land drive eutrophication by direct and indirect mechanisms, which in turn drive hypoxia. For all established cases of human-caused hypoxia, eutrophication (increase in the rate of supply and accumulation of nutrients, particularly nitrogen and phosphorus, Nixon, 1995 and Rabalais *et al*. 2010) played a key role. Worldwide, the increase in the occurrence, intensity and duration of hypoxia in coastal areas is primarily driven by increased eutrophication (Diaz and Rosenberg, 2008). Physical controls on water movement, especially limited horizontal water movement and stratification or layering that limits vertical water exchange, also have been important background factors in almost all cases of hypoxia. The external and internal sources and volumes of nutrient inputs driving eutrophication have increased. On coastal shelves and along continental slopes, major external sources are nutrients and organic matter derived from agricultural and other runoff, ocean upwelling sources formed offshore, or organic matter coming from untreated sewage and industry. However, the major driving factor of eutrophication is usually internal – increased primary production in the waters themselves fueled by the excess of externally derived nutrients – but not easily separated from other stressors and drivers of change within a system (Rabalais *et al.*, 2010).

Reactive N production has increased more than 20 times from 1860 to 2005, currently accounting for about 187 TgN annually (Galloway *et al.*, 2008). Over the same period, global phosphorus flux to the ocean increased 3-fold to about 22 Tg per year by the end of the 20th century (Tilman *et al.*, 2001). The main N sources are artificial fixation of atmospheric nitrogen (N) into fertilizers, nitrogen oxide emissions from the burning of fossil fuels, and the vaporization of various N containing compounds (Galloway *et al.*, 2008; Paulmier and Ruiz-Pino, 2009; Seitzinger *et al.*, 2010). Evidence is growing that coastal and oceanic hypoxia may contribute net nitrogen oxide emissions to the atmosphere (Bulow *et al.*, 2010;

Fisheries and Multiple Stressors in the Black Sea

In temperate and subtropical estuaries and semi-enclosed seas, hypoxia is not the single limiting factor for total landings of finfish and mobile macro-invertebrates. In such complex systems as the Black Sea, the effect of any one stressor is difficult to interpret; as shown by the decline in demersal fisheries on the northwest continental shelf of the Black Sea. In the 1980s and early 1990s the northwest continental shelf of the Black Sea was in a severe state of deterioration from stress exerted by multiple factors including over fishing, exotic species introductions (the ctenophore *Mnemiopsis* spp.), pollution, altered hydrology, and nutrient enrichment that led to eutrophication-induced hypoxia (Mee, 1992; Kideys, 2002; Oguz, 2005). Historical data show that in the 1940s the northwest Black Sea was considered to be oligotrophic (having low nutrient levels), but by the 1970s nutrient enrichment had led to a highly eutrophic condition, which in turn led to alterations in the composition and quality of phytoplankton production including harmful algal blooms (HAB). In the 1970s, prior to the introduction of the ctenophore, and in the 1980s before ctenophore populations exploded, eutrophication resulted in increased anchovy (*Engraulis encrasicolus*) production and widespread hypoxia. Through the 1970s and 1980s hypoxia and anoxia became more prevalent and were the primary cause of mass mortality of the benthos including demersal fish. Other complex changes occurred, likely a response to multiple stressors including increased turbidity, decreased non-gelatinous zooplankton, a decline in biodiversity, and replacement of highly valued demersal fish species with less desirable planktonic omnivores. Of the 26 commercial species fished in the 1960s, only six still supported a fishery in the early 1990s (Mee, 1992). In 1989 the ctenophore populations exploded and caused a crash in the pelagic anchovy and non-gelatinous zooplankton that was not oxygen related. The resilience of the Black Sea ecosystem was observed in the 1990s when nutrient loads declined between 1991 and 1997. Primary production declined, a species shift back to diatoms occurred, harmful algal blooms decreased, non-gelatinous zooplankton increased, and pelagic fish reappeared (Kideys, 2002; Mee, 2006). The introduction of the ctenophore *Beroe* spp., a predator of *Mnemiopsis* spp., further improved the Black Sea ecosystem. The take-home message is that the entire combination of stressors affecting the Black Sea needs to be examined in order to understand ecosystem responses.

Freshly caught anchovy fish

Walker *et al*., 2010). Phosphorous (P) sources to the ocean include P-fixed fertilizers, untreated animal manure, and animal waste products washed from the land (Tilman *et al*., 2001; Cordell *et al*., 2009).

By the year 2050, agricultural expansion driven by global population growth and changes in consumption patterns could increase nitrogen and phosphorous fertilization by an additional 2.4-2.7 times, resulting in widespread eutrophication of terrestrial, freshwater and coastal ecosystems (Tilman *et al*., 2001). Riverine nutrient inputs are considered significant factors in increasing eutrophication (Mayorga *et al*., 2010). Nutrient management in agriculture, extent of sewage treatment, and phosphorus detergent use are key factors affecting magnitude and direction of river exports of dissolved inorganic nitrogen and dissolved inorganic phosphorus.

Pressures and impacts

Research is revealing the impacts of hypoxia on water column and bottom dwelling biological communities (reviewed in Ekau *et al*., 2009 and Levin *et al*., 2009) as well as on the geochemistry of the water column and bottom sediments (reviewed in Middelburg *et al*., 2009). To date, economic and social analyses of the impacts of coastal hypoxia are almost totally lacking and will be challenging to undertake as many impacts are indirect and have a lag period, such as sub-lethal effects on marine life. This sub-section focuses specifically on hypoxia impacts on geochemistry and fisheries.

The concentration of dissolved oxygen in the water column strongly controls biogeochemical processes in sediments and the exchanges of nutrients at the sediment/water interface. Meadows of tidal marsh, seagrass and macro-algae such as kelp plants play an important role in trapping significant amounts of nitrogen and phosphorus and halting eutrophication of surrounding waters. However, above a certain nutrient level, they also are susceptible to eutrophication impacts (Darby and Turner, 2008).

Recent studies demonstrate that fluxes of methane (CH_4), a potent greenhouse gas, to the atmosphere from the expanding coastal hypoxic zones will probably be insignificant. However, coastal upwelling areas with shallow OMZs represent significant sources of nitrous oxide (N_2O), a 300-fold more potent greenhouse gas than CO_2 (Naqvi *et al*., 2009). Shallow OMZs may represent an important source of CO_2 to the atmosphere when in conjunction with coastal upwelling events (Paulmier *et al*., 2008). Continuing ocean acidification over time might accelerate this process (Feely *et al*., 2008).

For pelagic marine life communities, larger mobile predator species are the first to be affected by hypoxic areas. For example, the habitats of Atlantic blue and white marlin and sailfish are compressed and appear to have decreased with the shoaling of the OMZ in the Pacific Ocean (Prince and Goodyear, 2006). In the Atlantic, the disappearance of sardine off Namibia (associated with overfishing) triggered a sequence of complex ecosystem responses that lead to similar habitat reductions (Utne-Palm *et al*., 2010). As a result, pelagic fishes more vulnerable to hypoxia have declined and large populations of hypoxia tolerant gobies now dominate the trophic structure of upwelling areas. Among pelagic winners are gelatinous plankton and squid, as observed in Benguela and California upwelling regions. However, the exact changes in composition of pelagic communities are difficult to estimate. On demersal fisheries, in addition to direct impacts of low oxygen concentrations on behavior and physiology, other cascading factors such as loss of prey and habitat modification may have the greatest effect (see text box) (Breitburg *et al*., 2009). Under hypoxic conditions, the proportions of demersal fish and shellfish usually decline relative to pelagic fishes (Caddy, 2000; Levin *et al*., 2009). Furthermore, early life stages of some species are particularly vulnerable to decreased oxygen concentrations (as demonstrated by Baltic cod and Chesapeake Bay anchovy). Kills of fish and other large marine organisms have been recorded (Zhang *et al*., 2010).

A young girl extracts fish from her net on the shores of Lake Titicaca.

Overall, the existing evidence derived from laboratory and limited field studies show adverse effects of hypoxia on reproductive functions and the physiology of marine organisms. This suggests that further expansion of hypoxic zones globally represents a significant threat to fisheries and other marine life (Wu, 2010).

Response actions

The causal relationship between eutrophication and the occurrence of hypoxia is well established. The most commonly used assumption in developing management strategies for hypoxia in estuarine and semi-enclosed seas has been that decreasing nutrient loads will lead to reduced eutrophication and as such reduce or eliminate hypoxia. The most studied intervention for eutrophication has been reduction in organic matter loads and/or nutrients from point discharges. However, the analysis of existing, well studied systems in North America and Europe suggests that the relationship linking nutrient reduction to reduced eutrophication to reduced hypoxia often is non-linear, especially in large systems (Kemp *et al.*, 2009) and differs from system to system. Monitoring and research specific to each system and its sources of nutrient pollution will be required in order to understand and adapt prevention and remediation actions. The evidence does suggest that hypoxic conditions improve rapidly and linearly in smaller systems (such as estuaries and inlets) with combined reductions of available organic matter and nutrients from point sources. However, in larger stratified systems with diffused input of nutrients as the main drivers of the increased primary production, the response is mostly non-linear (Kemp *et al.*, 2009). The co-occurrence of other factors such as climate change, fishing harvest and species invasions, contributes to the development of hypoxia and causes the baseline to shift, hence the hysteresis-type response curves (i.e., those in which the effect lags behind its cause and cause and effect are not linear).

The reasons geographically larger systems such as large estuaries, semi-enclosed bays and seas usually showed non-linear or no-responses to hypoxia remediation efforts could be that they are more resilient than smaller systems, more under the control of climatic and/or water mixing, and they have more complex food webs and biogeochemical cycles. The success of remediation actions could be masked by shifting baseline conditions or be unrelated to management actions.

Nutrient control measures have been more successful in reducing point rather than non-point sources of N and P, especially when reductions have been concentrated on both nutrients. For example, 10 years after the implementation of the Clean Water Act in the USA in 1972, water quality and oxygen conditions improved generally across the US mainly as a result of reducing point sources (Smith *et al.*, 1987). However, in some instances nutrient use and control practices may have shifted the ecosystem to a different structure, causing "undesirable" ecosystem impacts on species abundance and composition, and leading to changes in quality of primary production (Cloern, 2001; Turner *et al.*, 2003).

Evidence is not conclusive as to which remediation efforts can be more effective – those concentrated only on nutrients or those including organic matter (that from once-living organisms). In shallow and well-mixed coastal systems where both these drivers of eutrophication are important, a positive (often linear) response is best achieved when both drivers are reduced simultaneously. In deeper stratified estuaries and shelf regions, where nutrient inputs usually dominate over organic matter loads, nutrient reductions led to either no substantial changes in hypoxia occurrence or the response was non-linear, as in Chesapeake Bay (Kemp *et al.*, 2009).

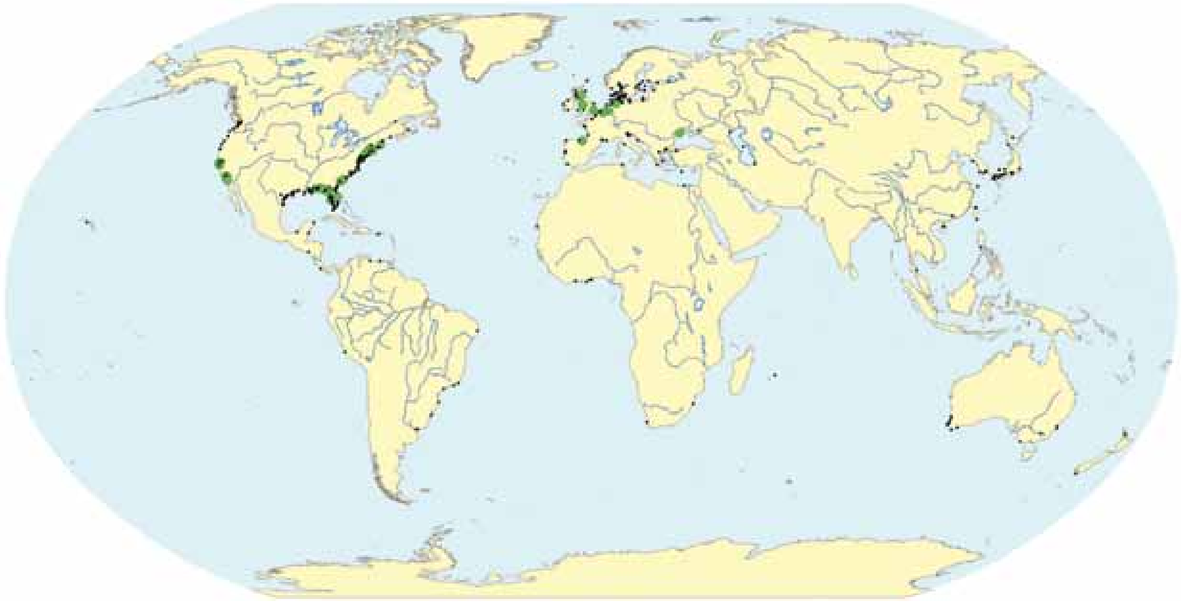
Overall, evidence is mounting that in many smaller systems around the world reductions in nutrient loadings led to reduced eutrophication and hypoxia. However, a response time of five to ten years has been typically observed (Smith *et al.*, 1987). Currently there are about 50 documented cases of improved oxygen conditions from management of nutrients and organic loading (Fig. 2).

Notwithstanding the current state of knowledge regarding the pathways by which different coastal ecosystems enter and recover from hypoxic conditions, the overall message is that, to prevent and remediate coastal hypoxia, the drivers of eutrophication need to be reduced. This means reducing the loads of nutrients and organic matter entering the sea. To diagnose local conditions and pollution sources and to monitor the progress of remedial action, locally specific monitoring and scientific research programs will need to be developed.

How should GEF agencies address coastal hypoxia?

The scientific evidence on the need to address hypoxia is compelling. GEF's response to preventing and remediating coastal hypoxia will need to take into account the location and scale of the hypoxic or potentially hypoxic system. The most well established hypoxia remediation action is nutrient reduction. Measurable results have been achieved for smaller-scale systems (estuaries and semi-enclosed bays). In larger systems such as OMZs, coastal upwelling areas and other open coastal systems, nutrient reduction efforts have been less successful in terms of hypoxia reduction. With the growing importance of climate change impacts on such larger systems, a causal-chain approach and measurable targets will become increasingly difficult. However, GEF projects could usefully start with action directed at the smaller and more tractable parts of larger coastal systems.

FIGURE 2 - Location of systems that have recovered from hypoxia (green circles), primarily through reduced nutrient loads. Black dots are systems that remain hypoxic (Rabalais *et al.*, 2010)



A Haitian chemistry graduate checks the chlorine level in a water sample at a water treatment plant on the outskirts of Port au Prince, Haiti.

3. Measuring and Monitoring Eutrophication and Hypoxia

Key measuring and monitoring variables

To establish long-term trends and identify changes including the emergence or intensification of hypoxic sites, regular monitoring of the coastal environment is necessary. To establish the current state of the environment and to track changes, an inventory is required of all inputs reaching the coastal zones and reduction measures within the whole area affecting the coastal zone. For conceptual and practical convenience, a distinction is usually made between point and diffuse sources. Point sources of nutrient inputs include urban settlements with sewer systems and sewage treatment works, industrial discharges including intensive livestock including intensive poultry raising. For these sources, the point of input to the river system (outfall pipes) is identifiable, accessible to load monitoring and can be addressed directly by legal (individual licensing stipulating requirement or restrictions) and technical measures (building or upgrading of treatment plants, changing production practices).

In many highly susceptible areas, such as the Bay of Bengal and Andaman Sea that receive large river runoff and are located close to regions of high population density as well as intense agriculture, baseline data are lacking. In potential hotspots, regular observations at fixed coastal sites are urgently needed under the ongoing and planned initiatives such as the Large Marine Ecosystem projects and in national programs. Monitoring could begin with a basic suite of parameters using just modest funds, infrastructure and facilities (e.g. using fishing boats for sampling). Based on available resources, the next step would be to scale-up monitoring into fully-fledged, permanent programs. For instance, a nation-wide or regionally-coordinated monitoring network or survey program, designed with standardized data collection procedures, would provide an appreciation of the temporal dynamics and spatial distribution of hypoxia. This would provide countries with a more complete representation of the extent of hypoxia in large marine ecosystems and coastal zones.

Key variables that must be measured when monitoring hypoxic conditions are:

- Physical: temperature, salinity and depth.
- Chemical: DO, pH, nutrients (nitrate, nitrite, ammonium, phosphate, and silicate).
- Biological: chlorophyll.

Additional parameters to be measured wherever possible are:

- Physical: currents, bio-optical properties.
- Chemical: hydrogen sulphide, methane, total organic nutrients, particulate and dissolved organic carbon, biological oxygen demand, alkalinity, dissolved inorganic carbon.
- Biological and biodiversity indicators:
  - microbes - total bacterial counts, flow cytometric, molecular (phylogenetic) analysis
  - phytoplankton biomass and composition – size-fractionated chlorophyll, pigments (HPLC), microscopy, flow cytometry
  - zooplankton – macro-, meso- and micro-zooplankton
  - benthos – macro- and meio-benthos: abundance and diversity
  - fish catch – quantity and composition
  - sediment and geochemistry indicators: grain size, total organic carbon

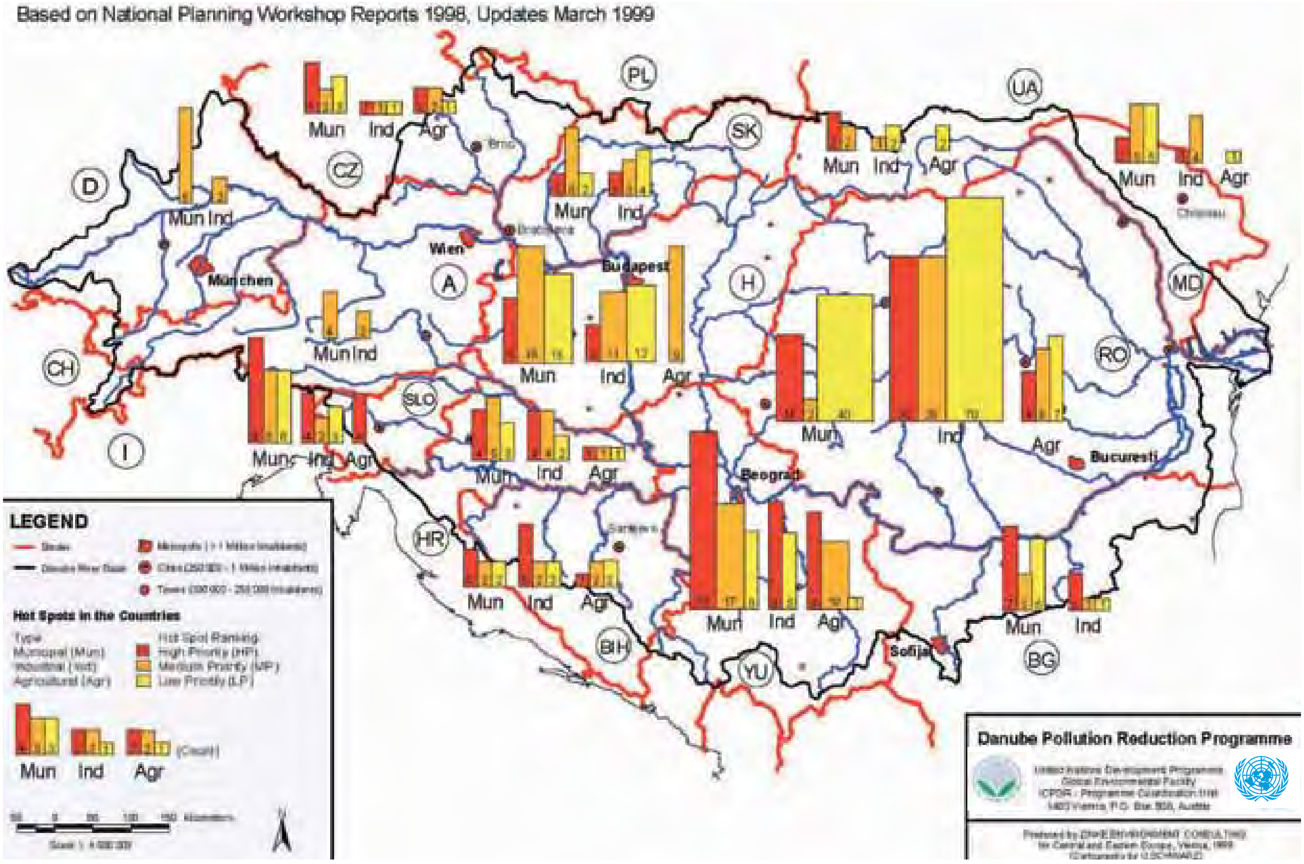
Testing the chlorination level in the water distributed in a camp next to the neighborhood of Cite de Dieu in Port-au-Prince.

Identifying hypoxic zones

Eutrophication involves an increase in concentrations of macro-nutrients (nitrogenous compounds such as nitrate, ammonium and urea; phosphate and silicate), but the ratios in which these nutrients are delivered to the ocean are vastly different from the ratios in which they occur in seawater (i.e. close to the Redfield (1934) ratio of C:N:P=106:16:1). Anthropogenic nutrients typically have excessive nitrogen and are often relatively deficient in silicate. Coastal eutrophication leads to phytoplankton blooms, but due to the high N:P and N:Si ratios the composition of phytoplankton may be different from that found prior to eutrophication and in less affected areas. Harmful algal blooms, often comprising dinoflagellates, can arise from this anthropogenic nutrient supply.

The threshold oxygen concentration for hypoxia is not well defined, but a value of 2 mg l^{-1} (63 μmol) has been widely used as the behaviour of organisms has been found to be affected at lower oxygen concentrations. Different groups of organisms, however, may have different oxygen thresholds and organisms living in the naturally-formed oxygen-deficient zones are better adapted to low-oxygen concentrations. The thresholds associated with suboxia and anoxia could be better defined as they are associated with changes in modes of biogeochemical cycling. Suboxia is usually taken to represent the prevalence of reducing conditions short of sulfate reduction (mainly denitrification - reduction of nitrate to molecular nitrogen coupled with the mineralization of organic matter by heterotrophic bacteria and similar reduction of oxidized iron (III) and manganese (IV)). The ambient oxygen concentration needed for these processes to occur is very close to zero (sub-micromolar concentrations, probably tens of nanomolars). Due to the errors associated with oxygen concentration measurement at such low levels, the exact oxygen threshold for hypoxia is difficult to identify, but an effective indicator of suboxia is nitrite, an intermediate of denitrification. However, nitrite is also produced by nitrification and assimilatory nitrate reduction by phytoplankton, and so its co-occurrence with near-zero oxygen levels is essential for it to be an indicator of suboxia. Suboxic conditions are also characterized by the accumulation of other reduced chemical species (e.g. Fe (II)

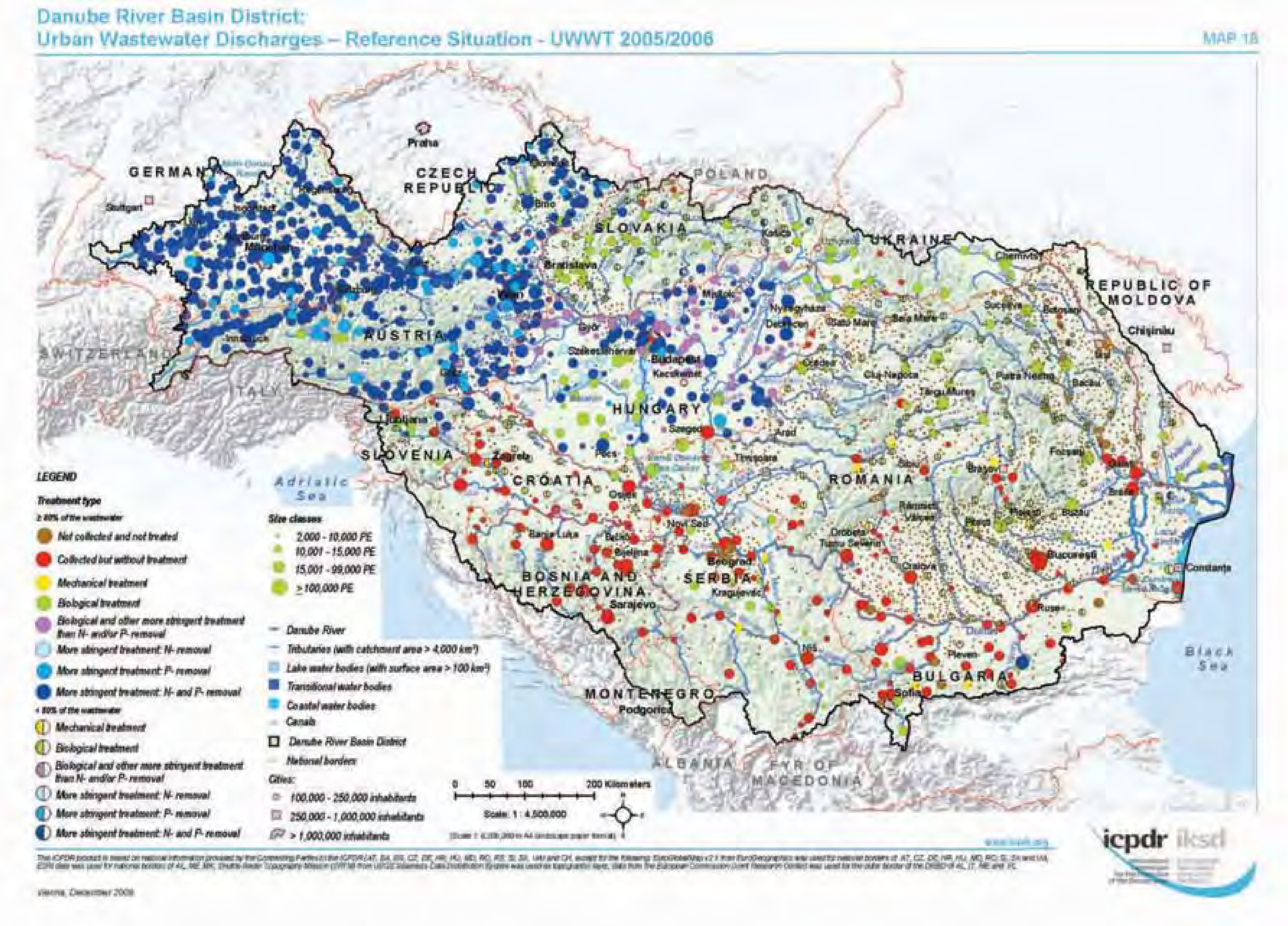
FIGURE 3 - Hot spots in the Danube Basin countries based on national planning workshop reports of 1998, updated in March 1999



and Mn (II)) which are difficult to measure on a routine basis. One other important aspect of suboxic environments is the cycling of nitrous oxide (N_2O), a potent greenhouse gas. For reasons that are not entirely clear, but are obviously related to the fact that N_2O is both produced and consumed during the reduction sequence of nitrate to N_2, suboxic environments are distinguished by extreme accumulation as well as depletion of N_2O. The occurrence of truly anoxic conditions is marked by the accumulation of hydrogen sulfide (H_2S) that can be easily detected due to its strong odor even when present in concentrations below 1 µmol. Its occurrence implies complete loss of oxygen and nitrate, and an accumulation of ammonia. Very often, anoxic (sulfidic) aquatic waters are also characterized by the buildup of methane (CH_4), another important greenhouse gas, especially in freshwater environments.

The absence of trawling is a very reliable indicator of severe hypoxia/suboxia/anoxia. Sulfidic waters are, of course, most inhospitable to higher form of marine life. While the motile organisms are either driven away from anoxic zones, or get killed if and when they cannot escape, benthic and demersal (bottom and near bottom dwelling) organisms, with a few exceptions, are completely wiped out. The absence of higher forms of demersal marine life extends to suboxic and even hypoxic zones with variable tolerance to hypoxia from one group to another. Over the Indian shelf that experiences severe bottom-water oxygen-depletion on a seasonal basis primarily caused by the upwelling of deeper offshore water, demersal fish get trapped in inshore areas as the oxygen-deficient layer moves closer to the coast and intensifies. This leads to spurts of heavy catches of demersal species, especially prawns. At this time, a zone extending several tens of kilometers offshore to a water depth of 40-60 m appears which is conspicuous by a complete absence of trawling activity, with very intense fishing activity seaward of this zone probably related to an increase in subsurface oxygen

FIGURE 4 - Danube River Basin District urban wastewater discharges



concentration. In addition to the above-mentioned changes in phytoplankton composition caused by altered macro-nutrient ratios, hypoxia may also modify the relative abundance of primary producers, favoring cyanobacteria (blue-green algae) over larger plankton especially diatoms. The presence of harmful algal blooms (HABs) also serves as a visible indicator of a potential hypoxic area.

Apart from the biogeochemical indicators of hypoxia discussed above, socio-economic indicators of hypoxia need to be more thoroughly developed. These could include specific gauges for indicators of societal benefits and wellbeing (e.g. human and ecosystem health, economic conditions and long term sustainability) and effects on ecosystem services.

Baseline for remediation

The most important indicator for stress reduction is the annual load entering the coastal areas via riverine inputs. However, a reliable load determination requires a carefully designed monitoring program both on concentrations and run-off and a careful adjustment to a "standard run-off situation" (c.f. the software R-Trend which is used by the OSPAR Commission). A second indicator should be the analyses of the emissions discharged to the river catchment from point and diffuse sources. A useful frequency for this indicator might be approximately every five or six years.

Public information instruments like Pollutant Release and Transfer Registers (as stipulated by the United Nations Economic Commission for Europe (UNECE) Convention on Pollutant Release and Transfer Registers) provide annual updates on pollutant loads discharged by point sources. Building an inventory of point source loadings can be an initial step toward reducing the emissions. In the Danube, this process was initiated in the mid-1990s as an attempt to identify the hot spots which were then addressed by two subsequent action plans. Fig. 3, taken from the Danube Pollution Reduction Program report (ICPDR, 2006), shows the result of the hot spot analyses as a first major step. Normally the identification and elimination of these hot spots results in the relatively fast reduction in emitted loads as well as in the first positive biological responses, for which indicators are also necessary.

In subsequent years, driven by the joint implementation of the EU Water Framework Directive and of European environmental law by countries which joined the European Union in 2004-2005, a much more detailed picture became available. Figure 4, taken from the 2009 Danube River Basin Management Plan (ICPDR, 2009), displays the heterogeneous situation with respect to urban wastewater treatment at the end of 2005. Figure 3 only displays settlements above 100,000 person equivalents (p.e.), whereas the second map covers all settlements with more than 2000 p.e., (the relevant threshold in the underlying EU Urban Waste Water Treatment Directive). This directive has already been implemented in the upper part of the basin (Germany and Austria) and should be fully implemented by all current members of the EU in the Danube Catchment by 2018.

Diffuse or nonpoint sources are inputs resulting from widespread activities like agriculture, traffic, storm water or settlements not connected to sewer systems where the pollution enters the aquatic environment through processes such as erosion, atmospheric deposition or groundwater flow. These processes are strongly dependent on hydrological conditions, which mean that the pollutant load transported to the coastal area is mainly determined by run-off. Quantitative estimates of substance loads from diffuse sources require model calculations and loads have to be extrapolated to a "standard run-off situation" in order to analyze the effects of reduction measures.

Reduction measures for diffuse sources of pollution are far more difficult to implement and enforce as they require significant changes in agricultural and other practices. A further obstacle to implementation of reduction measures is that the effects of remediation measures are difficult to observe in a "politically relevant" time-frame, as the nutrient transport mechanisms may cause delays between reduction measures and observable reductions. In

Evaluating Responses in the Black Sea

Under planned measures in the Danube, average nitrogen emissions to surface waters will be approximately 12% lower by 2015, compared to the present state (2000-2005). The load to the Black Sea will reach a level that is below the present state but still far above (40%) that of the 1960's. This means that the situation in the Danube River Basin and the Black Sea with respect to nitrogen pollution will improve, but not ensure the achievement of the management objectives and the Water Framework Directive (WFD) environmental objectives on a basin-wide scale by 2015.

Compared to the present state (avg. 2000-2005) the P emissions to surface waters will, through the planned measures, be in 2015 about 21 % lower. The load to the Black Sea will reach a level which is still 15 % above 1960s levels. Therefore, for phosphorous the respective management objective on the basin-wide scale will not be achieved by 2015, and this is most likely also the case for the WFD environmental objectives. Reductions in nutrient pollution will be achieved as soon as more stringent urban waste water treatment obligations with N and P removal for urban agglomerations of more than 10,000 p.e. are applied for EU member states. This could reduce the discharged emissions in EU members of total N by 37% – 43% and of total P by 45% - 56% compared to the reference situation. However, the knowledge and understanding of the inter-linkages between Danube loads and the ecological response in the North West shelf of the Black Sea still need to be refined and improved.

Wachau

Satellite Image of the Black Sea

the case of ground water polluted by intensive livestock production, for instance, hydrological conditions may delay the impacts of successful reduction measures by up to several decades, depending on the hydrological conditions. In these cases where changes are slow to show, inventories of pollution loadings can be more infrequently compiled, say on a five-year basis.

Experiences show that reductions in overall inputs achieved over the last 20 years are mostly through point sources, which were dominating emissions at that time. In turn, this means that the relative contribution of diffuse sources has increased and measures to reduce non-point source nutrient pollution are urgently needed.

Evaluating responses

Since coastal hypoxia is caused by pressures from large geographical areas and from a variety of sources whose contribution to the problem change over time, stress reduction requires an iterative approach. Reduction will be a long-term process and definitions of a vision and of intermediate steps are necessary. To be able to correct and readjust the process over time, the selection of useful feedback indicators is required. These could include:

- Biodiversity indicators (e.g. the presence or absence of certain species).
- Loads entering the affected coastal zone via important river catchments draining into that area.
- The sources and their relative strengths of nutrients in the catchment.
- Intermediate depots both in the catchments and the coastal areas.
- Observed negative effects.
- Limiting factors for eutrophication effects.

Fisherman repairing his nets on the beach in Mozambique

4. Hypoxia and Nutrient Reduction in GEF Projects

Diagnostic analyses of GEF-LME projects

GEF has adopted LMEs as the organizing units for its transboundary coastal projects and has supported projects in 19 of the 64 designated LMEs. These ocean spaces, with areas of 200,000 km^2 or greater, are characterized by distinct bathymetry, hydrography, productivity and trophic interactions. According to the National Oceanic and Atmospheric Administration of the United States, most LMEs are subjected to significant eutrophication in coastal waters (Sherman et al., 2008).

In order to gain a better picture about the likely presence of hypoxia in GEF LME projects, the available GEF-LME Transboundary Diagnostic Analyses (TDA), Strategic Action Programmes (SAP) and related project documents were searched using the IW:Science knowledge base (UNU-INWEH, 2010). Sixteen of these supported LMEs have information that is sufficiently advanced as to enable examination for the attention to coastal hypoxia. First, a set of hypoxia-related keywords was used to systematically mine the documents for any mention of hypoxia, location of hypoxic areas and concomitant management measures (see Fig. 5). The results were then tabulated and cross-referenced with Diaz and Rosenberg's 2008 global inventory of hypoxic sites and its recent unpublished updates.

The GEF LME documents and the global database maintained by Diaz generally matched in their reports of coastal hypoxia, but with some differences.

Generally good matching reports were found from the IW:Science document repository and the globally hypoxic sites inventory in the following six LMEs: the Gulf of Mexico (very high degree of matching sites), the Mediterranean Sea (high degree of match), the Black Sea, the Guinea Current, the Red Sea and the Yellow Sea. In the Guinea Current LME, the TDA reports the presence of eutrophication and harmful algal blooms in most of the 16 countries. Diaz et al.'s findings show only 4 hypoxia sites in two countries.

FIGURE 5 - Keyword "hits" showing the presence of hypoxia-related information in GEF-LME project Transboundary Diagnostic Analyses (TDAs) and Strategic Action Plans (SAPs) using the IW:Science database (UNU-INWEH)

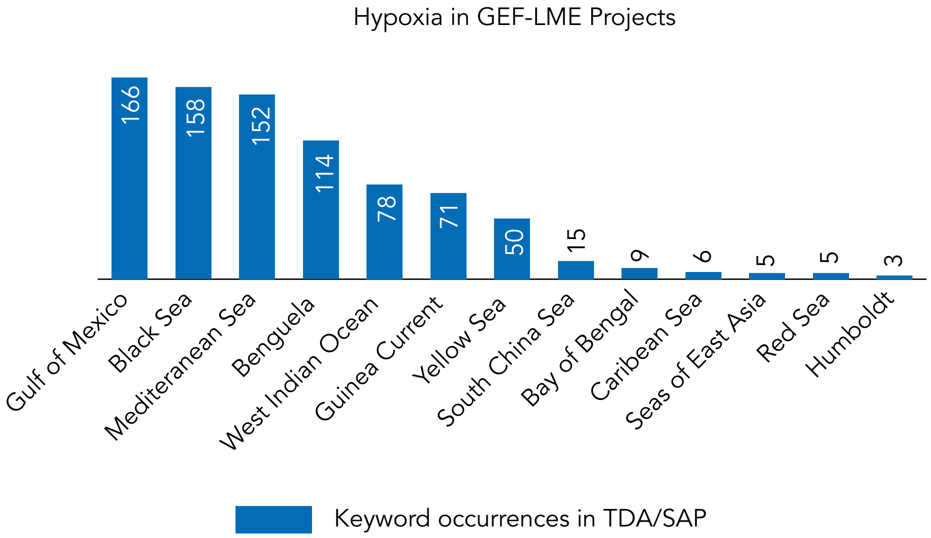
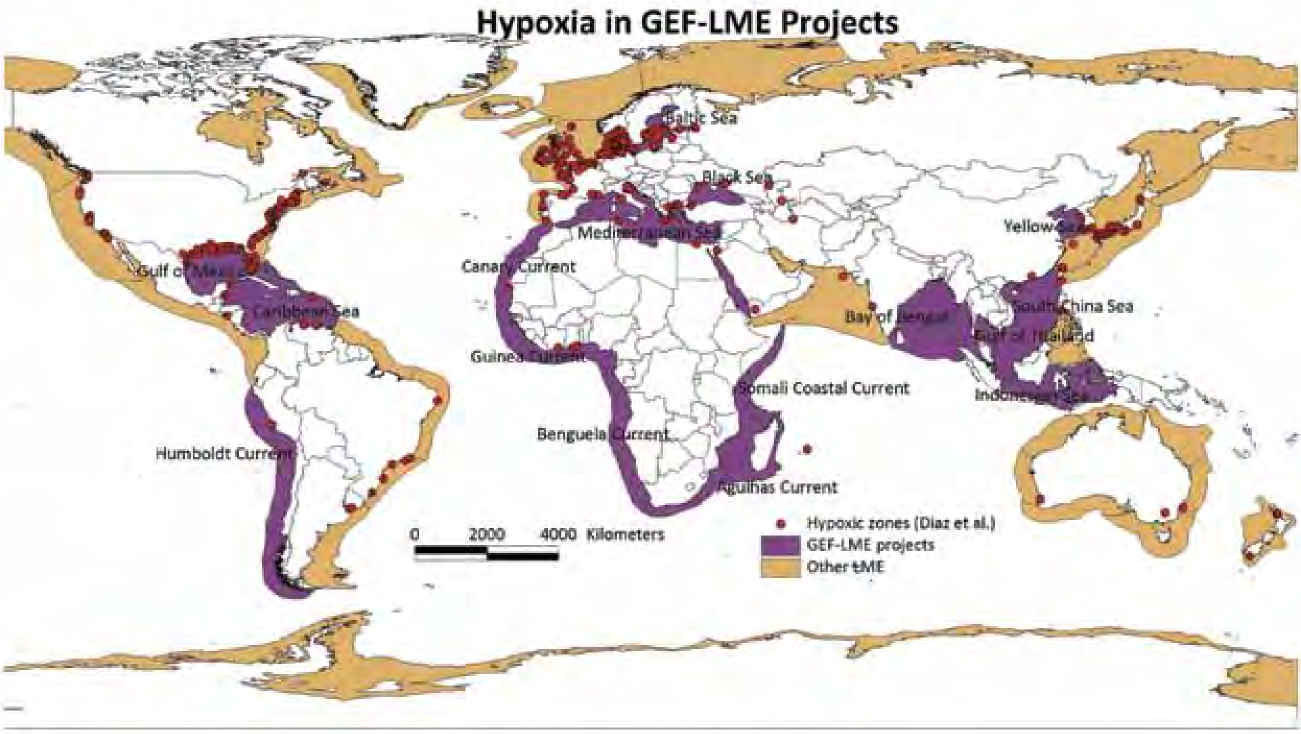


FIGURE 6 - Mapping Hypoxic Zones in GEF-supported LMEs as identified utilizing the IW:Science database (UNU-INWEH, 2010)



Note: Coordinates for hypoxic zones were not provided in LME TDA/SAPs. LME boundaries GIS data provided by the NOAA (see NOAA, 2009)

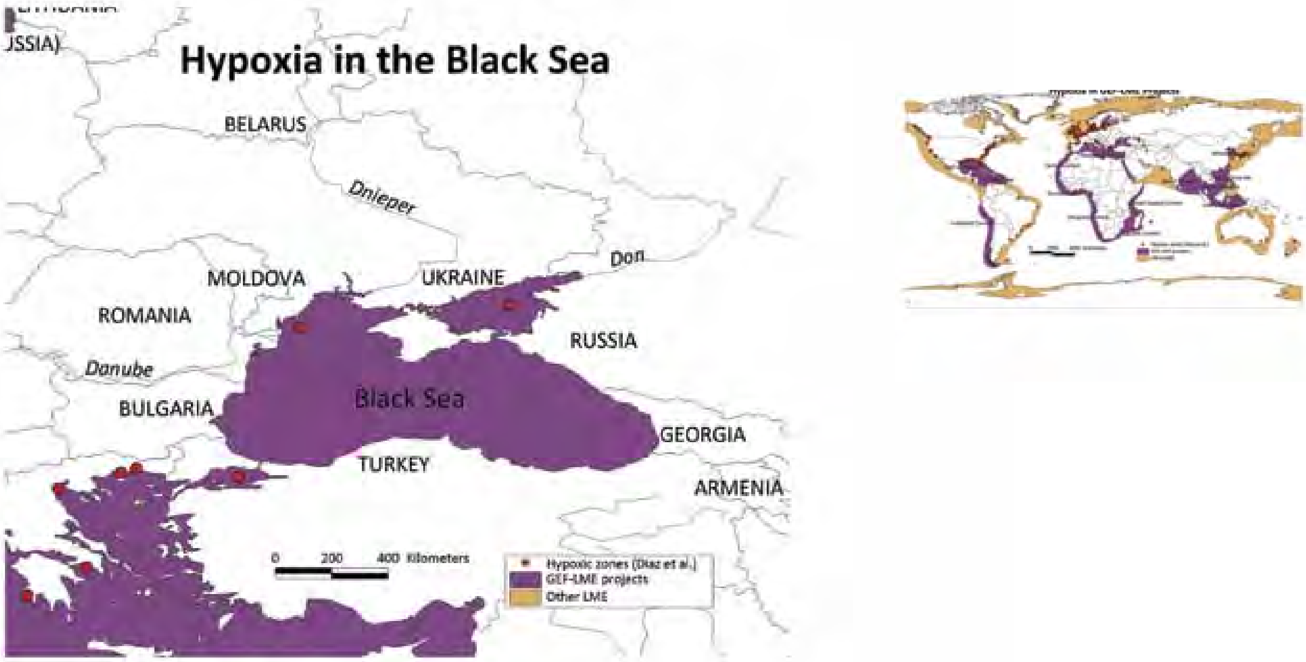
Project documents from five LME projects (Bay of Bengal, Benguela Current, Caribbean Sea, Humboldt Current and South China Sea) reported hypoxia information that was not able to be matched directly with those in the global database. In some cases the GEF LME reports were more precise and in others less. The Bay of Bengal TDA indicates that eutrophication, algal blooms and hypoxia have all been observed in the region, although it fails to specify exactly where. While none of Diaz et al.'s findings show hypoxic zones in the Benguela Current LME (BCLME), the 1999 TDA indicates that much of the system, in particular off Namibia and Angola, is naturally hypoxic or even anoxic. This is compounded by depletion of oxygen from more localized biological decay processes. The BCLME TDA also reports unusually severe oxygen depletion of shelf waters (especially in 1993-94) resulting in widespread anoxia and hypoxia. Although most pronounced in the northern Benguela LME, episodic depletion of oxygen does occur in the southern Benguela (e.g. in autumn of 1994). The preliminary TDA for the Caribbean Sea LME reports unusual reef fish mass mortalities that occurred simultaneously in several countries in the southeast Caribbean in 1999. These fish kills were likely caused by an algae bloom associated with an increase in the influx of nutrient-rich water from the Orinoco and Amazon Rivers, an increase of water temperature, and oxygen depletion. No information was available to compare the results of Diaz and Rosenberg (2008) with the Humboldt Current.

Six LME projects are still in early stages of development and have not yet provided all relevant information (Agulhas and Somali Current, Canary Current, Baltic Sea, Gulf of Thailand and Indonesian Sea. Some information, however, is available in early project documents. Diaz (unpublished) reports a single hypoxic zone off the coast of Mauritania in the Canary Current LME whereas the GEF project document reports anoxic conditions in coastal hotspots such as Hann Bay, Dakar, as well as high inputs of dissolved organic carbon, nitrogen and phosphorous in the wetter countries (Senegal, Gambia, Guinea Bissau, Guinea). In the South China Sea, eutrophication is mentioned as a growing problem in the Gulf of Thailand according to the Sustainable Development Strategy of the Seas of East Asia. (PEMSEA, 2003).

To respond effectively to the increasing severity of the hypoxia problem, nutrient reduction and hypoxia management measures need to be explicitly embedded in GEF methodology and properly developed in LME projects. Overall, available TDAs and SAPs are unclear or unable to provide specifics on the scientific methodology used to monitor and assess instances of hypoxia and anoxia. Furthermore, the unavailability of key documents for certain LMEs hindered comparisons between existing data on hypoxic zones and past or ongoing GEF projects.

According to the World Resources Institute, mapping and research into the extent of hypoxia are improving, but in many regions information is still insufficient to establish the actual extent of hypoxia or identify its causal factors. To improve knowledge of hypoxia occurrence and impacts, GEF LME projects need to proactively assess and monitor water quality. Specifically, variables commonly linked to eutrophication such as nutrient levels and dissolved oxygen should be measured regularly. In addition, internationally accepted methods and definitions for assessing hypoxic coastal waters—including proxies for eutrophication—need to be developed further and used within project TDAs and SAPs to increase the transparency, consistency and comparability of water quality information (Selman et al., 2008).

Selected GEF case studies

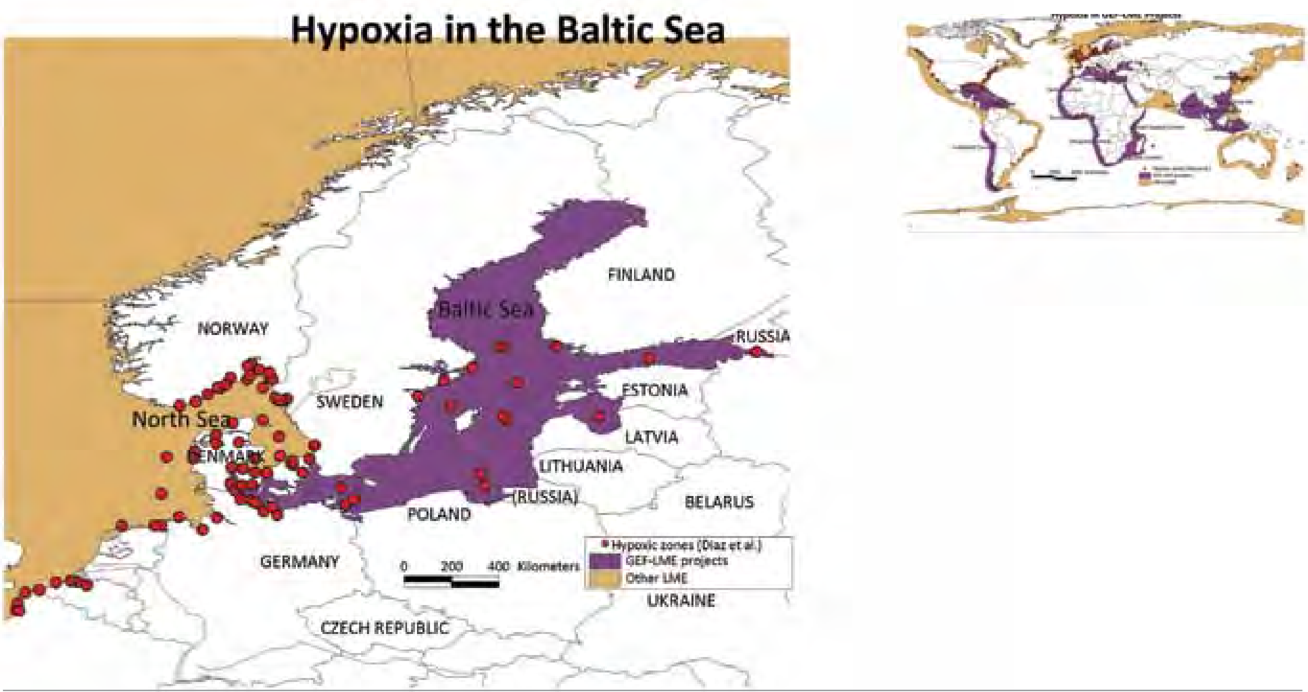


Black Sea - Danube River

Figure 7 - Black Sea-Danube River LME

Summary prepared by: Joachim Heidemeier; Ivan Zavadksy; Chuck Chaitovitz; Nicole Harper	
Background	• Covers an area of 423,000 km^2, stretches 2,870km in length, and drains approximately one-third of continental Europe (approximately 800,000 km^2). • Over enrichment of the Black Sea with nutrient pollution resulted in serious oxygen depletion, causing massive losses in animal life from about 1970 until the early 1990s. • Hypoxia reached a peak in 1990, when approximately 40,000 km^2 of the Northwest Shelf bed was considered "dead".
Specific Nutrient Challenges	• Nitrogen and phosphorus levels from agricultural, municipal and industrial sources have seriously degraded the Black Sea ecosystem. • Transboundary nutrient and toxic pollution from the Danube River Basin, which flows into the Black Sea, created many of the threats to water quality in the region. • Compounded by erosion and the introduction of exotic species.
Addressing the Problem	• The Danube Regional Project (DRP) established as a component of the Global Environment Facility's strategic partnership on nutrient reduction in the Danube/Black Sea Basin. • Overall objective was to reduce nutrient loading and improve water quality in the Danube River and its tributaries. • Designed to complement the activities of the International Commission for the Protection of the Danube River. • Best Agricultural Practices (BAPs) were implemented and through increasing institutional capacity contributed to the success of hypoxia remediation in the Black Sea/Danube region.
Outcomes	• Formerly expansive hypoxic zone covering the Northwest Shelf has been virtually eliminated. • Diversity of benthic indicator species has roughly doubled since the 1980s. • Provided input to a nutrient pathway estimation model, MONERIS (See Behrendt et al., 1999), which can now be used more efficiently in other nutrient reduction activities. • In the Danube Basin, nitrogen emissions have decreased by 20% and phosphorus almost by 50% over the last 15 years. (ICPDR, 2007). • Launched over 100 small grant projects to reduce nutrients at the community level.

(Map source: UNU-INWEH)

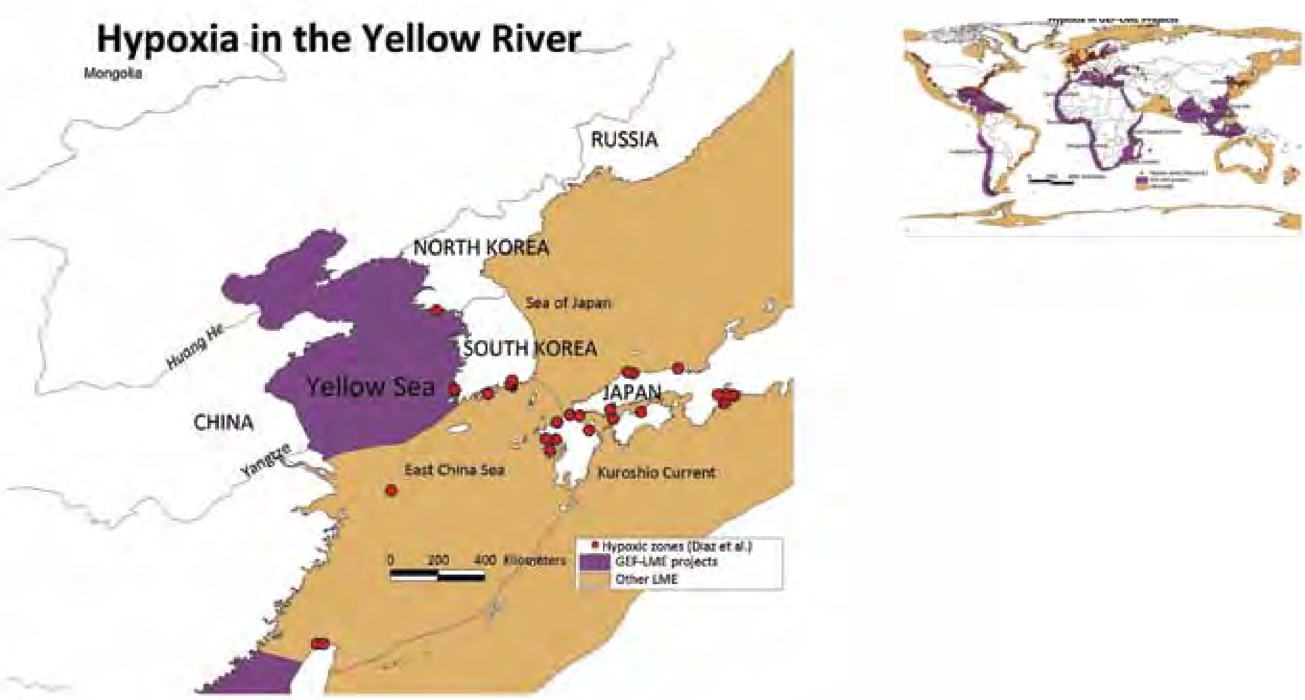


Baltic Sea

Figure 8 - Baltic Sea LME

Summary prepared by: Nicole Harper	
Background	• Since its formation over 8000 years ago, hypoxia has occurred intermittently in the Baltic Sea. In the water column, low dissolved oxygen concentrations have been observed locally for over a century. • Anthropogenic hypoxia has increased due to increased eutrophication. • Hypoxia has resulted in habitat loss over vast areas, the eradication of benthic fauna, and the severe disruption of food webs. • Limited water exchange with the North Sea makes the Baltic Sea more susceptible to eutrophication than more "open" marine systems.
Specific Nutrient Challenges	• Periodic anoxia is a natural phenomenon in the Baltic, but prolonged hypoxia continues to occur in the bottom water of the central Baltic Basins. • Internal nutrient loading is high, leading to long response times to nutrient abatement measures (Müller-Karulis , 2010). • Nitrogen load increases especially pronounced in areas with intensive agriculture. • Nitrogen loads believed to have increased fourfold since the start of the 20th century. • Phosphorous loads have increased by eight times (Müller-Karulis , 2010).
Addressing the Problem	• In 1992, HELCOM began routine monitoring program of nutrient discharges to Baltic Sea. • The Program reports on nutrient loads of all major rivers and load estimates for unmonitored rivers, as well as loads from major point sources discharging into the Sea. • Identification and remediation of specific hot spots was crucial and effective. • EU regulations on industry contributed to nutrient reduction.
Outcomes	• Nutrient pollution from point sources has decreased significantly especially in former Soviet Union countries such as Latvia, Estonia, Poland and Lithuania (IOC, 2009). • New Baltic Sea Action Plan with country-specific reductions contains renewed efforts and commitments by the surrounding nations to achieve significant progress. • Growing number of exploratory projects in progress. • Recommended that additional measures for nutrient load abatement be considered, including constructed wetlands or reactive barriers, to achieve needed decrease in nutrient loading.

(Map source: UNU-INWEH)

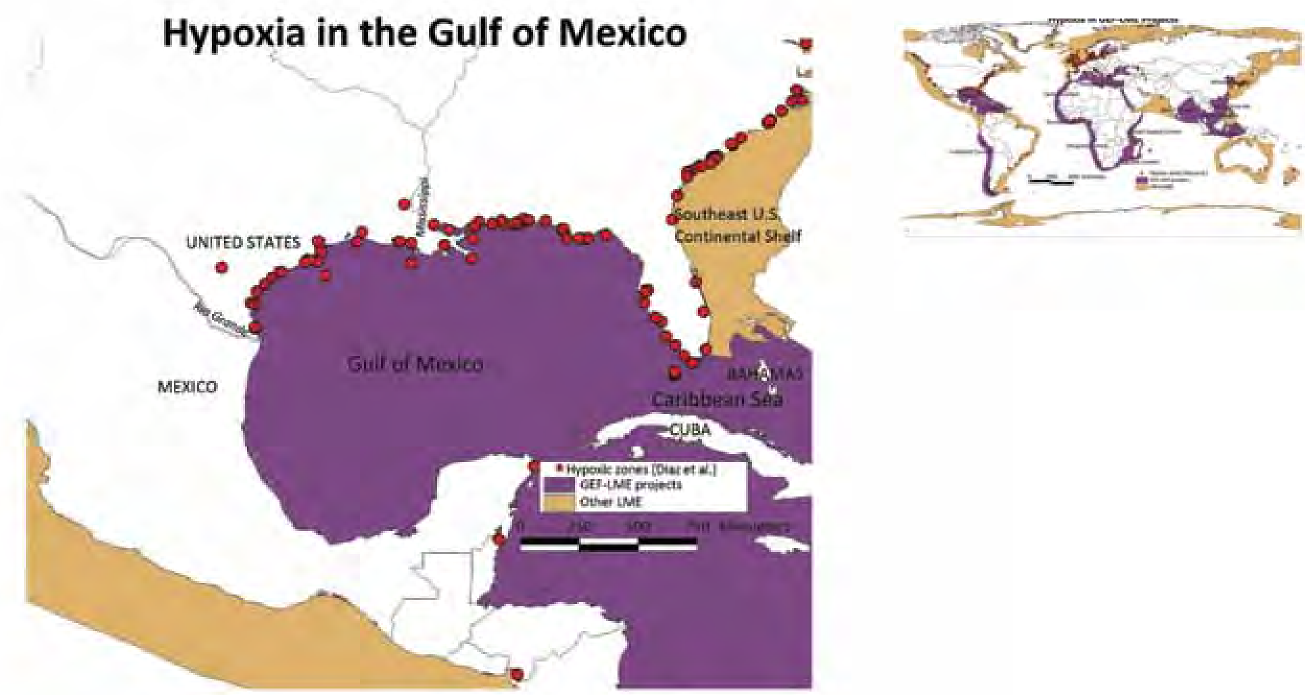


Yellow Sea

Figure 9 - Yellow Sea LME

Summary prepared by: Yihang Jiang; Nicole Harper	
Background	• The Yellow Sea is one of the LMEs most affected by human development (Qilun Yan in IOC, 2009). • Rapid economic development and population growth place increasing pressure on the environmental integrity of the LME. • Suffers an increasingly significant threat of nutrient over enrichment.
Specific Nutrient Challenges	• Nutrient export mainly caused by high-density, high-impact agricultural activities, low-efficiency fertilizer utilization and soil erosion. • Southern Yellow Sea regions contribute more nitrogen to coastal areas than northern areas, due to higher concentrations of population and agricultural land. • The low nutrient conditions in the Yellow Sea LME are complex, including deviations from typical nutrient ratios (Redfield Ratio), annual and seasonal variations. • Mariculture/aquaculture is also a significant economic activity whose effects on hypoxia are still being studied. • The greatest challenges this LME faces are the numerous harmful algal blooms (HABS) as well as explosions in jellyfish and starfish populations that have drastically altered ecosystem structure and fisheries dynamics and threaten human health.
Addressing the Problem	• The YSLME is at a foundational stage of capacity building toward nutrient reduction, but has still managed to develop some important initiatives addressing specific problems. • Chinese government is buying fishing boats and switching to aquaculture to diminish the fishing burden. • Scientists are using a unique mariculture model that uses sea cucumbers in a biological nutrient reduction mechanism.

(Map source: UNU-INWEH)

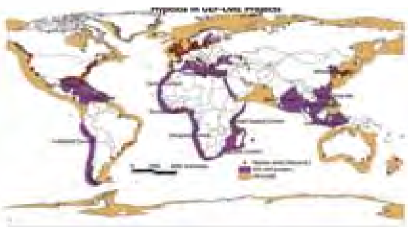


Gulf of Mexico

Figure 10 - Gulf of Mexico LME

Summary prepared by: Chuck Chaitovitz	
Background	• Largest hypoxic zone affecting the US; second largest anthropogenic hypoxic zone worldwide after the Baltic. • Size, frequency and duration of the hypoxic zone are driven by water quality in the Mississippi River, the River's discharge, and the physics of the coastal system.
Specific Nutrient Challenges	• The primary targeted nutrient for management is nitrogen. • Significant land use changes have occurred throughout the Mississippi River Basin watershed over the last 200 years as landscape was converted for agricultural purposes. • Agricultural systems are the dominant source of increased amounts of nitrogen. • Changes in the landscape have resulted in degradation of soil, water, and air, and the loss of wildlife habitat and community resources.
Addressing the Problem	• Primary land-use objective is to develop and promote profitable farm enterprises based on perennial crops and products of continuous living cover systems. • Perennial cropping systems offer opportunities for new and profitable enterprises in rural areas and for production of healthy foods. • Additional objectives include improvements in sewage treatment systems, storm water runoff treatment, reduction in fossil fuel emissions, and management of confined animal feed operations.
Outcomes	• Promotion of environmentally sustainable approaches to biofuel production and associated cropping systems. • Improved management of nutrients by emphasizing infield nutrient management efficiency and effectiveness. • Construction and restoration of wetlands, improved targeting of conservation buffers to control surface-borne nutrients, and introduction of tighter N and P limits on point sources all contributed to project success.

(Map source: UNU-INWEH)



Guinea Current

Figure 11 - Guinea Current LME

Summary prepared by: Christian Susan	
Background	- Encompasses the coasts of Guinea Bissau to Angola, covering sixteen countries. - All the GCLME countries are ranked in the last tier of the Human Development Index. - Approximately 40 % of the region's 300 million people (more than half of the continent's population) live in the coastal areas of the GCLME.
Specific Nutrient Challenges	- Unregulated and often haphazard urbanization and industrialization. - Over-exploitation of fishery resources; impacts from activities in land-based settlements; industrial, urban and domestic sewage run-off; and mining activities such as oil and gas. - Nutrients from inorganic effluents and sewage pollution. - Cannot afford significant investments required to keep abreast with providing sufficient drinking water to ever growing urban populations. - Phosphate factory in Kpémé, Togo is responsible for the highest nutrient load to the GCLME with transboundary impacts on Benin and Nigeria.
Addressing the Problem	- Ecological sanitation, a decentralized approach to sanitation, combining the separation of black[5], yellow[6], and grey[7] water, treating different wastewater streams in separate processes, and allowing for the re-use and recycle of nutrients, can be an appropriate and cost-efficient solution (also an effective means of reducing nutrient load in remaining domestic waste water effluent). - Similarly encouraging results are seen in constructed wetlands, another appropriate low-investment and low-maintenance end-of-pipe solution for the centralized treatment of urban waste water.
Outcomes	- GCLME SAP development project has identified a cost efficient solution for the treatment of the phosphate-rich waste waters released by the phosphate factory in Kpémé, Togo. - Construction of waste water treatment plant will be a major component of Togo's efforts under its National Action Plan. - Promotion of ecological sanitation and the implementation of the TEST (Transfer of Environmentally Sound Technologies) approach will form integrative elements of this project.

(Map source: UNU-INWEH)

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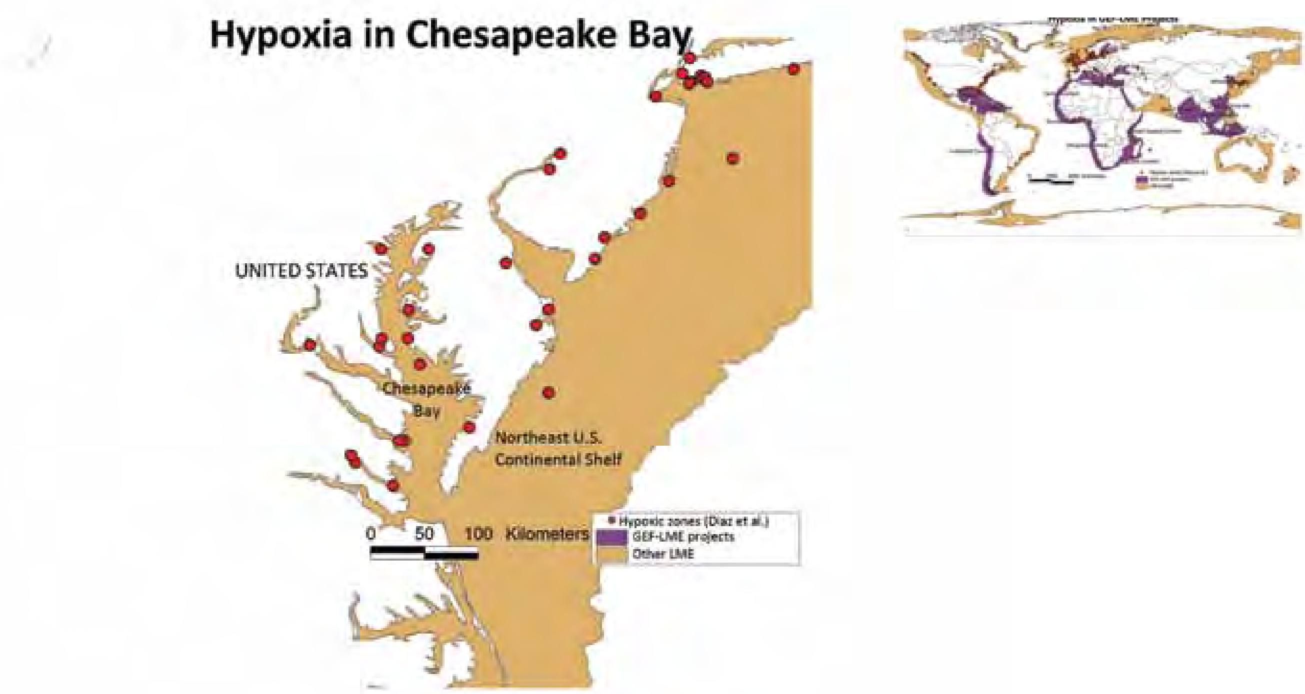
[5] Fecally contaminated waste water containing the majority of pathogens but little nutrients.

[6] Urine-based wastewater containing most of the nutrients and no pathogens

[7] Wastewater resulting from domestic activities e.g. personal hygiene, washing clothes, cooking etc. containing few pathogens and only a limited nutrient load (mainly determined by the phosphate content in detergents)

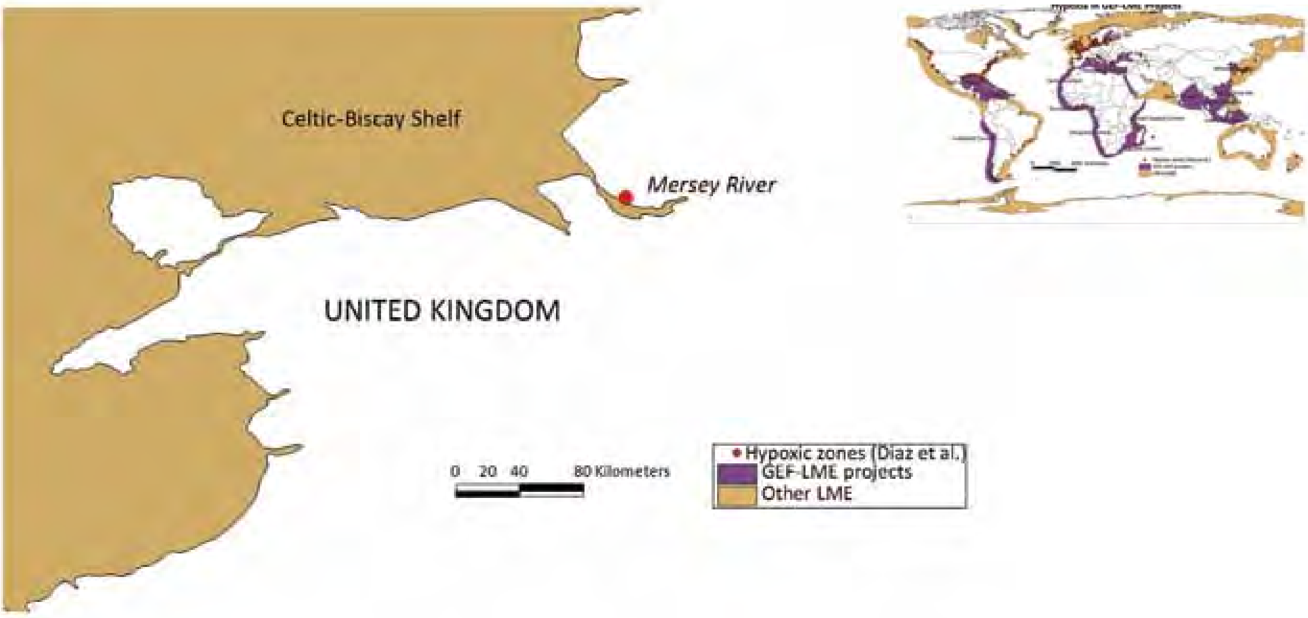


Chesapeake Bay (non-GEF case)

Figure 12 - Chesapeake Bay LME

Summary prepared by: Michael Kemp	
Background	• Trends of increasing summer hypoxia from 1950s to early 1980s were first identified and linked to nutrient pollution in 1984. • This upward trend has strengthened significantly during the two decades that followed. • Volume of hypoxic water had been increasing while inputs of nutrients (primarily nitrogen) have leveled or slightly declined since 1985. • More than twice as much hypoxia was being generated in the 1990s than in the 1970s.
Specific Nutrient Challenges	• Scientific analyses revealed that the increase in hypoxia generation per unit nitrogen loading was coincidental with a shift in the direction of prevailing summer winds, driven by a dynamic 20-30yr climate cycle, suggesting that increased hypoxia was resulting in part from changed climatic conditions. • Effectively reduced vertical mixing and associated ventilation of bottom waters. • Extent and intensity of low-oxygen water in the mid July-August period began to level-off 20 years ago and has been gradually declining, a trend strongly correlated with parallel trends in nitrogen loading from the watershed to the Bay.
Addressing the Problem	Nutrient remediation in the Chesapeake Bay watershed will continue to be achieved through: • Implementation of BAPs. • Enhanced nutrient removal from 66 sewage treatment facilities. • Implementation of stringent point-sources effluent for CAFOs (Concentrated Animal Feeding Operations) in watershed. • Maximum reduction in atmospheric nitrogen deposition via strict EPA enforcement of air quality standards for industrial source emission and automobile exhausts. • Coordinated watershed-wide implementation of TMDL (Total Maximum Daily Load) system at county scale through cooperation of state and federal agencies.
Outcomes	• Recent analyses are the first to demonstrate that Chesapeake Bay's hypoxia responds rapidly to reductions in nutrient loading. • Results suggest that early-summer oxygen conditions will improve once the climate cycle shifts back to its previous direction. • Findings show that changing climatic conditions must be considered when developing hypoxia remediation strategies.

(Map source: UNU-INWEH)



North Sea - Mersey River (non-GEF case)

Figure 13 - North Sea - Mersey River LME

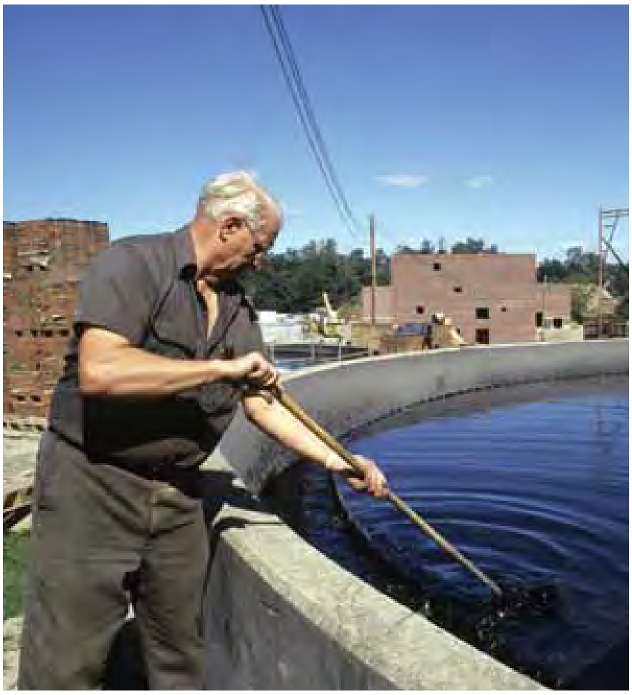
Summary prepared by: Nicole Harper	
Background	• Macro-tidal estuary with tidal range exceeding 10m on extreme spring tides. • High-energy system with strong currents, high concentrations of suspended material, and constantly moving low water channels and sandbanks. • Became most polluted river in the UK after enduring decades of direct dumping of untreated effluent and noxious discharges from industry and urban point sources.
Specific Nutrient Challenges	• Vast volumes of untreated wastewater completely removed dissolved oxygen from long stretches of the estuary during summer. • Large amounts of effluent left beaches polluted with heavy crude sewage and residues. • Spread of rampant anoxia and high concentrations of ammonia. • System considered to be effectively "dead" in 1960s.
Addressing the Problem	• Addressed from a policy perspective with the EU Urban Wastewater Treatment Directive. • Addressed from a scientific perspective with monthly water quality surveys in the 1960s. • Monitoring programs improved in the 1980s with the addition of trace contaminant analyses. • Main objective of scientific work was to increase dissolved oxygen to negate "foul smelling odors," and to remove crude sewage and effluents from beaches. • Principal components of the Mersey Clean Up Strategy were to improve water quality, construct interceptors and effluent treatment works to provide "enhanced" or "first time" sewage treatment, and impose stringent controls on industrial discharges (Jones 2006).
Outcomes	• Mersey saw a 10-fold reduction in the organic load to its estuary. • The phased introduction of treatment allowed substantial load from crude discharges to be gradually reduced. • Dramatic reductions of nutrient loads from treated effluents due to secondary treatment were observed • DO concentrations in the Mersey River went from <10% to over 65% in 2003. • Improvements were accompanied by the return in significant numbers of fish that have been absent for many years (Jones 2006). • The Mersey River is an acknowledged and accomplished leader in river management strategy after twenty years of public, private and voluntary efforts to regenerate and rehabilitate the estuary.

(Map source: UNU-INWEH)

Existing GEF support to nutrient reduction

Interventions and investments with multiple benefits

GEF has already had a strong focus on reducing nutrient inputs to transboundary water systems to achieve multiple benefits. Over the past decade, more than 120 million USD in GEF grants have been issued to nutrient reduction or related projects in several regions, the most significant of which is the Danube River and Black Sea basin. In a multi-partner collaboration between GEF, UNDP, the World Bank, the European Union and the sixteen Basin countries, pilot demonstrations have undertaken nutrient reduction in agriculture, municipal sewage and the industrial sector, as well as nutrient trapping in restored floodplains. The US $95 million[8] **GEF Strategic Partnership for Nutrient Reduction in the Danube/Black Sea Basin** is GEF's largest and perhaps most ambitious water-related project. This partnership is composed of three complementary parts:



Cleaning the sludge thickener tank at the Water Pollution Control Plant, Danbury, Connecticut, U.S.A.

- The Black Sea Ecosystems Recovery Project - a GEF-Black Sea Regional capacity building and technical assistance element implemented in cooperation with the Black Sea Commission under the leadership of UNDP and with the assistance of UNEP.
- The Danube Regional Project (DRP) which aims to strengthen the implementation capacities for nutrient reduction in the Danube River Basin, implemented in cooperation with the ICPDR and under the leadership of UNDP.
- The GEF-World Bank Investment Fund for Nutrient Reduction is a partnership focused on single country nutrient reduction investments.

As a result of these combined efforts in the last 15 years, nitrogen emissions in the Danube Basin/Black Sea area have decreased by about 40% and phosphorus by almost 30%. The physical environment of the Black Sea has responded with improved water quality, greater biodiversity and reduced hypoxia. Although the observed recovery of the Sea is partially linked to the closure of numerous agricultural facilities and reduced fertilizer use during the economic collapse of the early nineties, the significant investments and governance reforms promoted by the GEF Strategic Partnership has also had an important impact on measured improvements (See Table 1).

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[8] $95M was initial funding; Total investment was $71.7M for GEF grant and $195.7M in co-financing.

Overview of existing GEF nutrient reduction projects

The following table summarizes the duration, funding, results and types of projects that have been funded[9]

Table 1 - Overview of existing GEF nutrient reduction projects

Black Sea Danube Investment Fund

Country	Project Title	Approval Date	Closing Date	GEF Grant (US $mil.)	Co-financing (US $mil.)	Estimated Annual N + P Reduction (tons)[10]	
Romania	Agricultural Pollution Control Project	12/2001	06/2007	5.15	5.5	200	25
Bulgaria	Wetland Restoration and Pollution Reduction Project	06/2002	12/2008	7.5	5.78	218-813	23.4-37.4
Moldova	Agricultural Pollution Control Project	02/2004	12/2009	4.96	5.79	134	80
Turkey	Anatolia Watershed Rehabilitation Project	06/2004	06/2012	5.6	41	200	25
Serbia & Montenegro	Reduction of Enterprise Nutrient Discharges Project (RENDR)	05/2005	12/2010	9.02	13.12	430	70
Bosnia-Herzegovina	Water Quality Protection Project	06/2006	02/2011	4.25	11.4	31	5
Hungary	Reduction of Nutrient Discharges	03/2006	06/2011	12.5	80	4000	260
Moldova	Wastewater, Environmental Infrastructure	06/2007	12/2011	4.5	3.5	37	9
Romania	Integrated Nutrient Pollution Control Project	10/2007	N/A	5.5	87.5	4000	1000
Croatia	Bio-solids/Agriculture Pollution Control	12/2007	07/2012	5.0	15	400	200
TOTAL				63.98	268.59		

Examples of GEF-financed nutrient reduction investment projects targeting land-based pollution in coastal areas.

Pollution Reduction – East Asia Investment Fund

Country	Project Title	Approval Date	Closing Date	GEF Grant (US $mil.)	Co-financing (US $mil.)
China	Ningbo Water and Environment Project	06/2006	12/2010	5.0	140.1
China	Shandong 2nd Environment Project	05/2007	12/2013	5.0	201.5
Vietnam	Coastal Cities Environment and Sanitation Project	05/2009	11/2014	5.0	21.7
Manila	Third Sewerage Project	05/2007	06/2012	5.0	87.8
China	Liaoning Medium Cities Infrastructure	05/2007	12/2013	5.0	187.7
China	Shanghai Agricultural and Non-Point Pollution Reduction	08/2007		4.79	29.9
China	Huai River Basin Marine Pollution Reduction	02/2010		5.00	30.6
TOTAL				34.79	699.3

Sustainable MED Investment Fund

Country	Project Title	Approval Date	Closing Date	GEF Grant (US $mil.)	Co-financing (US $mil.)
Tunisia	Northern Tunis Wastewater Project	06/2010	N/A	8.0	60.6

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[9] See http://go.worldbank.org/H65JH36R00

[10] The reduction estimates relate strictly to investments made during the life time of the project which serve mainly the purpose of demonstration and awareness-raising. In the years following the implementation of the project, it is expected that these practices will be replicated widely and hence the nutrient load reduction will be significantly higher.

In Bulgaria, the GEF/World Bank Wetland Restoration and Pollution Reduction Project (commenced 2002)- saw the restoration of 2,340 ha of former marshes along the lower course of the Danube, helping to reduce land-based nutrient pollution to the Black Sea. The wetlands restoration approach has a high replication value throughout the Black Sea Basin region. Based on the nutrient trapping capacity of just two restored Belene and Kalimok/Brushlen marshes, 800 tons of N and 40 tons of P input could be reduced every year, accounting for 5% of Bulgaria's total nutrient contribution to the Danube.

Hungary's Nutrient Pollution Reduction of Urban Effluent and Rehabilitation of Floodplain Wetlands project (commenced 2001) aimed to decrease nutrient discharge through the improvement of the North-Pest (Budapest) sewage treatment plant as well as re-establish the nutrient retention capacity of the downstream Danube floodplains. The total expected nutrient reduction from this project is 8,445 tons of N and 574 tons of P annually. In addition, the project is developing knowledge and technical data to further understanding of the role and impact of wetland restoration in nutrient reduction, which will enable a better prediction of outcomes for future projects.

The GEF/World Bank Agricultural Pollution Control Project in Romania introduced new agricultural practices through the integrated management of a 90,000 ha catchment area in the Calarasi region. This included improved on-farm livestock pollution reduction practices and the ecological rehabilitation of a high-priority floodplain in the Lower Danube River. Due to manure management interventions at commune and household levels, over 80 tons of N and P are being reduced each year. Following the success of this project, the Romanian Government decided in 2007 to adopt nation-wide best practices for nitrogen reduction. A new GEF/World Bank project is now scaling up approaches to all Nutrient Vulnerable Zones (from the EU Nitrate Directive) which is expected to yield reductions of 15,350 t/y and 8,950 t/y of N and P, respectively.

In Turkey, the GEF/World Bank Anatolia Watershed Rehabilitation Project is using Integrated Soil Erosion and Nutrient Management to rehabilitate 28 degraded micro-catchments in Central Anatolian Basins, thereby reducing nutrient inflow to the Black Sea. Although nutrient reduction is difficult to predict at the micro-basin level, this project expects to reduce pollution by 200 t/y of N and 25 t/y of P through improved nutrient management, organic farming and animal husbandry.

Wetlands are proven effective nutrient reduction instruments as tertiary treatment with over 90% efficiency in BOD, N and P reductions after a combination of several low-tech solutions has been used (post-treatment filtration, sludge pre-treatment, post-treatment aeration). In addition to projects described above, GEF has invested in several wetlands remediation projects (Table 2).

Table 2 - Summary of GEF wetland remediation projects (GEF PMIS)

Country	Project Name	Type of action
Albania/Macedonia (UNDP)	Integrated Ecosystem Management of the Prespa Lakes Basin	Construction of SFS/FWS systems
Egypt (UNDP)	Lake Manzala Engineered Wetland	Combination of constructed SFS & FWS wetland systems
Uganda/Tanzania/Kenya (WB)	Lake Victoria Environmental Management Project	Combination of constructed SFS, FWS and natural wetland systems
China (WB)	Ningbo Water and Environment Project	Construction of SFS & FWS wetland systems
Africa – Regional (UNEP)	Addressing Land-based Activities in the Western Indian Ocean (WIO-LaB)	Interception wetland coastal buffer zones and constructed wetland
Albania (WB)	Integrated Water and Ecosystems Management Project	Combination of constructed SFS, FWS and natural wetland systems
Danube River and Black Sea	Projects under WB-GEF Strategic Partnership for Nutrient Reduction in the Danube River and Black Sea	See below
Bosnia-Herzegovina (WB)	Water Quality Protection Project	Combination of constructed SFS, FWS and natural wetland systems
Bulgaria (WB)	Wetland Restoration and Pollution Reduction Project	Restoration of wetlands and management of riparian SFS/FWS wetlands
Hungary (WB)	Reduction of Nutrient Discharges	Restoration of wetlands and management of riparian SFS/FWS wetlands
Romania (WB)	Agricultural Pollution Control Project	Restoration of wetlands and management of riparian SFS/FWS wetlands
Moldova (WB)	Agricultural Pollution Control Project	Restoration of wetlands and management of riparian SFS/FWS wetlands
Russian Federation (WB)	Agricultural Pollution Control Project	Restoration of wetlands and management of riparian SFS/FWS wetlands
Croatia (WB)	Agricultural Pollution Control Project	Restoration of wetlands and management of riparian SFS/FWS wetlands

Case Study: Living Water Exchange

The Living Water Exchange: Promoting Nutrient Reduction Best Practices constitutes the next phase of the long-term commitment of the Global Environment Facility (GEF)/United Nations Development Programme (UNDP) to achieving environmental health and significant nutrient reduction in water resources across the Central and Eastern Europe (CEE) and Eastern Europe, Caucasus and Central Asia (EECCA) regions. The Living Water Exchange[1] is a learning project that facilitates information sharing and accelerating the replication of the most appropriate nutrient-reduction practices developed from GEF and other investments over the last fifteen years.

Since the 1960s, the area of summer-autumn hypoxia zones in the Black Sea increased more than 1,000 times.[2] The Global Environment Facility (GEF) International Waters (IW) Focal Area[3] was one of many organizations that made significant investments to address the challenges posed by this nutrient pollution in Central and Eastern Europe (CEE) and Central Asia. These efforts created a wealth of experiences and practices, focusing on the Danube River-Black Sea basin. However, it is unclear whether those investments were systematically linked, build on one another in a meaningful way or focused on individual interventions rather than a systems approach to improvement. Therefore, the Living

Water Exchange: A GEF/UNDP project to promote nutrient reduction best practices in Central and Eastern Europe, will share information and accelerate the replication of the most appropriate nutrient reduction practices to achieve environmental health and significant nutrient reduction in water resources across the CEE and Central Asia.

Initial findings regarding the value of the GEF investments include:

- Potential stress reduction from the Living Water Exchange inventoried projects in the region is approximately 13,020 tons per year nitrogen and 4,510 tons per year phosphorous based on MONERIS[4] load estimates. These numbers reflect reductions due to agricultural and wetland impacts but not waste water treatment plants. While overall figures for GEF projects are not that large, they should be seen as catalyzing change by demonstrating what can be achieved. It is expected that further replication through other financial resources would increase reductions further. At the same time the results also highlight the need to monitor projects, collect data and implement appropriate operations and maintenance.
- The GEF leveraged its more than $122 million in investment with approximately $400 million in co-finance.
- Measurable improvements have been observed in the ecosystem, including increases in the number of benthic species[5] and virtual elimination of the hypoxic zone in the Northern Black Sea from 1991 to 2001. While these early reductions are primarily due to the economic downturn in the region, the ongoing challenges of hypoxia in the Black Sea and how they have been solved can serve as a shining example of how initiatives to restore the agricultural economy in the region can be coupled with changes in culture/human behavior and actions, such as nutrient management can improve water quality over the long-term.
- The GEF catalyzed cooperation in the region and built on efforts of the International Commission for the Protection of the Danube River to jointly address the pressures of nutrient pollution. One of the key findings of the Danube Regional Project was the benefit of close cooperation between the ICPDR and GEF projects in the region.
- Peer-to-peer exchanges held at Living Water Exchange demonstration sites among policy makers and practitioners/farmers are a good model to build capacity to further replicate practices. So much so that the Minister of the Environment for Albania is hosting a ministerial-level meeting during first quarter of 2011 to discuss how to foster further cooperation to address nutrient pollution in the region.
- The new GEF full size project entitled "Global Foundations for Reducing Nutrient Enrichment and Oxygen Depletion from Land Based Pollution in Support of the Global Nitrogen Cycle" or the Global Partnership for Nutrient Management is developing a policy tool box which will utilize the Living Water Exchange practice inventory, analysis and database as the foundation for its development and ensure that key practices are replicated and implemented to meet performance expectations and outcomes in key nutrient "hot spot" regions worldwide.

References:
1. Living Water Exchange Project: URL: http://nutrient-bestpractices.iwlearn.org/
2. http://www.europe.culturebase.net/contribution.php?media=307
3. The GEF is a global partnership among 182 countries, international institutions, non-governmental organizations (NGOs) and the private sector investing in transboundary water issues.
4. The MONERIS model, developed by ICPDR calculates the emissions of nitrogen and phosphorus to the surface water, by different pathways as well as the instream retention in the surface water network Through MONERIS the nutrient loads within the Danube river network has been calculated for today and a scenario has been developed for 2015.
5. GEF, 2007

A renovated water treatment plant in Juba, South Sudan

5. Key Considerations in Hypoxia and Eutrophication Prevention and Remediation

Preventing and remediating coastal hypoxia through integrated management

Experience with successful remediation efforts shows that management actions will need to be coordinated across sectors and scales as needed. Daunting in their totality, fully integrated efforts can be built sequentially, gradually adding depth and integration to the various actions as information and experience accumulates. Indeed, responsible actors cannot afford the time to wait to develop fully integrated approaches before starting systematic work on prevention and remediation. Successful first steps often lead to bigger follow-on actions. In a few cases (see box following), integrated action was embarked on early due to political support at the right level. More commonly, integration emerges as the dimensions of the problem are realized.

The case for integrated approaches

As coastal hypoxia has multiple causes and scales of action in time and space, integrated approaches ultimately are needed. Nutrient effluents must be managed from many different sources and so policy makers, managers, and effluent-emitting industries must work together. Integrated approaches can foster problem definition and cooperation among sectors that may not normally communicate. One relevant process is Integrated Coastal Management (ICM), which emphasizes the importance of sustainability. Beyond the coastal zone, hypoxia links land-based activities and water resources. As articulated in this report, significant economic implications can be associated with poor management of either system, but neither are closed systems. For example, many marine species rely on multiple environments including freshwater ecosystems or land based events for different parts of their life cycles. Moreover, marine environments are the ultimate downstream receiving waters. A key approach to ensure that policies, actions and management of one system does not have unintended adverse impacts on the other is to integrate management, agree common objectives and ensure effective communication between all stakeholders. Land-based watershed management has been embraced (IWRM) as the best way to protect, conserve and utilize water using the river catchment as the base unit, rather than traditional political boundaries. Thus, the integration of both ICM and IWRM management systems, i.e. the interface between land and marine systems, is essential for dealing with issues such as hypoxia that have cross-cutting impacts on environment, economy and health.

In ICM and IWRM approaches, the challenges are: mainstreaming socioeconomic development and environmental sustainability priorities within various economic sectors; garnering sufficient strong political will, backed by management capacity and effective, institutionalized enforcement.

Success is possible through using effective ICM tools. As the Xiamen case shows (see box), marine functional zoning is one effective tool within ICM as it reduces conflicts among users/sectors and improves economic development and sustainability of use for a coastal area.

Building on existing instruments and tools

Although the general causes and effects of hypoxia are well documented, specific tools are needed to help coastal managers, industries and governments to mitigate, remediate and manage hypoxic zones in their areas of responsibility. Fortunately, a range of useful tools already exist or are being developed. This section provides a short summary of key tools listed in Annex I. More details of the tools are in the companion to this report, the Annotated Resource Guide (Harper, 2010).[11]

Many important processes associated with the formation of hypoxia cannot be monitored directly and, therefore, models are needed to explain them. For inputs, the models require a realistic description of nutrient sources and loads, the best possible quantitative estimates, including those from diffuse sources, and a comparison with the loads transported in rivers. Nutrient inputs are heavily dependent on local marine and freshwater hydrology, which has to be included in the considerations. The Intergovernmental

Boat traffic on the Saigon River, Vietnam

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[11] The Annotated Resource Guide can be downloaded at: http://www.unep.org/stap/LinkClick.aspx?fileticket=MpOyegpvgwo%3d&tabid=4740&language=en-US

Case Study on Integrated Management, Xiamen, China

A successful example of integrated management is the case of Xiamen, China (Uychiaoco, et al., 2009). After sustaining one of the fastest economic growth rates in China in the 1990s, the coastal zone around Xiamen Island experienced an upswing in pollution from several sources, including its burgeoning aquaculture industry, explosive construction, an explosive growth in urban/suburban population and associated untreated sewage, industrial and shipping accidents. Soon conflicts arose among rapidly growing marine industries and the environment, and grew as fast as the city itself; the shipping industry vs. aquaculture; coastal engineering vs. conservation vs. shipping; and waste disposal vs. fisheries vs. tourism. These conflicts combined with rampant pollution, resulted in biodiversity and habitat losses and altered coastlines and water flows. Major fish kills occurred twice a year and algal blooms as well as hypoxia became increasingly frequent events.

ICM was instrumental in restoring and revitalizing the Xiamen coastal zone. An interagency coordinating mechanism was set up to integrate the actions of coastal-use sectors and coastal environmental management for sustainable development. It incorporated a multi-disciplinary experts group, developed an integrated profile of the coastal sectors in which interactions were carefully noted and an integrated strategic plan. The executive vice-mayor led the interagency coordinating mechanism, made up of 22 government agencies, supported by the Marine Management Office and advised by the expert group. The latter included environmental, economic and legal experts as well as key government planners and managers. The integrated coastal profile identified the following interrelated issues:

- Natural factors and cross-sectoral conflicts were hampering further development
- Inadequate government capacity (human, organizational, informational, legal, financial, technical, enforcement) existed to manage cross-sectoral issues and pollution
- Low environmental awareness among policy-makers AND the public
- Lack of a master plan for the coastal area as a whole
- Inadequate pollution management

The ICM initiative was successful in its integration of law enforcement and a sea-use permit and fee system; as well as environmental management with sea area use regulation. After the primary sea area users were identified (navigation, fisheries and tourism), the area surrounding Xiamen was divided into geographic subareas that were matched with each use deemed most likely to provide the greatest societal benefit in terms of both economic, environmental and future needs.

The zoning initiative, called "Regulations for the Management of Sea Area Use in Xiamen", also mandated a permit and user fee system which helped finance rehabilitation efforts. The fees capture benefits of private sea area use for local stakeholders and help internalize lost opportunities or ill effects that become public issues via individual or corporate sea use. User fees also support administrative costs for system management – 30% go to the national treasury and 70% are retained in the local treasury. The fees are specifically allocated for development, protection and management instead of being pooled for general use. The resource-rent capture, generated by charging user fees, helped secure substantial resources (more than the entire budget of the Xiamen Ocean Fisheries Bureau in 2007) to facilitate effective enforcement. Upon seeing the success of ICM in Xiamen, the People's Congress of China passed a law on the Administration of Sea Areas leading to the designation of all coastal provinces in the country under sea area use ordinances. Every year, thousands of noncompliance penalties are issued which further contributes to the financial stability of the zoning program.

Oceanographic Commission (IOC) of UNESCO is currently developing a model-based tool as part of its Nutrient Export from Watersheds User Scenario Evaluation (NEWS2USE) toolbox. This tool will integrate the results of studies on nutrient impacts on harmful algal blooms, hypoxia and effects on fisheries using a combination of empirical and deterministic approaches to estimate the magnitude of current and anticipated effects of coastal nutrient loading.

PEMSEA's State of the Coasts (SOC) Reporting System (PEMSEA, 2011) is a valuable reporting tool that monitors existing conditions and response actions of coastal areas, measurable through process and impact indicators and targets (160 in total, with 35 core indicators). Other tools developed by PEMSEA are the Manila Bay Refined Risk Assessment, which provides retrospective vs. prospective approaches to risk assessment and a sound protocol for loading estimation methodology (PEMSEA, 2006). The IFA Task Force on Reactive Nitrogen (IFA, 2007) includes nutrient best management practices (NBMP), indicators developed by the International Fertilizer Industry Association to determine the impact of NBMPs as well as tools for assessing the nutritional status of growing crops. A comparison of existing tools for managing nitrogen in fertilizer is also available (Harper, 2010).

Broad regulatory instruments include the United Nations Convention on the Law of the Sea (UNCLOS); FAO Code of Conduct for Responsible Fisheries; Nanjing Declaration on Nitrogen Management. Other approaches to mandatory and voluntary regulation can be found in FAO/Economic Commission for Europe (1991). By way of example at the national level, Canada has a nutrient management regulation within the Water Protection Act. From a policy and governance perspective, the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) (UNEP, 2007) published case studies of effective policy implementation. Reviews of emerging policies show how negative impacts associated with reactive nitrogen may be successfully addressed locally, nationally and regionally, given similar challenges, shared experiences and effective solutions. More recently the GPA published "Building the foundations for sustainable nutrient management" (UNEP, 2010) which advocates for efficient use of nutrients and the development of a systematic and comprehensive nutrient management tool box.


Checking the chlorine level of drinking water outside of Verrettes Hospital in Haiti.

For interventions, the GPA has published Guidelines on Municipal Wastewater Management (UNEP/WHO/HABITAT/WSSCC, 2004). Other recommendations for action and nutrient reduction strategies have been developed by the Nutrient Management Workshop of the Chesapeake Bay Program (1996)[12]; PEMSEA (2006); Ignazi (1993); Galloway *et al.* (2007); Giller *et al.* (2004); and Conley *et al.* (2009).

Capacity development is also very important. Several resources exist, including "Making Mainstreaming Work – An Analytical Framework, Guidelines and Checklist for the Mainstreaming of Marine and Coastal Issues into National Planning and Budgetary Processes" (Soussan, 2008) and the "process guide" of Higgason and Brown (2009).

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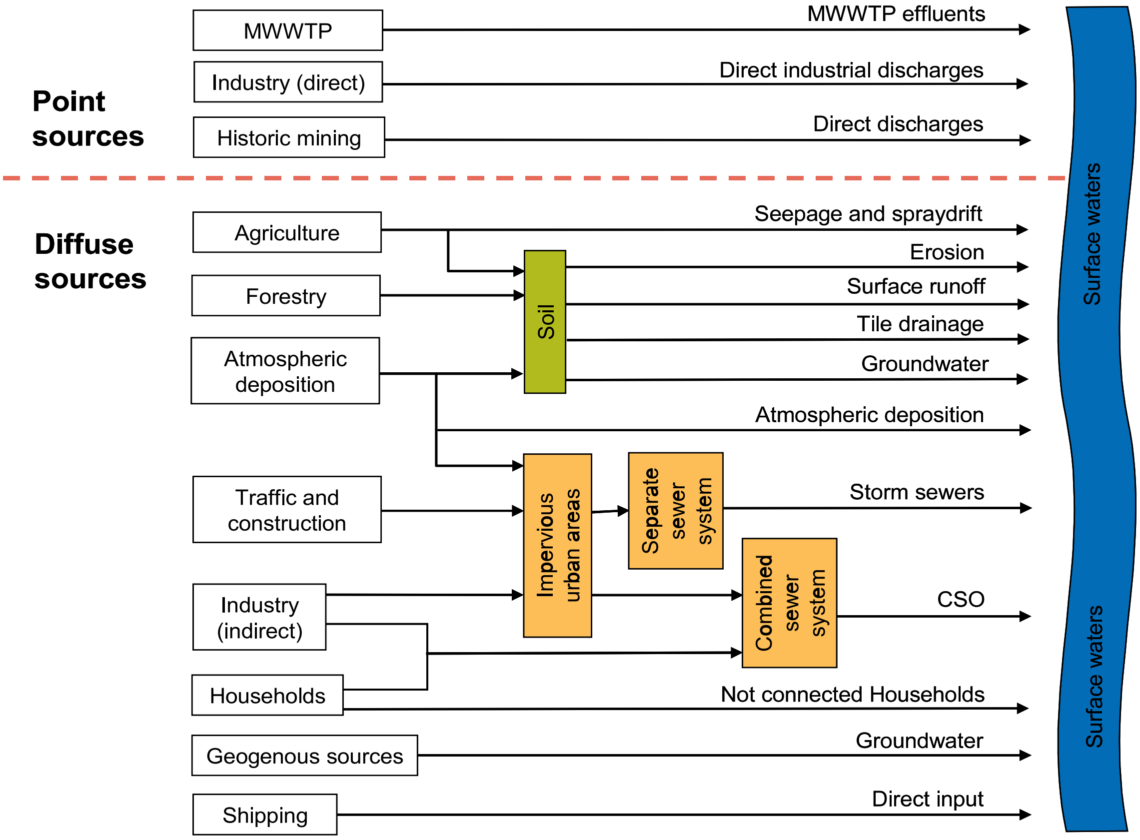
[12] Managing nutrients to prevent pollution: Conference Summary and Recommendations for Action http://www.chesapeakebay.net/content/publications/cbp_12383.pdf.

FIGURE 14 - Pathways considered in MONERIS



With respect to models, MONERIS is used in the Danube River (developed by H. Behrendt *et al.*, 1999). This model has been extended beyond nutrient emissions, enabling it to calculate heavy metal concentrations and selected organic pollutants.

MONERIS is a macro- to mesoscalic empirical model, which calculates the emissions from point and diffuse sources into river catchments via several pathways which subsequently may be aggregated to assess the contributions of greater catchments or countries. The average size of these catchments, which limits the spatial resolution (so called analytical units) of the results, depends mainly on data availability. Catchment size ranges from ~ 100 km² in Germany to ~1400 km² for the Danube catchment. As MONERIS also addresses pollution retention processes, estimated emissions can be compared with riverine loads. Using such a model allows for a quantitative comparison of the contributions from several sources or regions (see Fig. 14), which greatly enhances transparency in the management


Secretary-General visits sewage treatment plant in Xi'an, China

process and allows better targeting of reduction efforts to the most important sources. Figure 15 illustrates for the Danube Basin a map of the baseline situation for phosphorous emissions averaged over the years 2000-2005, using modeling to provide data continuity across sub-catchments.

The effects of reduction measures can be included in these calculations if a reliable map of the effects on model input parameters is available. For example, research has shown that the phosphorus concentration in raw sewage drops by approximately 50 % when phosphate-containing laundry detergents are no longer used. The effects on the input to the surface water can thus be modeled using this estimate for urban discharges with and without phosphorus removal, combined with sewer overflows and data on households not connected to sewers (Figure 16).

In the process of developing the Danube river basin management plan, the anticipated effects were estimated for several scenarios. Results have shown that the management objectives and EU WFD objectives will not be met for nitrogen; even the N emissions to surface waters in 2015 will only be about 12% lower. Loads to the Black Sea will be approximately 40% above 1960s levels (based on the Danube agreed vision). P emissions to surface waters are estimated to be 25 % lower in 2015. However, if phosphate-free detergents are mandated in the whole basin, the required reduction targets could be reached in a cost-effective way.

Overcoming financial barriers

The urgent requirements for environmental facilities, services and programs to improve the management of land-based sources of marine pollution are well recognized. However, with the continuing high demands on official development assistance (ODA) resources and the oftentimes limited ability or willingness of developing countries to allocate sufficient portions of their budget for environmental protection and restoration, mobilizing new and additional financial resources to meet these requirements will be an indispensable component of any

Main sewage pump center in Chernigov, Ukraine

FIGURE 15 - Danube River Basin District: Nutrient pollution from point and diffuse sources – Reference Situation for Phosphorous (ICPDR, 2009)

Danube River Basin District:
Nutrient Pollution from Point and Diffuse Sources - Reference Situation for Phosphorous

MAP 23

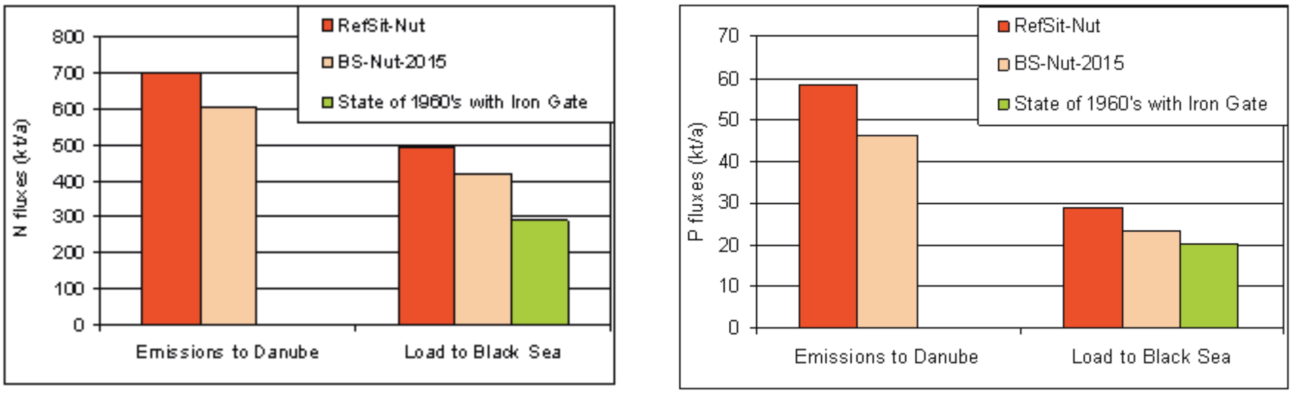
Significant efforts have been undertaken so far in the DRBD regarding diffuse source pollution and its illustration using the MONERIS Model System (Behrendt et al., 2007) . However, further research and monitoring is needed, as well as a continuous improvement and calibration of the MONERIS scenarios.
The MONERIS Model integrates the findings of point source analysis with those related to diffuse sources and reflects the overall nutrient input in the DRB in total and per Danube country.
SI is using a method based on the OECD method: Environmental indicators for agriculture. Methods and Results (2006).

www.icpdr.org

This ICPDR product is based on national information provided by the Contracting Parties to the ICPDR (AT, BA, BG, CZ, DE, HR, HU, MD, RO, RS, SI, SK, UA) and CH, except for the following: EuroGlobalMap v2.1 from EuroGeographics was used for national borders of AT, CZ, DE, HR, HU, MD, RO, SI, SK and UA; ESRI data was used for national borders of AL, ME, MK; Shuttle Radar Topography Mission (SRTM) from USGS Seamless Data Distribution System was used as topographic layer; data from the European Commission (Joint Research Center) was used for the outer border of the DRBD of AL, IT, ME and PL.

Vienna, December 2009

FIGURE 16 - Comparing fluxes of dissolved organic nitrogen and total phosphorus emissions to the Danube and loads to the Black Sea (ICPDR, 2009).



Key: RefSit-Nut: Reference Situation-Nutrients 2000-2005; BS-Nut 2015: calculated Baseline Scenario-Nutrients 2015 serious effort to address eutrophication of coastal waters. PEMSEA experience has shown that providing essential services like water supply, sanitation, sewerage, waste water treatment, and drainage in both urban and rural areas is a local affair, especially when the resource is locally available. Local governments are responsible for regulating such services and ensuring that appropriate service providers are appointed to develop and manage the services in a sustainable way and to develop and extend them to the unserved. As decentralization of governments proceeds in many countries, financing is increasingly devolved from national to local governments.

The bulk of the funds required for sustaining existing systems and for new investment in water services comes from user fees and the public budget. Mobilizing local social capital and public solidarity is essential in developing capacity to finance the provision of sustainable services. Each country, region, district or municipality has its own dynamics and has to rely on its own strengths. In enabling new investment, lending to sub-sovereign entities is becoming increasingly important and issues with sub-sovereign risk becoming more prevalent. In many cases, local governments either lack the financial and managerial capacity or the proper regulatory framework and authority to be considered credible financial partners.

To improve access to the financing required by local governments, major action is required on three fronts:

- Increasing the capability and creditworthiness of local governments to engage in financing.
- Shifting from foreign currency and sovereign financing to local currency and sub-sovereign financing.
- Ensuring that the volume of all financial flows will cover necessary costs.

Private sector participation can help to meet the growing demands on both central and local governments, particularly with regard to new investment capital, management expertise, technologies and operational know-how. These potential contributions of the private sector to environmental sustainability can be tapped through the promotion of public-private partnerships (PPP). Engaging the local governments, local stakeholders and private sector in a partnership requires time and preparation. Thorough and proper preparation and packaging of proposed environmental infrastructure projects are important factors for success. Commitment or buy-in of key actors at the local government and community levels should be secured to ensure continuity in project implementation. Private sector partners or investors should also display commitment to helping protect the environment as well as building up local capacity.

A comprehensive approach is needed for packaging and promoting environmental investment projects, including detailed technical evaluations of possible technological options, capital and operating cost estimates, financing alternatives, means of revenue generation and desired project outcomes. A comprehensive and integrated assessment of site concerns or issues will not only provide better understanding of the needs, but also help to identify a more comprehensive set of solutions and facilitate "packaging" of bankable projects. Potential private sector partners can build on these assessments to offer innovative and integrated solutions (e.g., combining wastewater treatment, energy generation and water use efficiency/conservation). The integrated approach also entails early involvement of the general public in the consultations, pre-feasibility studies and site selection. This approach will not only provide more options but will also be more cost and operation-efficient for both the local government and private sector.

Furthermore, financing sewage and other pollution reduction facilities and services needs to be addressed at the scale of river basins, as they are a principal source of nutrients to coastal waters and are a key component to ensuring sustainable development of marine and coastal areas. This entails partnerships across different sectors (e.g., agriculture; forestry; aquaculture; energy; cities/municipalities) and levels of government (local, national, regional) and between upstream and downstream beneficiaries. The development of such institutional arrangements and infrastructure will be too much of a burden for most local governments and, as such, central governments will have to play their proper role in coordinating river basin projects that cross political boundaries and involve multiple public and private sector stakeholders.

German Government officials pay a visit to the sewage treatment plant in Gaza.

For successful cross-sectoral mitigation of hypoxic zones, national governments have an essential role in enforcing environmental laws, promoting policies that encourage private sector participation in the provision of public infrastructure, and providing the needed technical and financial assistance to local governments. Development partners providing ODA or concessional finance should also work with concerned national government agencies or local governments to find ways of using their long-term funds and expertise to bring in contributions from the public and private sectors. Though ODA represents only a small part of the total funding required for investment and management of water and wastewater services, it can be highly significant in leveraging other money and developing confidence to create access to local and other capital markets. Establishing revolving funds and providing partial and total guarantees for loans and bond issues can enhance creditworthiness and develop confidence in local currency markets. Grants can also be used effectively for project and local capacity development.

STAP Advice for key stakeholders

By the nature of its causes and effects, coastal hypoxia touches the responsibilities of many different stakeholders. For all stakeholders, the overarching goal is to develop and implement scientifically sound, cost-effective nutrient reduction strategies to prevent, minimize and where possible, eradicate coastal hypoxia. The following STAP advice is formulated for different GEF agencies and other key groups in light of their mandates and current priorities. STAP advice is presented in two sub-sections. The first is generic advice organized into advice for each of seven stakeholder types, namely (1) intergovernmental organizations, (2) countries, (3) coastal zone managers and local government, (4) industry and the private sector, (5) scientific researchers, (6) NGOs and (7) communities and civil society. An over view of action recommended each of these stakeholder types follows and the details are provided in Annex I. The second sub-section addresses the needs of agency partners within the GEF system. All advice is based on four principal and cross-cutting key considerations: prevention, diagnosis, remediation and integrated management. The following advice is expanded in Annex II (Advice for Key Stakeholders).

1. Intergovernmental organizations

These bodies must facilitate multi-national, regional agreements on strategic action, normative instruments and create partnerships to bring nutrient reduction and hypoxia remediation to the fore of national pollution reduction agendas. This strategic action can facilitate a top-down drive to bring nutrient reduction and hypoxia management issues to the fore on national agendas as well as raise the visibility of the issues in stakeholders’ priorities. Partnerships at the global level can also help countries access capacity and capacity building to overcome the initial barriers of addressing the interconnected issues associated with hypoxia. Additionally, intergovernmental partnerships are key catalysts in helping countries address transboundary water management issues, including hypoxia.

- **Prevention.** Intergovernmental organizations (IGOs) should support national government to develop strategies and to implement preventative action. They can drive innovations in nutrient production, including through research and development and provide funds for demonstration projects. They can also use their global reach to support community education and outreach programmes.
- **Remediation.** Similar actions apply as for prevention but with additional urgency. IGOs can help by framing remediation messages consistently and positively to maintain action in the 10-30 year lag time to observable results, especially where initial remediation costs may be high but long-term more effective, e.g., wetlands restoration. IGO financial institutions play a particularly important role in pioneering project funding ideas and leveraging national funds. IGOs can also define and disseminate best management and monitoring practice.
- **Integrated Management.** IGOs lead in developing seamless and connected institutional/inter-agency action, promoting knowledge sharing.

2. Countries

National governments and agencies should establish, implement and maintain sound scientific monitoring strategies, management strategies and supporting regulatory and legislative framework for pollution reduction, including especially for farm fertilizer use, livestock waste and sewage discharges as key sources of nutrients and oxygen demanding pollutants. Unless international bodies and national government sector ministries act, countries will not achieve the Millennium Development Goals in the coastal zone, e.g., reversing the loss of environmental resources. National and sub-national (local) action is central to hypoxia prevention and remediation. Also, countries will need to cooperate at regional and inter-regional levels to help achieve a more integrated, coordinated effort.

- **Prevention.** Countries should establish and legislate scale-appropriate programmes for nutrient reduction, including conservation of riparian buffers and vulnerable coastal areas. National agencies can take responsibility for targeted hypoxia awareness programs. In partnership with the private sector, they drive the development of appropriate innovations.
- **Diagnosis.** National agencies are responsible for assessing the extent, duration, frequency and intensity of hypoxia in coastal waters and investing in sustained monitoring programmes, including for assessing remediation.
- **Remediation.** National responsible agencies provide policy and implementation frameworks for nutrient management plans, co-finance remediation projects and co-ordinate sectoral planning.
- **Integrated Management.** Competent authorities should be empowered to support responsible nutrient management including through proactive land management strategies. Government, industry and local communities must collaborate and meaningful and active participation of interested parties and potential stakeholders be encouraged.

3. Coastal zone managers and local government

Coastal zone managers are central to hypoxia prevention and remediation through reforming municipal utilities for water and sewage pollution reduction and engaging local stakeholders. They are uniquely placed to bring elements and actors together in a manner that best suits the specific problems affecting their respective coastal zones and engages their surrounding communities. Of the stakeholder groups listed so far, coastal managers are perhaps best suited to developing case-specific, scale-appropriate and multi-sectoral approaches and to ensure that local government units collaborate with each other.

- **Prevention.** Local agencies can develop a priori coastal zone management plans, coordinate and facilitate multi-stakeholder dialogue and foster private sector engagement. Although resources are often limited, local authorities should invest in innovative nutrient reduction technologies such as sewage treatment.
- **Diagnosis.** When hypoxia emerges, coastal managers may be among the first to know. They should react by setting us monitoring, incorporating a

variety of surrogate indicators (social, economic/financial, health, environmental, etc.), engaging with scientists who can help advise and disseminate regular updates on hypoxic status.

- **Remediation.** Coastal managers have the most to gain from remedial action and monitoring of its results.
- **Integrated Management.** Remediation will require integrated management within broader integrated management and geographic frameworks such as ICM, to ensure linkages between LMEs and river basins, and across local governmental units and engaging with "remote" actors such as farmers to generate buy-in. Coastal managers will need to frame messages positively and find common threads to foster cohesion among groups with different interests.

4. Industry and the private sector

The industrial sectors need to actively engage as stakeholders in policy-decision making and change their practices to reduce nutrient pollution. Although the contribution level of each will vary significantly by region and by sector, industrial actors must be engaged in policy decision-making and action. This can be accomplished by involving representatives of these sectors in stakeholder meetings, educational programmes and training sessions. Their role must be participatory so that sectors responsible for the largest point-source emissions (e.g. intensive agriculture, fertilizer industry) can be part of the solution rather than the problem.

- **Prevention and remediation.** Nutrient emitting industries should recognize impacts of their own practices and accept shared responsibility. Industry practices should be changed to reduce and/or treat emissions. Priority should be given to finding solutions for large point source emitters such as wastewater, intensive poultry raising. All industry sectors should contribute their data.
- **Integrated Management.** If private companies or their representatives engage in integrated management arrangements, they will be better aware of the need to strike a balance between economic development, growth and pollution reduction and convey facilitate educational programmes and training sessions for their clients and staff.

5. Scientific researchers

Researchers must emphasize sound scientific input, which is crucial in every step of hypoxia diagnosis, management and communication to decision makers. From problem diagnosis to remediation, the scientific and research community is on the front line of most aspects of hypoxia management, including includes academics, government scientists and task forces, private sector researchers, international experts and working groups.

- **Prevention.** Scientists should continue to develop and test new predictive tools and indicators and improve understanding of the role of climate change in hypoxia. Oxygen levels in coastal zones need to be more cost-effectively monitored, requiring innovative technologies and observing systems. Stream and river monitoring and modeling of nutrients should be enhanced to improve prediction of potential hypoxic zones. Hypoxia prevention education programmes need to be developed for both the current and next generations.
- **Diagnosis.** Scientists should provide science-based evidence for decision makers and improve comprehensive ecosystem models to assess how hypoxia affects commercially important resources such as fisheries to assist management strategies.
- **Remediation.** One of the most important and difficult remediation roles for science is to estimate and project response times to nutrient reductions. Scientific research can also improve planning and management of technological interventions.
- **Integrated Management.** Scientists can help evaluate alternative management options and translate research results into forms useful for legal and administrative responses. Researchers can tap different sources of research funds for aspects of hypoxia and nutrient reduction that are "risky" and long term. Developing country research capacity needs to be built quickly to address the growing problem of hypoxia. Integrated solutions also urgently require social and economic sciences to facilitate management decisions as well as implement the behavioural and cultural changes needed. Although marine biophysical scientists play a key role in helping stakeholders decide on the best course of action based on the nature of the hypoxia

itself, social scientists must now play a crucial part in transforming those options and plans into concrete action.

6. Non-Governmental Organizations

Non-Governmental Organizations (NGO) should be involved actively in integrated hypoxia management advocacy and actions. At present, few environmental and social welfare NGOs give priority to "brown" issues such as coastal hypoxia and nutrient reduction, preferring instead the more attractive "blue issues". However, their skills and capacities could be very effective in addressing hypoxia problems. NGOs have strengths in raising awareness of and seeking practical solutions to problems and addressing local socio-economic objectives. Place-based actions such as reducing land-based nutrient pollution and restoring coastal wetlands and shell beds are relevant. Smaller, local NGOs are well placed to address hypoxia, and some regional groups such as the Chesapeake Bay Foundation are especially attuned to nutrient reduction with a watershed approach.

- **Prevention.** Environmental and other NGOs should incorporate hypoxia and nutrient reduction in their advocacy activities and promote dialogue and awareness in the public sphere using their extensive networks and resources.
- **Remediation.** Conservation NGOs can incorporate strategies for localized hypoxic zones and transboundary and upstream nutrient pollution and engage with coastal zone users to raise awareness and encourage solutions.
- **Integrated Management.** NGOs can provide resources to assist nutrient reduction in developing countries. They can use their networks to connect groups associated with hypoxia and its solution. NGOs can help make the case on the significance of land-based sources of pollution and advocate for integrated management programs linking land and sea.

7. Communities and civil society

Communities and civil society play an important role as environmental stewards and should show a vested interest in the health of their coastal marine and watershed environments and in continued flows of economic and social benefits of the goods and services they provide. In addition to "engaged" citizens who tend to be involved in NGO and advocacy, all people can play some role in the way they conduct their daily lives beside and upstream of hypoxic zones. Environmental stewardship is everyone's responsibility.

Indonesia students practice testing and treating water to make it safe to drink

- **Prevention.** People have a responsibility to be informed and adjust behaviours to reduce nutrient loading (e.g. choosing phosphate-free cleaning products).
- **Diagnosis.** Citizens can alert authorities to visible indicators of hypoxia (i.e. fish kills, HABs).
- **Remediation.** People can participate in local community clean-up efforts and lobby government and local politicians.
- **Integrated Management.** Citizens can participate in stakeholder consultation meetings.

Specific Roles of the GEF partnership

GEF

Hypoxia and nutrient reduction is presently being addressed through the International Waters focal area of GEF, GEF agencies and partners. While clearly a cross- GEF agency matter, hypoxia is also a cross-focal area matter. Hypoxia impacts global environment benefits in all focal areas, namely Biodiversity (BD), Land Degradation (LD) and Climate Change (CC). Hypoxia and nutrient reduction relate to BD Objective 1 (to improve sustainability of protected area systems) that includes marine protected areas that are frequently sited in shallow coastal waters with high biodiversity, including on coral reefs; BD Objective 2 (mainstreaming protection in production landscapes) that refers to fisheries and forestry systems subject to negative hypoxia causes (deforestation) and effects in the water; CC Objective 5 (conserve and enhance carbon stocks through sustainable management of land use, land-use change); LD (all Objectives) and the cross-focal area objective of contributing to sustainable forest management. GEF-IW, alone and in collaboration with other GEF focal areas, has many avenues to assist at the national and transboundary scales. Finally, STAP's Advisory Document and companion information can assist countries to understand the likelihood and nature of hypoxia and nutrient pollution issues and provide a guide to key resources available to underpin projects to prevent/remediate the problem.

GEF projects should continue to support collaboration across agencies and portfolios to more effectively create institutional synergies to reduce nutrients for hypoxia remediation and other environment benefits. GEF should establish a common set of principles for choosing priority systems for testing management responses in permanent and seasonal hypoxic systems. The following factors could be considered in making choices:

- Smaller systems with existing hypoxic conditions are more amenable to hypoxia remediation than larger systems.
- Larger systems are strongly influenced by global climate and climate change impacts, which are not "controllable" in the short- to medium term.
- The largest increase in the number of hypoxic coastal areas is expected in eastern and southern Asia.

In coastal systems susceptible to hypoxia and considered amenable to prevention or remediation, GEF projects should help strengthen Institutional capacity and integrated management. GEF needs to establish a minimum and cost-effective set of environmental parameters to be measured and monitored in projects. The cost-effectiveness and long term sustainability of GEF investments need alliances with academic institutions working in the field of hypoxia research. GEF should also update its existing TDA and SAP procedures to incorporate the ICM framework, including guidance on procedures to address coastal hypoxia and nutrient reduction.

GEF Secretariat and the International Waters Task Force

The GEF Secretariat "*coordinates the formulation of projects included in the work programs, oversees its implementation, and makes certain that operational strategy and policies are followed.*" The Secretariat works closely with STAP and leads the International Waters Task Force (IWTF), comprised of senior representative of each of the GEF agencies. STAP recommends that the IWTF adopt the coastal hypoxia and nutrient reduction recommendations of this report and create a project screening tool to apply them to new GEF projects. The Secretariat, and

STAP in the case of the science and technology elements of the projects proposed, would then provide advice to the GEF Council as to the appropriateness of proposed interventions on hypoxia.

GEF Agencies

Most GEF agencies have an interest in coastal hypoxia and nutrient reduction in their GEF-funded projects and programs and their base programs. The following overview summarizes how these issues fit into the agencies' priorities and indicate why this STAP Advisory Document is relevant to their work.

- **World Bank, Regional Development Banks.** In the World Bank's Environment and Natural Resources thematic area, related priorities include water resource management, pollution management, environmental health, land administration and management, under which the Bank supports hundreds of loans and projects. As a GEF implementing agency, the Bank has some GEF projects addressing nutrient reduction (section 4). The Asian Development Bank (ADB), Inter-American Development Bank and the European Bank for Reconstruction and Development each have water program priorities, e.g., the ADB's "Water For All" water financing program.
- **UNEP.** The UNEP Medium Term Strategy 2010-2013 has six cross-cutting thematic priorities, (namely ecosystem management, environmental governance, harmful substances and hazardous waste, resource efficiency, sustainable consumption and production and climate change) and coastal hypoxia relates to several. UNEP would appreciate STAP's scientific advice on hypoxia, practical guidance on payments for environment services (GEF-STAP 2010), how the new Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) should address hypoxia, plus engagement with the cutting edge scientific community. The UNEP GPA, which meets next in November 2011, would benefit from an update on hypoxia. UNEP's Global Partnership on Nutrient Management (GPNM) is consistent with the "One UN" message, and is an important platform for fostering partnerships on nutrient reduction. As a focus for international institutional engagement, it uses a top-down approach to encourage countries to "nutrient proof" existing policy frameworks. The GPNM can also bridge the gap between hypoxia management and the larger picture of nutrient reduction. By linking to solutions emerging from the dialogue surrounding global nutrient reduction policies, programs and initiatives, the GPNM fits as the "natural next step" to the STAP hypoxia advice, and aims to develop a comprehensive Policy Toolkit detailing where and how hypoxia remediation can be achieved.
- **UNDP.** UNDP has a strong program on Water Governance in its Environment and Energy work. As the UN agency for development, it helps countries develop their capacity for integrated water management, among others. UNDP can also play a role in trends analysis and producing a 'state of the art' picture for hypoxia and nutrient reduction, noting that existing world maps of hypoxia suggest that it may not be detected yet in some parts of the developing world. UNDP could also help raise the awareness of hypoxia in improving the development process of TDA/SAPs.
- **UNIDO.** UNIDO could use its new Green Industries Initiative to create awareness, knowledge and capacity around hypoxia and nutrient reduction in countries with high nutrient emitting industries. This is particularly true for the Hot-Spot methodology that classifies the industries, wastewater treatment plants and large livestock based on the pollution load of their effluents, as well as for the Transfer of Environmentally Sound Technologies (TEST) methodology that identifies better production options and investment opportunities resulting in economic profit for the industry and environmental benefit for the receptive surface water bodies.
- **FAO.** The causes and effects of hypoxia are closely related to several FAO mandate areas, including livestock, crops, fisheries, aquaculture, forestry, and water. Through its normative work and programs on the ground, FAO promotes practical preventative action in the livestock, agriculture and aquaculture sectors. FAO can help the transformation of nutrient management from the linear to the circular paradigm, by seeing nutrients as a recyclable resource.

Countries

- NATIONAL. GEF countries can initiate country-wide programs to reduce the amount of nutrients entering water bodies, such as setting targets or limits regarding fertilizer use and coordinating overall management and policy responses, especially when bolstered by regional legislation such as the EU water directive. National governments can also mandate the preservation and protection of riparian buffers through conservation programmes and wetland construction. Finally, national governments should continue to support modelling efforts by supporting open-source model code development, programs that maintain large-scale modelling efforts, and programs that provide data that facilitate local-scale water quality models.
- REGIONAL. Sub-national regional governments, e.g., province, that promote sound nutrient management and those that deal with environmental protection offer the opportunity to improve the environmental performance of agriculture, for example in intensive poultry production and other effluent-emitting industries. Governments must give priority to transfer and adoption of technological innovations through funding mechanisms, capacity building initiatives, including sharing of knowledge and experiences, and generating ‘best management practices’ for the region that include guidelines and codes of conduct and that facilitate co-operation at regional, national and global levels.
- LOCAL. Local and municipal governments are best placed to address the problem directly through tangible and concrete changes. Local governments are crucial connectors and coalition-builders that can integrate citizens, industry, policymakers and scientists toward a common goal. In country, local governments should use STAP’s advice to promote the need for inter-sectoral coordination, especially across land-based and water-based ministries that do not typically work together, such as occurred in Xiamen. National or sub-national ministries that monitor coastal hypoxia, especially the fisheries and environment ministries, do not have the mandate to control its causes, such as agriculture and sewage. Municipal government can lead in implementing successful nutrient reduction strategies.

Industry sectors and GEF

GEF projects frequently engage private sector actors that contribute co-financing and business know how.

- AGRICULTURE/AQUACULTURE. Farmers of land and sea need to know and understand the impact their practices have on the coast. Education and communication are a large part of the solution, such as awareness programs and outreach (e.g. FAO’s Farmer Field School training programme). The large-scale implementation of improved agricultural conservation practices and nutrient best management practices (NBMPs) is also essential. Alternative agricultural practices can greatly reduce nutrient loads, improve water quality and help to remediate coastal hypoxia. NBMPs include reducing nutrient pollution through (1) reducing fertilizer use and changing tillage practices/cropping systems and (2) riparian buffers, wetlands, tile drainage management. Buffers are more expensive than cover crops but more effective.
- AGRIBUSINESS/FERTILIZER. Capitalize on slow-release fertilizer sales by integrating nutrient reduction segments into farmer outreach and education programmes. Address intensive livestock production wastes.
- SEWAGE/Waste Water Treatment. Focus on widespread and aggressive implementation of nutrient removal technologies for wastewater and stormwater. This improves public health and reduces nutrient enrichment, eutrophication and hypoxia.
- PRIVATE SECTOR. Where possible, the private sector should be encouraged to invest in hypoxia research and nutrient reduction technology in partnership with governments, especially in areas such as innovation-to-market, capacity and institutional development, sharing of information and experience, and incentives that promote environmentally responsible nutrient management. Projects, states and the private sector should collaborate in multidisciplinary research and development that links research to industry needs and improves environmental performance.

Fish Trap complex,
Tonle Sap lake edge, Cambodia

6. Research for More Efficient and Effective Hypoxia Prevention and Remediation

After several decades of research, much is known about coastal hypoxia, including spatial and temporal patterns and trends, factors controlling dissolved oxygen depletion and replenishment, and impacts on ecological processes. The scale of hypoxia varies among different coastal systems, depending on the relative mix of key hydrologic, oceanographic and climatic forces. Recent syntheses of scientific investigations from several well-studied hypoxic systems have related the growth of oxygen-depleted areas to both changes in physical processes and to increases in anthropogenic nutrient inputs from urban and agricultural lands. The complex and long term nature of solving coastal hypoxia problems suggests that more efficient and effective approaches are needed. This means learning as much as possible from existing knowledge.

Recognizing the negative consequences of hypoxia and related coastal eutrophication, many countries have recently made significant commitments to reducing nutrient loads in adjacent estuaries, bays and seas, upon which they depend, e.g., China (CCICED 2010). Trajectories of hypoxia expansion with increasing inputs of anthropogenic nutrients have been analyzed and published for numerous coastal systems. Recent summaries have reported over 500 published case-studies of coastal hypoxia and about 50 cases (mostly unpublished) of response to remediation worldwide. This lack of published studies of system responses to decreases in nutrient loading and recovery from hypoxia is a particularly important knowledge gap because trajectories of hypoxia development and remediation tend to be non-linear and asymmetric with recovery trends often experiencing time-lags and hysteresis. Although a growing number of nations and regions have initiated efforts to remediate coastal eutrophication and hypoxia, the lessons being learned are not helping others to undertake remediation more effectively and efficiently.

Need 1: Synthesize existing information. The spatial and temporal complexity of nutrients and coastal hypoxia needs to be understood, including the functioning of ecosystems and socioeconomic systems. This understanding could be rapidly advanced with a synthesis of the vast information gathered by experts across all sectors, from published scientific as well as grey literature, and, where possible, from unpublished reports documenting hypoxia responses to remediation efforts.

Effective strategies are needed to improve understanding of observed and expected responses to alternative approaches for remediating hypoxia. The initial effort should be to compile, summarize and synthesize available quantitative information on how hypoxic zones have been reduced by remediation efforts, including decreased inputs of inorganic or organic carbon, nitrogen or phosphorus, restoration of wetland, seagrass beds and benthic bivalve habitats and populations. Furthermore, overall project effectiveness and responses of social, economic, and ecologic components will need to be continually assessed. This information will feed back into models and refine future project efforts. For example, in areas at the sub-LME scale that have experienced a reversal of hypoxic conditions, which factors were responsible? Not only do we need to understand connectivity between land and sea in terms of biological, physical and chemical drivers, we also need to understand the roles of social and economic drivers and how they fit into the larger picture.

This synthesis should commence with a workshop assembling experienced regional scientists to identify where information exists, how to access it and to suggest instruments for action. Components of this knowledge synthesis could include:

- Watershed characteristics (anthropogenic and physical drivers).
- Coastal zone response and stressors that localize specific problems.
- Instruments for reducing nutrients within watershed and coastal zone of LMEs (preferably with associated efficacy assessments).
- Social and economic impacts, barriers, and opportunities scaled to LME or sub-LME levels.
- Instruments for distributing information gathered (e.g. toolkit, knowledge base, reports, visuals, etc.).

Concerned Citizen Association, Banate, Iloilo, Philippines

Need 2: Conduct focused action and research projects at 3-5 locations. These research and action projects would allow GEF to act as a facilitator of "value added", innovative research, including:

- **Establish capacity-building at national levels** to create baselines and monitoring programs for both ecosystems and economic/social systems. Explore the availability of relatively simple, inexpensive, low maintenance instruments for monitoring water quality. Develop a toolkit of metrics for assessing ecological and social conditions.
- **Assess project success/failure within and between LMEs.** Develop adaptive management approaches that are ecosystem-based to facilitate nutrient reduction and ecosystem recovery.
- **Assess the socio-economic costs** of coastal hypoxia in each case.
- **Develop educational material** to show the benefits of nutrient reduction and improved ecosystem services, both in the watershed and in coastal waters. Social sciences need a toolkit to engage managers and the public.
- **Develop linked economic and ecological models.**

Need 3: Identify future hypoxia hotspots using trends and future scenarios. GEF agencies and countries would be encouraged to focus attention on prevention and remediation of projected hotspots of hypoxia. Questions to be addressed are:

- Where will the interactions of climate change, population, and ecosystem health be most severe, and
- What factors will lead to long-term sustainability of ecosystem services? For example, if more than one smaller system within an LME is experiencing similar hypoxic trends over decades, then large-scale forces (e.g., climate, ocean circulation) are probably driving these changes.
- How can ecosystem-based management adapt to processes that are not controllable?

Need 4: Move toward an ecosystem-based management approach. Coastal hypoxia is one major problem for which ecosystem-based management is essential in order to understand the scope of problems at multiple scales from large marine ecosystems (LMEs) to small sub-LME scales. Sub-LME scales are important to economic and ecologic connectivity within LMEs (e.g., fish movement to avoid hypoxia, fishery behavior in response to fish abundance). Most LMEs have several/many areas of hypoxia within their boundaries.

Boats in the Mekong River, Bokeo, Laos

7. Conclusions

Hypoxia is a global problem and is increasing in frequency and extent. Although complex hydrological, oceanographic and climate factors play important roles in causing coastal hypoxia, eutrophication is the most important driving force that can be directly controlled. To manage hypoxia, the causes of eutrophication, namely emissions of nutrients, especially N, P and Si and organic that enter the coasts via rivers and from the atmosphere, must be addressed.

Due to the complex pathways and many sources of nutrients to the coasts, cross-sectoral integrated management in the form of ICM and IWRM is required as a framework to prevent or remediate hypoxia. In each area, nutrient sources and hypoxia need to be mapped, measured and estimated and pathways of cause and effect modeled in order to understand the particular system. Interventions, which will often be at sectoral level, should first be directed towards the most serious sources of nutrient pollution, starting with the largest point sources, e.g., sewage and industrial pollution, but establishing strategies for also reducing diffuse sources such as agriculture and intensive livestock production. In order to develop and implement cost-effective solutions, responsible agencies need to create institutions, develop stakeholder buy-in, estimate costs and benefits, raise public awareness and build capacity for the needed actions. Science has a major role. It must provide know-how for monitoring, remediation, evaluation and dissemination of information on hypoxic zones and nutrient management.

Integrated management activities require policy instruments, dialogue, cooperation and action from a wide range of actors and stakeholders. STAP advisory actions for these key stakeholders are summarized as follows:

- Intergovernmental bodies – must facilitate strategic action, normative instruments and partnership creation at the global level to bring nutrient reduction and hypoxia remediation to the fore of national agendas.
- Governments – should establish, implement and maintain sound scientific monitoring strategies, management strategies and supporting legislative framework.
- Industrial sectors – need to become more engaged as a stakeholder in policy-decision making and management actions.

- Scientific research community – must emphasize sound scientific input, which is crucial in every step of hypoxia management. The scientific and research community must be actively engaged all the way.
- Coastal zone managers, local governments – are central to tailoring hypoxia prevention and remediation to their respective coastal zones and engaging local stakeholders.
- NGOs – should be involved in hypoxia integrated management advocacy and actions at the national and local levels.
- Communities and civil society – play an important role of environmental stewardship and should show a vested interest in the health of their coastal marine and watershed environments.

In terms of GEF priorities and agencies, coastal hypoxia and nutrient reduction is a cross-focal area issue, with International Waters taking a lead but Biodiversity, Climate Change, Land Degradation and SFM GEF-5 program priorities also being implicated. Hypoxia and nutrient reduction are also issues for all GEF agencies, each of which have relevant loan, project, research and normative programs. GEF has already supported a considerably body of nutrient reduction work within the International Waters focal area. GEF's most significant investment in nutrient reduction has been in the Danube River and the Black Sea, where, in the last 15 years, nitrogen emissions have decreased by about 20% and phosphorus by almost 50% and resulted in improved water quality, greater biodiversity and reduced hypoxia.

STAP advises that GEF should continue to spearhead collaboration across agencies but also expand hypoxia and nutrient reduction efforts to span focal areas to include Biodiversity, Land Degradation, Climate Change in addition to International Waters. GEF's agencies must continue to play a crucial role in assisting GEF to build capacity in project countries, both in their role as GEF project Implementation Agencies and, through the aligning of their own hypoxia and nutrient remediation efforts and expertise.

What actions can the GEF take to prevent and remediate coastal hypoxia?

The growing and urgent problem of coastal hypoxia now requires heightened GEF attention in ongoing projects and from GEF agencies, including larger collaboration between coastal and land-based water system projects.

GEF to increase its support to nutrient reduction projects

GEF already has an established record of effective nutrient reduction projects, with development banks and other partnerships. GEF should increase continue its successful work and find ways, especially through co-financing with banks and the private sector, to greatly expand its nutrient reduction work to more areas, linking it to practical targets to protect global environmental benefits. GEF's contribution, in addition to financing, is a wealth of experience of a range of nutrient reduction practices well embedded in integrated management systems.

Establish principles for supporting priority systems in which to test management responses to permanent and seasonal hypoxic systems

In proposing projects that address coastal hypoxia prevention or remediation, GEF agencies should be aware of factors that pre-dispose areas for successful action or that are in need of priority attention, namely:

- Size of system
  - Smaller systems with existing hypoxic conditions are more amenable to hypoxia remediation than larger systems. This includes many shallow water and estuarine systems.
  - Larger systems are more likely to be strongly influenced by global climate and climate change impacts, which may not be "controllable" in the short- to medium term.
- Geographic region
  - The largest increase in the number of hypoxic coastal areas is expected in eastern and southern Asia.

Hypoxia toolkit

The Global Nutrient Management Program, with collaboration from STAP, should develop a "Hypoxia Toolkit" for managers and policy makers, similar in concept to the Persistent Organic Pollutants Toolkit (http://www.popstoolkit.com/) and hosted by the GEF IW:Learn project website. This would make explicit and accessible a large amount of presently scattered information in the scientific, coastal and water basin management and other literature. The Hypoxia Toolkit could become part of a larger toolkit addressing nutrient reduction and disruption of the global nutrient cycles, such as the best management practices tool kit being developed by the GEF Global Nutrient Management Project. An important part of the Hypoxia Toolkit should be a project screening tool to be used when developing and screening new GEF projects. This should also be readily available on the GEF IW:Learn website[13].

Address hypoxia and nutrient reduction in GEF-IW TDA and SAP manuals

The GEF-IW manual for preparation of TDAs and SAPs should include guidance on diagnosis, monitoring, prevention and remediation of coastal hypoxia in LMEs and on nutrient reduction approaches in all transboundary aquatic systems.

All existing LME projects should examine the current knowledge on coastal hypoxia and establish monitoring, prevention and remediation programs if these are not already in train

The increasingly pervasive, though location and situation-specific, nature of coastal hypoxia means that each LME project should address it. At least 6 LMEs are addressing coastal hypoxia thoroughly but not all the others have fully assessed their hypoxia conditions. Ongoing LME projects lacking specific knowledge of details of hypoxic areas should be encouraged to assess and report on current best available knowledge of hypoxia, its causes and likely projection. Those LMEs that have reported hypoxia or in which hypoxia may potentially arise, and for which no current remediation actions are in train, should be encouraged to take steps towards reducing nutrient inputs.

In coastal systems susceptible to hypoxia and considered amenable to prevention or remediation, GEF projects should help strengthen Institutional capacity and integrated management. GEF needs to establish a minimum and cost-effective set of environmental parameters to be measured and monitored in projects. The cost-effectiveness and long term sustainability of GEF investments need alliances with academic institutions working in the field of hypoxia research. GEF should update its existing TDA and SAP procedures to incorporate the ICM framework, and to include guidance on procedures to address coastal hypoxia and nutrient reduction.

Prevention and remediation of hypoxia should be based on realistic expectations for success

Realistic time-frames for remediation due to nutrient and eutrophication reduction may be of the order of 10-30 years, and yet interventions will need to be monitored and maintained.

GEF agencies to develop a hypoxia research proposal

UNEP, which has the greatest baseline capacity in addressing coastal hypoxia and nutrient reduction, should take the lead in developing research activities, some of which could be supported by GEF focal area and focal area set aside funds, to develop a small number of research activities. These activities, such as those described in Section 6 above, would fit clearly with GEF needs to fill critical knowledge gaps and would be incremental to research conducted in universities and national research institutes. Presently, little hypoxia and nutrient reduction research is undertaken in developing countries, with the exception of China, India, South Africa, Mexico and Chile. Research and technical capacity building for scientists in developing countries is urgently needed so that more developing countries, particularly in Asia, can be prepared to research and advise on the condition. The research and capacity development program should closely link to or be embedded in practical hypoxia projects.

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[13] See: http://iwlearn.net/

References

Art, H.W. (1993). Eutrophication, in H.W. Art, ed., A dictionary of ecology and environmental science (1st ed.): New York, New York, Henry Holt and Company, p. 196.

Bakun A., D.B. Field, A. Redondo-Rodriguez and S.J. Weeks. (2010). Greenhouse gas, upwelling-favorable winds, and the future of coastal ocean upwelling ecosystems. *Global Change Biology* 16: 1213-1228.

Behrendt, H., P. Huber, M. Kornmilch, D. Opitz, O. Schmoll, G. Scholz and R. Uebe. (1999). Nährstoffbilanzierung der Flußgebiete Deutschlands. *Umweltbundesamt Text* Nr. 75/1999. URL: http://www.umweltdaten.de/publikationen/fpdf-l/1755.pdf

Breitburg, D.L, D.W. Hondorp, L.A. Davias and R.J. Diaz. (2009). Hypoxia, Nitrogen, and Fisheries: Integrating Effects Across Local and Global Landscapes. *Annual Review of Marine Science* 1:329-349.

Bulow, S.E., J.J. Rich, H.S. Naik, A.K. Pratihary and B.B. Ward. (2010). Denitrification exceeds anammox as a nitrogen loss pathway in the Arabian Sea oxygen minimum zone. *Deep Sea Res Part I* 57:384–393.

Caddy, J.F. (2000). Marine catchment basin effects versus impacts of fisheries on semi-enclosed seas. *ICES Journal of Marine Science* 57: 628-640.

CCICED 2010. Policy Recommendations to the Government of China by the China Council for International Cooperation on Environment and Development (CCICED) Annual General Meeting - November 12th, 2010, Beijing.

CENR. (2000). Integrated assessment of hypoxia in the northern Gulf of Mexico: National Science and Technology Council Committee on Environment and Natural Resources, Washington, D.C. , 58 p. URL: http://oceanservice.noaa.gov/products/pubs_hypox.html

Cloern, J.E. (2001). Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series* 210: 223-253.

Cordell, D., J.-O. Drangert and S. White. (2009). The Story of Phosphorus: Global food security and food for thought. *Global Environmental Change* 19: 292-305.

Conley, D.J., H.W. Paerl, R.W. Howarth, D.F. Boesch, S.P. Seitzinger, K.E. Havens, C. Lancelot and G.E. Likens. (2009). Controlling Eutrophication: Nitrogen and Phosphorus *Science* 323: 1014-1015

Conley, D.J., J. Carstensen, R. Vaquer-Sunyer and C. Duarte. (2009). Ecosystem Thresholds with Hypoxia. *Hydrobiologia* 629: 21-29.

Conley, D.J., S. Björck, E. Bonsdorff, J. Carstensen, G. Destouni, B.G. Gustafsson, S. Hietanen, M. Kortekaas, H. Kuosa, H.E. Markus Meier, B. Müller-Karulis, K. Nordberg, A. Norkko, G. Nürnberg, H. Pitkänen, N.N. Rabalais, R. Rosenberg, O.P. Savchuk, C.P. Slomp, M. Voss, F. Wulff and L. Zillén. (2009). Hypoxia-Related Processes in the Baltic Sea *Environmental Science & Technology* 43(10): 3412-3420.

Conley, D.J., E. Bonsdorff, J. Carstensen, G. Destouni, B.G. Gustafsson, L.-A. Hansson N.N. Rabalais, M. Vioss and L. Zillén. (2009). Tackling Hypoxia in the Baltic Sea: Is Engineering a Solution? *Environmental Science & Technology* 43(10): 3407-3411.

Darby, F.A. and R.E. Turner. (2008). Effects of eutrophication to salt marsh roots, rhizomes, and soils. *Marine Ecology Progress Series* 363: 63-70.

Diaz, R.J. and R. Rosenberg. (1995). Marine benthic hypoxia - review of ecological effects and behavioral responses on macrofauna. *Oceanography and Marine Biology, Annual Review* 33:245-303.

Diaz, R.J. and R. Rosenberg. (2008). Spreading Deadzones and Consequences for Marine Ecosystems. *Science* 321:926-929.

Ekau, W., H. Auel, H.-O. Pörtner and D. Gilbert. (2009). Impacts of hypoxia on the structure and processes in the pelagic community (zooplankton, macro-invertebrates and fish). *Biogeosciences Discuss.*, 6:5073–5144.

FAO/ECE. (1991). Legislation and Measures for the Solving of Environmental Problems Resulting from Agricultural Practices (With Particular Reference to Soil, Air and Water), Their Economic Consequences and Impact on Agrarian Structures and Farm Rationalization. United Nations Economic Commission for Europe (UNECE) and *FAO, Agri/Agrarian Structures and Farm Rationalization Report No. 7.* United Nations, Geneva.

Feely, R.A., C.L. Sabine, J.M. Hernandez-Ayon, D. Ianson and B. Hales. (2008). Evidence for upwelling of corrosive "acidified" water onto the continental shelf. *Science* 320:1490-1492.

Galloway, J.N., J.W. Erisman, A. Townsend, E. Davidson, M. Bekunda, Z. Cai, J.R. Freney, L.A. Martinelli, S.P. Seitzinger and M.A. Sutton. (2007). Human Alteration of the Nitrogen Cycle – Threats, Benefits, and Opportunities. *UNESCO-SCOPE Policy Briefs* No. 4 URL: http://www.gpa.unep.org/documents/human_alteration_of_the_english.pdf

Galloway, J.N., A.R. Townsend, J.W. Erisman, M. Bekunda, Z. Cai, J.R. Freney, L.A. Martinelli, S.P. Seitzinger and M.A. Sutton. (2008). Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions. *Science* 320(5878): 889-892.

GEF-STAP. (2010). Payments for environmental services and the Global Environment Facility. A STAP Advisory Document. 16p.

Gilbert, D., N.N. Rabalais, R.J. Díaz and J. Zhang. (2010). Evidence for greater oxygen decline rates in the coastal ocean than in the open ocean. *Biogeosciences* 7: 2283-2296.

Giller, K.E., P. Chalk, A. Dobermann, L. Hammond, P. Heffer, J.K. Ladha, P. Nyamudeza, L. Maene, H. Ssali, and J.R. Freney. (2004). Emerging technologies to increase the efficiency of use of fertilizer nitrogen. In: A.R. Mosier, J. K. Syers and J.R. Freney (eds), *Agriculture and the Nitrogen Cycle*. Scope 65. Island Press Washington DC pp. 35-51.

Harper, N. (2010). Hypoxia - Technical Support to the Scientific and Technical Advisory Panel of the Global Environment Facility: Annotated Resource Guide. *UNU-INWEH/GEF.* URL: http://hqweb.unep.org/stap/LinkClick.aspx?fileticket=MpOyegpvgwo%3d&tabid=4740&language=en-US

Higgason, K.D. and M. Brown. (2009). Local solutions to manage the effects of global climate change on a marine ecosystem: a process guide for marine resource managers. *ICES Journal of Marine Science* 66: 1640-1646.

ICPDR. (2006). Danube Pollution Reduction Programme. ICPDR. URL: http://www.icpdr.org/icpdr-pages/dprp.htm

ICPDR. (2007). 15 Years of Managing the Danube River Basin 1991-2006. ICPDR. URL: http://www.icpdr.org/icpdr-files/14831

ICPDR. (2009). Danube River Basin District Management Plan. International Commission for the Protection of the Danube River. URL: http://www.icpdr.org/icpdr-files/15091.

IFA. (2007). Sustainable Management of the Nitrogen Cycle in Agriculture and Mitigation of Reactive Nitrogen Side Effects. *International Fertilizer Industry Association.* 1st Edition. URL: http://www.fertilizer.org/ifacontent/download/7076/111716/version/1/file/2007_ifa_reactive+nitrogen.pdf

Ignazi, J.C. (1993). Improving nitrogen management in irrigated, intensely cultivated areas: the approach in France. Prevention of Water Pollution by Agriculture and Related Activities. Proceedings of the FAO Expert Consultation, Santiago, Chile, 20-23 October 1992, FAO, Rome (Italy).

IOC. (2009). Coastal Eutrophication: Linking nutrient sources to coastal ecosystem effects and management: NEWS2USE. IOC/INF 1261. UNESCO.

Jones, P.D. (2006). Water quality and fisheries in the Mersey estuary, England: A historical perspective. *Marine Pollution Bulletin* 53:144-154.

Keeling, R.F., A. Körtzinger, and N. Gruber. (2010). Ocean deoxygenation in a warming world. *Annual Review of Marine Science* 2: 199–229.

Kemp, W.M., J.M. Testa, D.J. Conley, D. Gilbert and J.D. Hagy. (2009). Temporal responses of coastal hypoxia to nutrient loading and physical controls. *Biogeosciences* 6:2985–3008.

Kideys, A.E. (2002). Fall and rise of the Black Sea ecosystem. *Science* 297: 1482-1483.

Levin, L.A., W. Ekau, A.J. Gooday, F. Jorissen, J.J. Middelburg, W. Naqvi, C. Neira, N.N. Rabalais and J. Zhang. (2009). Effects of natural and human-induced hypoxia on coastal benthos. *Biogeosciences Discussions* 6: 3563–3654.

Living Water Exchange. (2010). Danube River Basin: Boosting capacities for nutrient reduction and transboundary co-operation. Living Water Exchange: GEF/UNDP project factsheets URL: http://documents.rec.org/publications/13_DRPclean.pdf

Mayorga, E., S.P. Seitzinger, J.A. Harrison, E. Dumont, A.H.W. Beusen, A.F. Bouwman, B.M. Fekete, C. Kroeze and G. Van Drecht. (2010). Global Nutrient Export from Watersheds 2 (NEWS 2): Model development and implementation. *Environmental Modelling & Software* 25: 837-853.

Mee, L.D. (1992). The Black Sea in crisis: The need for concerted international action. **Ambio** 21(3): 278-286.

Mee, L.D. (2006) Reviving dead zones: Scientific American, v. 295, p. 78–85.

Middelburg, J. J. and L. A. Levin. (2009). Coastal hypoxia and sediment biogeochemistry. *Biogeosciences* 6: 1273–1293

Mississippi River Basin Watershed Nutrient Task Force. (2010). Hypoxia 101: U.S. Environmental Protection Agency. URL: http://water.epa.gov/type/watersheds/named/msbasin/hypoxia101.cfm

Mueller, D.K., and D.R. Helsel. (1996). Nutrients in the Nation’s waters--Too much of a good thing? U.S. Geological Survey Circular 1136, 24 p. (http://pubs.usgs.gov/circ/circ1136/)

Müller-Karulis, B. (2010). Modelling carbon and nutrient fluxes in Baltic Sea subsystems. Doctoral thesis, Latvia University. URL: http://www.lu.lv/fileadmin/user_upload/lu_portal/zinas/Millere_Karulis_2010.pdf

Naqvi, S.W.A., H.W. Bange, L. Farias, P.M.S. Monteiro, M.I. Scranton and J. Zhang. (2009). Coastal hypoxia/anoxia as a source of CH_4 and N_2O. *Biogeosciences Discussions* 6: 9455–9523.

National Academy of Sciences. (1969). Introduction, Summary, and Recommendations, in Eutrophication--causes, consequences, correctives: Washington, D.C., National Academy of Sciences, p. 3-4.

Nixon, S.W. (1995). Coastal marine eutrophication: a definition, social causes and future concerns. Ophelia 41:199–219

NOAA. 2009. Large Marine Ecosystems of the World. URL: www.lme.noaa.gov

Oguz, T. (2005). Long term impacts of anthropogenic and human forcing on the reorganisation of the Black Sea ecosystem. *Oceanography* 18(2): 112-121.

Paulmier, A. and D. Ruiz-Pino. (2009). Oxygen minimum zones (OMZs) in the modern ocean. *Progress in Oceanography* 80: 113–128.

Paulmier, A., D. Ruiz-Pino, and V. Garçon. (2008) The Oxygen Minimum Zone (OMZ) off Chile as intense sources of CO_2 and N_2O. Continental Shelf Research, Vol. 28, N°20, 2746-2756, doi:10.1016/j.csr.2008.09.012

PEMSEA. (2003). Sustainable Development Strategy for the Seas of East Asia. Partnerships in Environmental Management for the Seas of East Asia. URL: http://www.pemsea.org/pdf-documents/sds-sea/SDSSEA-Full.pdf

PEMSEA. (2006). Policy Brief: Sustainable Development and Management of Manila Bay: A Focus on Water Quality. URL: http://iwlearn.net/publications/misc/presentation/sustainable-development-and-management-of-manila-bay-a-focus-on-water-quality

PEMSEA. (2011). Guidebook on the State of the Coasts (Draft). Partnerships in Environmental Management for the Seas of East Asia (PEMSEA), Quezon City, Philippines. 81p.

Prince, E.D. and C.P. Goodyear. (2006). Hypoxia-based habitat compression of tropical pelagic fishes. *Fisheries Oceanography* 15: 451–464.

Rabalais, N.N., R.J. Diaz, L.A. Levin, R.E. Turner, D. Gilbert and J. Zhang. (2010). Dynamics and distribution of natural and human-caused hypoxia. *Biogeosciences* 7:585–619.

Redfield A.C. (1934). On the proportions of organic derivations in sea water and their relation to the composition of plankton. In James Johnstone Memorial Volume. (ed. R.J. Daniel). University Press of Liverpool, pp. 177-192.

Riebesell, U., K.G. Schulz, R.G.J. Bellerby, M. Botros, P. Fritsche, M. Meyerhöfer, C. Neill, G. Nondal, A. Oschlies, J. Wohlers and E. Zöllner. (2007). Enhanced biological carbon consumption in a high CO_2 ocean. *Nature* 450:545-548.

Seitzinger, S.P., C. Kroeze, A.F. Bouwman, N. Caraco, F. Dentener and R.V. Styles. (2002). Global patterns of dissolved inorganic and particulate nitrogen inputs to coastal systems: Recent conditions and future projections. *Estuaries* 25(4b):640-655.

Seitzinger, S.P., E. Mayorga, A.F. Bouwman, C. Kroeze, A.H.W. Beusen, G. Billen, G. Van Drecht, E. Dumont, B.M. Fekete, J. Garnier and J.A. Harrison. (2010). Global river nutrient export: A scenario analysis of past and future trends. *Global Biogeochemical Cycles* 24: GB0A08, doi:10.1029/2009GB003587

Selman, M., S. Greenhalgh, R. Diaz, and Z. Sugg. (2008). Eutrophication and Hypoxia in Coastal Areas: A Global Assessment of the State of Knowledge. WRI Policy Note No.1 - Water Quality: Eutrophication and Hypoxia

Sherman, K. and G. Hempel (eds.) (2008). The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's regional seas. *UNEP Regional Seas Report and Studies* 182.

Smith, R.A., R.B. Alexander and M.G. Wolman. (1987). Water-quality trends in the nation's rivers. Science 235: 1507-1516.

Soussan, J. (2008). Making Mainstreaming Work – An Analytical Framework, Guidelines and Checklist for the Mainstreaming of Marine and Coastal Issues into National Planning and Budgetary Processes. GPA-UNEP. URL: http://www.environmental-mainstreaming.org/documents/SEI%20-%20mainstreaming%20coastal%20&%20marine.pdf

Stramma, L., S. Schmidtko, L.A. Levin and G.C. Johnson. (2010). Ocean oxygen minima expansions and their biological impacts. *Deep Sea Research Part I: Oceanographic Research Papers* 57 (4) 587-595.

Tilman, D., J. Fargione, B. Wolff, C. D'Antonio, A. Dobson, R. Howarth, D. Schindler, W.H. Schlesinger, D. Simberloff and D. Swackhamer. (2001). Forecasting agriculturally driven global environmental change. *Science* 292(5515): 281-284.

Turner, R.E. and N.N. Rabalais. (2003). Linking landscape and water quality in the Mississippi River Basin for 200 years. *BioScience* 53(6):563-572.

UNEP/WHO/HABITAT/WSSCC. (2004). Guidelines on Municipal Wastewater Management. UNEP/GPA Coordination Office, The Hague, The Netherlands. URL: http://esa.un.org/iys/docs/san_lib_docs/guidelines_on_municipal_wastewater_english.pdf

UNEP. (2007). Reactive Nitrogen in the Environment – Too much or too little of a good thing? URL: http://www.unep.org/pdf/dtie/Reactive_Nitrogen.pdf

UNEP. (2010). Building the foundations for sustainable nutrient management. A publication of the Global Partnership on Nutrient Management. URL: http://www.unep.org/pdf/Building_the_foundations.pdf

UNU-INWEH. (2010). Enhancing the Use of Science in International Waters Projects to Improve Project Results. The IW:Science Project. URL: http://www.inweh.unu.edu/River/IWScience.htm

U.S. Environmental Protection Agency. (2010). Glossary of technical terms. URL: http://www.epa.gov/oust/cat/TUMGLOSS.HTM

U.S. Geological Survey. (2011). Toxic Substances Hydrology Program. URL: http://toxics.usgs.gov/

Utne-Palm, A.C., A.G.V. Salvanes, B. Currie, S. Kaartvedt, G.E. Nilsson, V.A. Braithwaite, J.A.W. Stecyk, M. Hundt, M. van der Bank, B. Flynn, G.K. Sandvik, T.A. Klevjer, A.K. Sweetman, V. Brüchert, K. Pittman, K.R. Peard, I.G. Lunde, R.A.U. Strandabø and M.J. Gibbons. (2010). Trophic structure and community stability in an overfished ecosystem. *Science* 329(5989): 333-336.

Uychiaoco, A. et al. (2009). Xiamen's Transition to Orderly Seas. *PEMSEA/UNOPS/UNDP/GEF Case Study:* 1(2): 1-8.

Vaquer-Sunyer, R. and C.M. Duarte. (2008). Thresholds of hypoxia for marine biodiversity. *The National Academy of Sciences of the USA* 105(40): 15452–15457

Walker, J.T., C.A. Stow and C. Geron. (2010). Nitrous oxide emissions from the Gulf of Mexico hypoxic zone. *Environmental Science & Technology* 44: 1617-1623.

Wu, R. (2010). Hypoxia: New insights on an old pressing environmental problem. *GESAMP Scoping Paper* 37(7):1.

Zhang, J., D. Gilbert, A.J. Gooday, L. Levin, S.W.A. Naqvi, J.J. Middelburg, M. Scranton, W. Ekau, A. Peña, B. Dewitte, T. Oguz, P. M. S. Monteiro, E. Urban, N.N. Rabalais, V. Ittekkot, W.M. Kemp, O. Ulloa, R. Elmgren, E. Escobar-Briones, and A.K. Van der Plas (2010). Natural and human-induced hypoxia and consequences for coastal areas: synthesis and future development, *Biogeosciences*, 7, 1443-1467, doi:10.5194/bg-7-1443-2010.

Annexes

Annex I. Resource Guide

Governance and Policy

GPA: Reactive Nitrogen in the Environment – Too much or too little of a good thing? http://www.gpa.unep.org/documents/non-technical_review_on_reactive_english.pdf

Adaptive Management/Other Integrated Management Frameworks

State of the Coasts (SOC) Guide and Checklist - Guidebook on the State of the Coasts (Draft). Partnerships in Environmental Management for the Seas of East Asia (PEMSEA, 2011), Quezon City, Philippines. 81p.

Policy Brief: Achieving Sustainable Development Targets in a Changing Climate: How can ICM help? http://pemsea.org/eascongress/section-support-files/policy_brief.pdf

Guidelines and Intervention Tools

Intergovernmental Oceanographic Commission (of UNESCO): Coastal Eutrophication: Linking Nutrient Sources to Coastal Ecosystem Effects and Management (NEWS2USE) http://unesdoc.unesco.org/images/0018/001828/182875e.pdf

Guidelines on municipal wastewater treatment http://www.gpa.unep.org/index.php?option=com_docman&task=doc_download&gid=8&Itemid=81

Key Principles for Aquaculture- http://www.gpa.unep.org/index.php?option=com_docman&task=doc_download&gid=12&Itemid=81

Sustainable Management of the Nitrogen Cycle in Agriculture and Mitigation of Reactive Nitrogen Side Effects -International Fertilizer Industry Association http://www.gpa.unep.org/index.php?option=com_docman&task=doc_download&gid=11&Itemid=81

World Resources Institute's NutrientNet – online market tool for nutrient trading http://www.nutrientnet.org/index.cfm

Regulatory Instruments

FAO Code of Conduct for Responsible Fisheries - http://www.fao.org/docrep/005/v9878e/v9878e00.HTM

Canadian nutrient management regulation law - http://faolex.fao.org/docs/pdf/mn86626.pdf

Nanjing Declaration on Nitrogen Management http://www.initrogen.org/fileadmin/user_upload/nanjing/nanjing_declaration-041016.pdf

United Nations Convention on the Law of the Sea (UNCLOS) http://www.un.org/Depts/los/index.htm

Science Advice

Mitigation of Dead Zones (Virginia Institute of Marine Science) http://www.vims.edu/research/topics/dead_zones/mitigation/index.php

IOC-UNESCO GlobalNEWS Publications http://www.ioc-unesco.org/icr/index.php?option=com_content&view=article&id=48&Itemid=100007

Capacity Development

Making Mainstreaming Work – An Analytical Framework, Guidelines and Checklist for the Mainstreaming of Marine and Coastal Issues into National Planning and Budgetary Processes - http://www.gpa.unep.org/index.php?option=com_docman&task=doc_download&gid=16&Itemid=81

Human Alteration of the Nitrogen Cycle – Threats, Benefits and Opportunities - http://unesdoc.unesco.org/images/0015/001509/150916e.pdf

Nutrient and wastewater management – new initiatives of UN Water - http://www.gpa.unep.org/index.php?option=com_docman&task=doc_download&gid=13&Itemid=81

Databases

(Accessed on April 24, 2011)

FAO Stat - http://faostat.fao.org/default.aspx

Aquastat - http://www.fao.org/nr/water/aquastat/dbase/index.stm

Fertibase on nutrient response - http://www.fao.org/ag/agl/agll/nrdb/

FAO Land Resources - http://www.fao.org/nr/land/en/

IPNS Glossary on integrated nutrient management - http://www.fao.org/ag/agp/ipns/index_en.jsp

FAO Geo-network - http://www.fao.org/geonetwork/srv/en/main.home

FAO/AGL – documents on soil fertility and plant nutrition -http://www.fao.org/ag/agl/agll/oldocsp.jsp

- Plant nutrition for food security-A guide for integrated nutrient management
- Guidelines for Participatory Diagnosis of Constraints and Opportunities for Soil and Plant Nutrient Management
- Guide to efficient plant nutrition management
- Global estimates of gaseous emissions of NH3, NO and N2O from agricultural land
- Current World Fertilizer Trends and Outlook to 2010/11
- Fertilizer requirements in 2015 and 2030 revisited

AGP – Fertilizer and Plant Nutrition Bulletins - http://www.fao.org/agriculture/crops/publications/fertilizer-and-plant-nutrition-bulletins/en/

Fertilizers as water pollutants - http://www.fao.org/docrep/W2598E/w2598e06.htm#TopOfPage

Chesapeake Bay Database – Publications, progress reports, management tools related to nutrient reduction http://www.chesapeakebay.net/publications.aspx?menuitem=15219

Case Studies

Philippines

Policy Brief: Sustainable Development and Management of Manila Bay: A Focus on Water Quality -

http://iwlearn.net/publications/misc/presentation/sustainable-development-and-management-of-manila-bay-a-focus-on-water-quality

Manila Bay Refined Risk Assessment - http://www.emb.gov.ph/mbemp/dloads/MB%20RRA.pdf

Example of a completed State of the Coasts Report (Batangas, Philippines) - http://pemsea.org/pdf-documents/publications/soc_batangas.pdf

Baltic Sea

HYPER – Hypoxia mitigation for Baltic Sea Ecosystem Restoration - http://hyper.dmu.dk/ProjectDescription/

China, Xiamen

Case Study: Environmental Rehabilitation in a Rapidly Developing Urban Area - http://beta.pemsea.org/sites/default/files/casestudy-v1n4-xiamen.pdf
Case Study: Xiamen's Transition to Orderly Seas - http://beta.pemsea.org/sites/default/files/casestudy-v1n2-xiamen.pdf

United States of America, Chesapeake Bay

Case Study: Restoring water quality in the Chesapeake Bay. http://www.chesapeakebay.net/restoringwaterquality.aspx?menuitem=14728

Annex II. Advice for key stakeholder types

1. Intergovernmental bodies

Strategic action at the intergovernmental level can facilitate a top-down drive to bring nutrient reduction and hypoxia management issues to the fore on national agendas as well as raise the visibility of the issues in stakeholders' priorities. Partnerships at the global level can also help countries access capacity and capacity building to overcome the initial barriers of addressing the interconnected issues associated with hypoxia. Additionally, intergovernmental partnerships are key catalysts in helping countries address transboundary water management issues, including hypoxia.

Prevention

- **Support partner governments** to develop *national strategies, standards, guidelines, directives and best management practices for nutrient reduction.*
- **Drive essential innovation** by mainstreaming *cutting-edge research* and updating governments, agencies and other partner stakeholders with the latest scientific findings on hypoxia and nutrient reduction.
- **Provide funding** for projects that utilize and implement *"preventative" BMPs* such as wetland conservation/construction or the installation of riparian buffer systems.
- **Support the establishment** of *community education and outreach programmes*, tailored to stakeholder and regional needs.
- **Dispense small grants** to generate *good governance and policy reform.*
- **Support and promote** *targeted research* that could lay the groundwork for a global hypoxia community of practice and monitoring network.

Remediation

- **Support the mainstreaming** of in-country *protection and conservation efforts.*
- **Promote** the transfer of *Environmentally Sound Technologies (ESTs).*
- **Frame key messages positively**, i.e. a net-benefits approach that fosters stakeholder engagement and individual buy-in (e.g. facilitating support from agribusiness). Positive framing is doubly important when considering the significant amount of lag-time some systems might see before observable results are achieved.
- **Ensure stakeholder understanding** of *timelines* involved, i.e. recognition that hypoxia remediation may not be measurable until 10-30 years after implementation of best practices and advisory measures.
- **Perform cost-benefit analyses** that favour long-term, site-specific and cost-effective projects. For instance, wetland restoration is initially costlier than fertilizer reduction, but can be more effective over the long term.
- **Provide support for innovative financing instruments** *with enhanced education & stakeholder engagement* (e.g. community consultations, surveys and focus groups).
- **Close funding gap** during development and scale-up of nutrient reduction BMPs by leveraging federal programs, corporate funding/partnerships, venture capital and angel investors.
- **Develop tools and indicators** to measure national capacity for development and implementation of improved nutrient management practices and to identify needs and gaps.

Integrated Management

- **Promote seamless and connected institutional/inter-agency action.** Given the complexity and range of connections needed to act on coastal hypoxia through nutrient reduction, many United Nations agencies, programs and conventions are key targets in the interest of cross-agency action under the United Nations 'Delivering as One' initiative. For instance, the aims of the Convention on Biological Diversity (CBD) are also compromised by coastal hypoxia since marine ecosystems, protected areas and genetic resources are jeopardized.
- **Promote knowledge sharing** to optimize the use of financial, human and information resources. GEF projects relating to hypoxia should continue to engage in knowledge translation, synthesis and exchange (KTSE) activities to enhance capacity building across relevant sectors. This should include the continued utilization of online platforms and other mechanisms for sharing information on policies, legislation, research and best practices such as IW:Science and IW:Learn.
- **Strengthen institutional capacity** in the public and private sector, especially in developing countries, by co-financing nutrient reduction technology development in partnership with national, regional and local governments.

2. Countries

National and sub-national (local) action is central to hypoxia prevention and remediation. Also, countries will need to cooperate at regional and inter-regional levels to help achieve a more integrated, coordinated effort.

Prevention

- **Establish and legislate** scale-appropriate, site-specific programmes for nutrient reduction, including loading targets, standards, incentives and bans.
- In partnership with the private sector, **drive the development of essential innovation** by investing in appropriate technologies and policy programmes that *minimize runoff and nutrient loading*, especially through industrial retrofitting.
- Participate in the development and dissemination of **hypoxia awareness programs** for various stakeholder groups and for the general public.
- **Legislate** the conservation and preservation of riparian buffers and particularly vulnerable coastal/marine areas.

Diagnosis

- **Invest** in *sustained monitoring programmes* at all scales (spatial, temporal, social, economic and biochemical) that are regionally co-ordinated.
- Establish strategies to **systematically assess the extent, duration, frequency and intensity of hypoxia in coastal waters.**

Remediation

- **Provide a policy and implementation framework for nutrient management plans** at the appropriate scale that identify where and how reductions should take place, as well as the intensity, timeframe and resources required.
- **Co-finance** remediation projects and support **long-term funding** of successful projects.
- **Co-ordinate sectoral planning** and ensure that all stakeholders have a voice.

Integrated Management

- **Establish and empower competent authorities** to promote, support and regulate *responsible nutrient management.*
- **Enact proactive land management strategies** that integrate *nutrient management BMPs.*
- Policies should authorize and **enable strong collaboration** among government, industry and local communities.
- **Establish formal mechanisms** for *meaningful and active participation* of interested parties and potential stakeholders.

3. Coastal zone managers and local government

Coastal zone managers are uniquely placed to bring elements and actors together in a manner that best suits the specific problems affecting their respective coastal zones and engages their surrounding communities. Of the stakeholder groups listed so far, coastal managers are perhaps best suited to developing case-specific, scale-appropriate and multi-sectoral approaches and to ensure that local government units collaborate with each other.

Prevention

- **Develop a priori coastal zone management plans** including considerations for hypoxia.
- **Coordinate and facilitate** multi-stakeholder dialogue in the form of community consultations.
- **Foster private sector engagement** to encourage involvement in policy development, regulatory framework planning and management actions such as capacity building around nutrient reduction.
- **Invest in innovative technology** for nutrient reduction across scales and sectors.

Diagnosis

- **Facilitate sustained monitoring** so that potential sites can be flagged immediately and accurate, site-specific indicators can be developed.
- **Incorporate a variety of surrogate indicators** (social, economic/financial, health, environmental, etc.) to monitor progress, in addition to potentially expensive and difficult to obtain biogeochemical indicators.
- **Utilize scientific information to refine management strategies** to protect coastal economies.
- **Disseminate regular updates** on hypoxic status in the form of newsletters or report cards.

Remediation

- **Plan remedial action** that is timely and holistic and embedded in the larger context of social development, economics, human health and environmental sustainability.
- **Use monitoring and modeling results** to verify progress in achieving management goals.

Integrated Management

- **Situate overall management for hypoxia remediation within broader integrated management frameworks** such as integrated coastal management (ICM), to ensure linkages between LMEs and river basins, and across local governmental units.
- **Implement specific actions sectorally** and at the appropriate scale (e.g. national, regional, municipal, local, project-level).
- **Engage with "remote" actors** such as farmers to generate buy-in.
- **Frame messages positively** and **use common threads to foster contact resolution and cohesion** among groups with opposing interests e.g. effective nutrient reduction will not only lessen the occurrence and severity of hypoxia, but will mitigate other impacts such as algal blooms, which are harmful to organisms and pose a threat to human health.

4. Industry and the private sector

Although the contribution level of each will vary significantly by region and by sector, industrial actors must be engaged in policy decision-making and action. This can be accomplished by involving representatives of these sectors in stakeholder meetings, educational programmes and training sessions. Their role must be participatory so that sectors responsible for the largest point-source emissions (e.g. intensive agriculture, fertilizer industry) can be part of the solution rather than the problem.

Prevention/remediation

- Recognize impacts of own nutrient pollution and accept **shared responsibility.**
- **Adjust industry practices** accordingly to reduce and/or treat emissions.
- Focus on **centralized solutions** for wastewater.
- **Contribute meaningful data** from point and diffuse pollution sources.

Integrated Management

- **Strike a balance** between economic development, growth and pollution reduction.
- **Participate** in stakeholder meetings.
- **Facilitate educational programmes and training sessions** especially for clientele.

5. Scientific researchers

From problem diagnosis to remediation, the scientific and research community can contribute to almost every aspect of hypoxia management. The community of practice includes academics, government scientists and task forces, private sector researchers, international experts and working groups.

Prevention

- Continue to **develop and test new predictive tools** that integrate complex science and indicators.
- **Improve understanding of the role of climate change** in hypoxic sites.
- **Monitor oxygen levels in coastal zones more systematically** using innovative technologies and observing systems – this is crucial for forecast model development, indicator development, fisheries management, and determining the success of nutrient reduction strategies.
- **Extend stream and river monitoring and modeling** to document sources of nutrients, thus enhancing prediction of potential hypoxic zones (using NEWS2USE, MONERIS).
- **Develop hypoxia prevention training programmes** for capacity building and professional development of both of the current and next generations.

Diagnosis

- **Provide science-based evidence for decision makers** in easily digestible formats and supported by rigorous research, monitoring and modeling and descriptive of the extent of hypoxia, what causes it, and how it impacts coastal ecosystems.
- **Improve holistic ecosystem models** to assess how hypoxia affects commercially important fish populations in order to refine and contribute to management strategies that protect coastal economies.

Remediation

- **Estimate/project response times** for changes in nutrient yields.
- **Improve planning and management of technological interventions during project design, construction and operation** phases to significantly increase environmental performance and to achieve a balance between output and environmental integrity (e.g. decreased nutrient loading).

Integrated Management

- Support the **evaluation of alternative management options** using data and models.
- **Identify and fill research gaps** required for integrated, sciences-based decisions.
- **Translate research results** to inform appropriate legal and administrative policy responses.
- **Use Targeted Research modality** to access resources and build networks around typically "risky" research that is difficult to get funding for, such as studying hypoxia and climate change.
- **Support** research, training and institutional capacity development initiatives in developing countries.
- Actively broaden the research agenda beyond biophysical sciences to **involve social/economic sciences** in order to facilitate discussion of management responses as well as the implementation of behavioural/cultural changes needed to bring about nutrient reduction in hypoxic or hypoxia-prone coastal zones. Although marine scientists play a key role in helping stakeholders decide on the best course of action based on the nature of the hypoxia itself, social scientists can play a crucial part in transforming those options and plans into concrete action.

6. Non Government Organizations

Few environmental and social welfare non government organizations (NGO) give priority to such "brown" issues as coastal hypoxia and nutrient reduction. However, their skills and capacities could be very effective in addressing these problems. NGOs have strengths in raising awareness of and seeking practical solutions to problems, addressing local socio-economic objectives. Place-based actions such as reducing land-based nutrient pollution and restoring coastal wetlands and shell beds are relevant. Smaller, local NGOs are well placed to address hypoxia, and regional groups such as the Chesapeake Bay Foundation are especially attuned to nutrient reduction with a watershed approach.

Prevention

- **Incorporate issue of hypoxia into advocacy activities** through messaging appropriate to the individual, e.g. conservation, health, recovering costs, etc.
- **Promote dialogue and awareness** in the public sphere using extended networks and resources.

Remediation

- Where appropriate, **incorporate conservation approaches suitable to transboundary hypoxia** in addition to strategies for localized hypoxic zones.
- **Engage with coastal zone users** to promote their awareness of and encourage their involvement in solutions.

Integrated Management

- **Devote resources to assisting nutrient reduction programs in developing countries** with limited access to data and tools.
- Use networks to connect groups with public and form **functional communities of practice.**
- **Utilize influence** where appropriate to make the case that land-based sources of pollution are significant.
- Use connections and networks to **advocate for integrated management programs linking land and sea.**

7. Communities and civil society

In addition to "engaged" citizens who tend to be involved in NGO and advocacy, there is a significant role for all individual living beside and upstream of hypoxic zones. Environmental stewardship is everyone's responsibility and not just that of industry, governments and NGOs.

Prevention

- Be informed and promote education and awareness.
- Adjust individual behaviours that could increase nutrient loading (e.g. choosing to consume phosphate-free products and sustainably-grown food).

Diagnosis

- Alert local authorities/coastal zone management to visible indicators of hypoxia (i.e. fish kills, HABs).

Remediation

- Participate in local community clean-up efforts.
- Lobby government to address the issue by adopting best practices; request individual politicians' support.
- Get involved with local environmental NGOs or task forces and raise the hypoxia issue.

Integrated Management

- Participate in stakeholder consultation meetings.

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