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79

Filling Gaps in Large Marine Ecosystems (LME) Nitrogen Loadings Forecast for 64 LMEs

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Filling Gaps in Large Marine Ecosystems (LME) Nitrogen Loadings Forecast for 64 LMEs

GEF/LME global project Promoting Ecosystem-based Approaches to Fisheries Conservation and Large Marine Ecosystems

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Abstract

Participants from 7 LMEs attended two workshops (23-25 January 2006 and 18-20 September 2006), held at UNESCO-IOC in order to receive training on the use of GIS-based models relating land use and human activities in watersheds to nutrient transport by rivers to coastal systems. Moreover, participants conducted further analyses using the software and model interface given to them during the workshop, developed science-based summary documents for their home region, provided their LME director with the model findings, as well as gave presentations to their regional government officials and at scientific meetings. This project specifically used an innovative Nutrient Export from Watersheds Model (NEWS N-Export model) to predict dissolved inorganic nitrogen (DIN) export by rivers to the coast as a function of watershed N inputs (point and diffuse sources), hydrology, and other factors. Developed by *Dumont et al.,* [2005], NEWS-DIN has been extended to allow its application to LMEs. The model was used to examine DIN export into seven LMEs: Baltic Sea, Bay of Bengal, Benguela Current, Guinea Current, Gulf of Mexico, Humboldt Current and Yellow Sea and also from a global perspective. This Technical Report outlines the results of these two workshops, and gives a comprehensive summary of the Large Marine Ecosystem Approach developed by Kenneth Sherman.

Acknowledgments

We thank all the members of the Global Nutrient Export from WaterSheds (Global NEWS) workgroup for their efforts in developing and implementing the NEWS model system. We also gratefully acknowledge the support and assistance of UNESCO-IOC in conducting the workshops supported by the GEF MSP described in this document.

Supporting Organizations

Global NEWS
Global Nutrient Export from Water(S)heds

Global Environment Facility

UNEP

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

Foreword

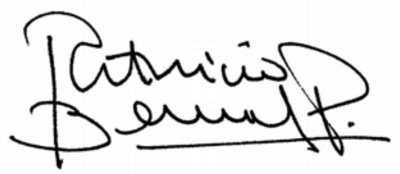
Estimating nutrient export to the coastal zone has been a challenge, but enormous advances have been made with respect to global models over the past several years. The first global model of nitrogen loading to coastal systems was published less than 10 years ago (Seitzinger and Kroeze 1998). The IOC Global Nutrient Export from WaterSheds Program (NEWS) has now developed models of nutrient export for dissolved inorganic, organic and particulate nitrogen, phosphorus and carbon, as well as for dissolved silica. These models account for nutrient sources (natural as well as anthropogenic, including fertilizer, atmospheric deposition, crops, manure and sewage), hydrology, land use, and physical factors in watersheds.

The current known and potential future impacts of increased nutrient mobilization on human and ecosystem health and environmental quality warranted further development of spatially explicit global models to forecast (and hindcast) the export of N, P and Si to coastal ecosystems as a function of land-use, human activities and natural processes in watersheds. The Intergovernmental Oceanographic Commission of UNESCO has contributed to bring together experts in a number of fields to develop the next generation of spatially explicit, global nutrient models. Through the combined efforts of these individuals we hope to have made significant new advances in understanding the relationship between human activities and natural processes on land and nutrient inputs to coastal systems.

This report is an incremental step towards the development of quantitative indicators at the ecosystem level, by providing new definitions of reference points aimed at building a bridge between scientific results, societal needs, and an effective Ecosystem Approach to management.

We ambition this to be used as a reference by managers and researchers, in support of sustainable, science-based, sound ocean and coastal development as requested by the WSSD Implementation Plan.

As Executive Secretary of the Intergovernmental Oceanographic Commission I would like to dedicate this publication to the memory of Dr.Ümit Ünlüata, former Head of the Ocean Sciences Section of our Commission, for the guidance and leadership he provided throughout this study.



Patricio A. Bernal
Assistant Director-General, UNESCO
Executive Secretary, IOC

Introduction

The present UNESCO-IOC Technical Report, presents the outcomes from the activities related to the 3rd component "Filling gaps in LME Nitrogen loadings forecast for 64 LMEs", of the GEF/LME global project: Promoting Ecosystem-based Approaches to Fisheries Conservation and Large Marine Ecosystems.

Since 1995, the Global Environment Facility (GEF) has provided substantial funding to support country-driven projects for introducing multisectoral ecosystem-based assessment and management practices for Large Marine Ecosystems (LMEs) located around the margins of the oceans. Globally, GEF/LME projects support capacity building in developing countries and countries with economies in transition through the transfer of advanced methods, practices and tools for coastal management. At present 110 developing countries are engaged in the preparation and implementation of GEF/LME projects, totalling over a billion dollars in start-up funding.

The GEF/LME projects presently funded or in the pipeline for funding in Africa, Asia, Latin America and Eastern Europe represent a growing network of marine scientists, marine managers, and ministerial leaders who are pursuing ecosystem and fishery recovery goals. In addition to rebuilding depleted fish stocks and restoring degraded coastal habitats, LME projects are also concerned with mitigating effects of nitrogen loadings.

Globally, human activities related to food and energy production have greatly increased the amount of nutrient pollution entering the coastal environment from land-based sources. Humans have more than doubled the rate by which nitrogen (N) becomes available for use by organisms on land. This global change results from increases in land-based activities associated primarily with the production of food and energy to support over 6 billion person global population. Nitrogen inputs associated with these activities include for example fertilizer production, fossil-fuel combustion, and cultivation of N_2-fixing crops. A substantial portion of the excess nitrogen applied or deposited in terrestrial ecosystems enters rivers and is transported to downstream coastal ecosystems where it contributes to a host of environmental problems including degradation of fisheries habitats, increased algal growth, alteration and loss of seagrass habitats, increase in extent and duration of anoxic and hypoxic water, eutrophication, harmful algal blooms -some of which are harmful to fish and other marine life-, deterioration in water quality, reduction in the fisheries potential of coastal waters, reduction in tourism potentials and health problems among the human populations, and other effects.

Over the next 50 years, human population, agricultural production, and industrialization are predicted to increase especially rapidly in many developing regions of the world, leading to increased nutrient (nitrogen and phosphorus) inputs to the coastal zone. In view of current global trends, and in order to optimize use of land for food and energy production while at the same time conserving coastal habitats, it is important to understand the links between land-based activities and nutrient inputs to coastal systems. In addition, it has become necessary to provide information on possible future scenarios with regard to nutrient pollution, in order to formulate and adopt appropriate response strategies. Rivers are the major pathway by which nutrients are transported from watersheds to coastal systems. There is therefore an urgent need for intervention to address this development. GIS-based river nutrient export models provide a tool to elucidate and manage these links.

In this regard, two workshops on nutrient modelling were organized by the Global Environment Facility in collaboration with IOC/UNESCO under Component Three of this global GEF/LMEs project. Individuals from seven LME regions participated over a two-year period in two workshops held at UNESCO-IOC, to receive training on the use of GIS-based models relating land use and human activities in watersheds to nutrient transport by rivers to coastal systems.

The first workshop was held from 23 to 26 January 2006 and the second workshop was held from 18 to 20 September 2006. Scientists from developing countries and countries with economies in transition were trained through the IOC Eutrophication Network in the methods and application of a nitrogen-based model used to forecast eutrophication conditions in coastal waters of selected LMEs.

Specifically this project used a new and innovative Nutrient Export from Watersheds Model (NEWS Model) that predicts inorganic N export by rivers to the coast as a function of watershed N inputs (point and diffuse sources), hydrology, and other factors. The aim of the Workshops was to apply a state-of-the-art GIS model, Nutrients Export from Watersheds (NEWS), developed by *Dumont et al.* [2005] to selected large marine ecosystems. The workshop emphasized Dissolved Inorganic Nitrogen (DIN) because it is the most readily bio-available form of N, and in many human-impacted regions constitutes the majority of N inputs.

The NEWS-DIN model, which is one of the Global NEWS[1] nutrient export models, was used during the workshops to estimate global DIN export for the 1990's (current conditions) and 2030 (future conditions) in a spatially explicit manner, and to indicate dominant sources and sinks of DIN export for each LME. The NEWS-DIN model is a tool that provides understanding of the current and future rates of nutrient (DIN) inputs to coastal waters as well as the nutrient sources. This will provide governments and institutions with information that is necessary in order to reduce the environmental impacts resulting from nutrient over-enrichment by putting in place policies to reduce and control nutrient (DIN) inputs to water systems.

Participants learned to use the river nutrient export model under current and future conditions and applied it to their particular LME region, and met and exchanged information with other workshop participants. In addition to attending the workshops, participants conducted further analyses using the software and model interface given to them during the workshop, developed science-based summary documents for their home region, provided their LME Director with the model findings, as well as gave presentations to their regional government officials and at scientific meetings. Furthermore, mechanisms were established for long-term communication with the participants through electronic communication of an IOC-UNESCO IT Eutrophication Network of participating scientists, which continue to communicate and involve the participants in eutrophication-related activities.

The present UNESCO-IOC Technical Report is divided into eight chapters. The first chapter starts with a brief introduction to the LME concept based on the scientific articles and publications from *Kenneth Sherman et al*. The second chapter develops the nutrient loading and eutrophication problem through a watershed perspective. The third chapter presents a detailed description of the Global NEWS-DIN model based on the scientific document developed by *Dumont et al.,* [2005].

The workshops goals, including the list of participants, are presented in chapter four of this report. The fifth chapter presents the results of the nutrient DIN loads and the source apportionment in the seven LMEs represented at the workshop (Bay of Bengal, Baltic Sea, Yellow Sea, Benguela Current, Guinea Current, Humboldt Current, and Gulf of Mexico LME's). Chapter six analyzes in more detail two example cases; Baltic Sea and Yellow Sea LMEs, respectively. Chapter seven illustrates the follow up activities of the workshop participants enabled by the training workshops. In chapter eight the nutrient DIN loads and source apportionments in the 64 LMEs are studied on a global perspective. To finalize, the document ends with the final conclusion, which attempts to illustrate the response of the GEF/LME project to societal imperatives.

[1] Global NEWS is an international, interdisciplinary scientific taskforce, focused on understanding the relationship between human activity and coastal nutrient enrichment. It was formed in the spring of 2002 as a workgroup of UNESCO's Intergovernmental Oceanographic Commission (IOC), with co-sponsorship by UNEP, US-NSF, and US-NOAA. Global NEWS is a LOICZ affiliated project. The primary aim of Global NEWS is to construct and apply the next generation of spatially explicit, global nutrient export models, linking the resulting river loads to quantitative assessments of coastal ecosystem health. The first set of global river export models was published in late 2005 in a special collection of the journal Global Biogeochemical Cycles.

I – The Large Marine Ecosystem (LME) Approach

In 1982 when the United Nations Law of the Sea Convention established Exclusive Economic Zones (EEZs) up to 200 nautical miles from the baselines of territorial seas, granting coastal states sovereign right to explore, manage and conserve the natural resources of the zones; a new paradigm in ocean use was initiated. Therefore, the LME approach to the assessment and management of marine resources was introduced in 1984, and the first international LME conference was held in 1990 in Monaco.

Afterward a significant milestone was achieved in June 1992 with the adoption of follow-on action to the declarations on the ocean of the United Nations Conference on Environment and Development (UNCED) which recommended that nations: *1) "prevent, reduce, and control degradation of the marine environment so as to maintain and improve its life-support and productive capacities"; 2) "develop and increase the potential marine living resources to meet human nutritional needs, as well as social, economic, and development goals" and 3) "promote the integrated management and sustainable development of coastal areas and the marine environment".*

This followed a growing awareness world-wide that the quality of coastal marine ecosystems, and consequently their capability for long-term sustainability of natural resources use, were being adversely impacted and reduced. This, in turn, has stimulated efforts by scientists and resource managers to shift their focus form the assessment and short-term management of individual ecosystem components to that of entire ecosystems on a long-term basis.

Whit the establishment of EEZs, the Intergovernmental Oceanographic Commission (IOC) of UNESCO has encouraged coastal nations to establish national programs for assessing and monitoring coastal ecosystems so as to enhance the ability of national and regional management organizations to develop and implement effective remedial programs for improving the quality of degraded ecosystems [*Sherman* 1995].

Consequently, in recent years, there has been a change in approach to the management of the world's natural resources from that of compartmentalized efforts focusing on maximizing short-terms yields and economic gains towards ecosystem management and long-term sustainability (Table 1). Within this framework the LME concept was developed over the years from a fisheries oriented ecological approach to the assessment, monitoring and management of coastal ocean ecosystems and their goods and services [*Sherman and Duda* 1999a].

Table 1. Management: A paradigm Shift
(Adapted from *Lubchenko* 1994)

From →	**To**
Individual species	Ecosystems
Small spatial scale	Multiple Scales
Short-term perspective	Long-term perspective
Humans: Independent of ecosystems	Humans: Integral part of ecosystems
Management divorced from research	Adaptive management
Managing commodities	Sustaining production potential for goods and services

The research on ecosystem-based fisheries management, marine biodiversity conservation, and other marine fields required appropriate maps of the major natural regions of the oceans, and their ecosystems. In this order, a global ocean classification system was proposed by *T. Platt and S. Sathyendranath* [1988; 1989; 1991; 1992; 1993] and implemented by *A. R. Longhurst* [1995; 1998], which was defined largely by physical parameters that subdivide the oceans into four 'biomes' and 57 'biogeochemical provinces' (BGCPs). Later on, this classification merged with the system of 64 Large Marine Ecosystems (LMEs) identified by K. Sherman and colleagues as transboundary geographic coastal and watershed units [*Watson et al.,* 2003].

LMEs are relatively large regions, on the order of 200,000 Km^2 or larger, characterized by distinct bathymetry, hydrography, productivity, and trophic patterns [*Sherman et al.,* 1986*;* 1991*;* 1996*;* 1999a*;* 1999b*; Sherman,* 1994*; Sherman and Duda,* 2002]. LMEs were ecologically defined to serve as a framework for the assessment and management of coastal fisheries and environments including watersheds, while BGCPs have physical definitions, including borders defined by natural features, and extend over open ocean regions [*Watson et al.,* 2003]. Large Marine Ecosystems provide a convenient framework for addressing issues of natural resources management. In addition, given that most of them border developing countries, LMEs also provide a framework for addressing issues related to economic development [*Hempel and Sherman,* 2003].

The LME is a distinct region of ocean space encompassing coastal areas out to the seaward boundary of continental shelves and the outer margins of coastal current systems. The development agencies of the United Nations system, The Global Environment Facility (GEF), the United Nations Development Programme UNDP, the United Nations Environmental Programme (UNEP), the United Nations Industrial Development Organization (UNIDO), and the World Bank have endorsed the LME concept as a framework for several of their international assistance projects.

Mapping LMEs allows for the computation of GIS-derived properties such as mean depth, temperature, primary production and other ecosystem attributes; and their analysis in relation to fishery abundance data for any study area in the combined system. Moreover, this integration allows for the quantification of the distribution of marine features (e.g., primary production, coral reef areas) so far not straightforwardly associated with different coastal states [*Watson et al.,* 2003].

Nowadays, the 64 LMEs are the source of 80 percent of the world's annual marine fisheries yield [*Garibaldi and Limongelli,* 2003, *Sherman et al.,* 2008]. Most of the global ocean pollution, overexploitation, and coastal habitat alteration occurs within the 64 LMEs. The LMEs are being subjected to increased stress from growing exploitation of fish and other renewable resources, coastal zone damage, river basin runoff, dumping of urban wastes, and fallout from aerosol contaminants [*Sherman,* 1993].

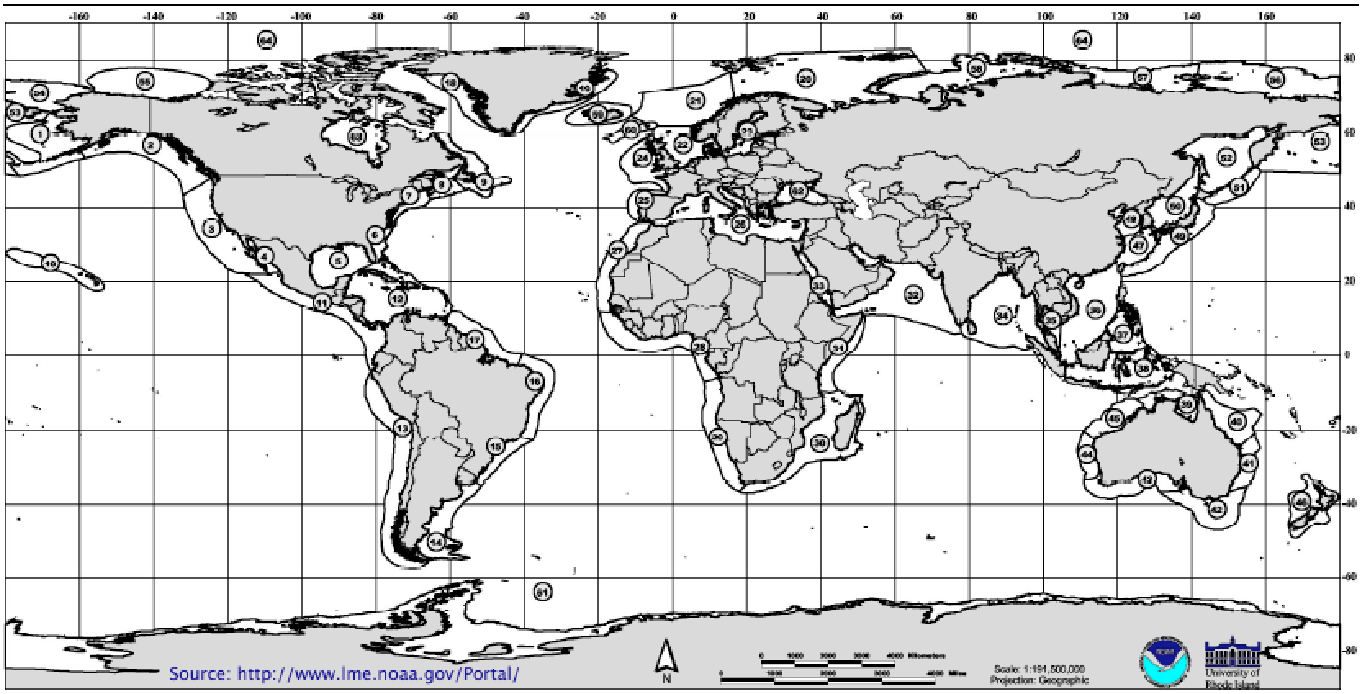
The growing awareness that fisheries yields are being influenced by multiple, but different, driving forces in marine ecosystems around the globe has accelerated efforts to broaden research strategies to encompass food chain dynamics and the effects of environmental perturbations and pollution on living marine resources from a ecosystem perspective. Mitigating actions to reduce stress on living resources in the LMEs are required to ensure the long-term sustainability of biomass yields.

The LME concept promotes multidisciplinary research, assessment, and transdisciplinary thinking and leads to the development of networks of international cooperation among countries, institutions and individual scientists and resources managers. Under the framework of LME projects, building up of scientific and administrative capacity are enhanced. Right from the start; the interaction between fisheries and fish stocks was seen in the broad context of trophodynamics and of abiotic impacts on recruitment ecology.

Later, the role of pollution and of the invasion of alien species came into focus. Until recently the socioeconomic and governance dimensions of ecosystem management have been studied less intensively than physical and biological dynamics. The present and planned LME projects are aimed at safeguarding and restoring ecosystems and ensuring sustained use of living resources and habitats in balance with socio-economics needs and limitations [*Duda and Sherman,* 2002].

Since the mid 1990s, the Global Environment Facility (GEF), in partnership with several United Nations agencies, has supported LME assessment and management methods in 16 LME projects directed at the recovery and sustainability of marine resources and their environments in Africa, Asia, Latin America, and Eastern Europe. The results of these projects together with LME research in other parts of the world have been reviewed in LME symposia, and in 14 published peer reviewed volumes on LME case studies, and synopses of LME methodology and theory [*Sherman et al.,* 2008].

Figure 1. 64 Large Marine Ecosystems of the World



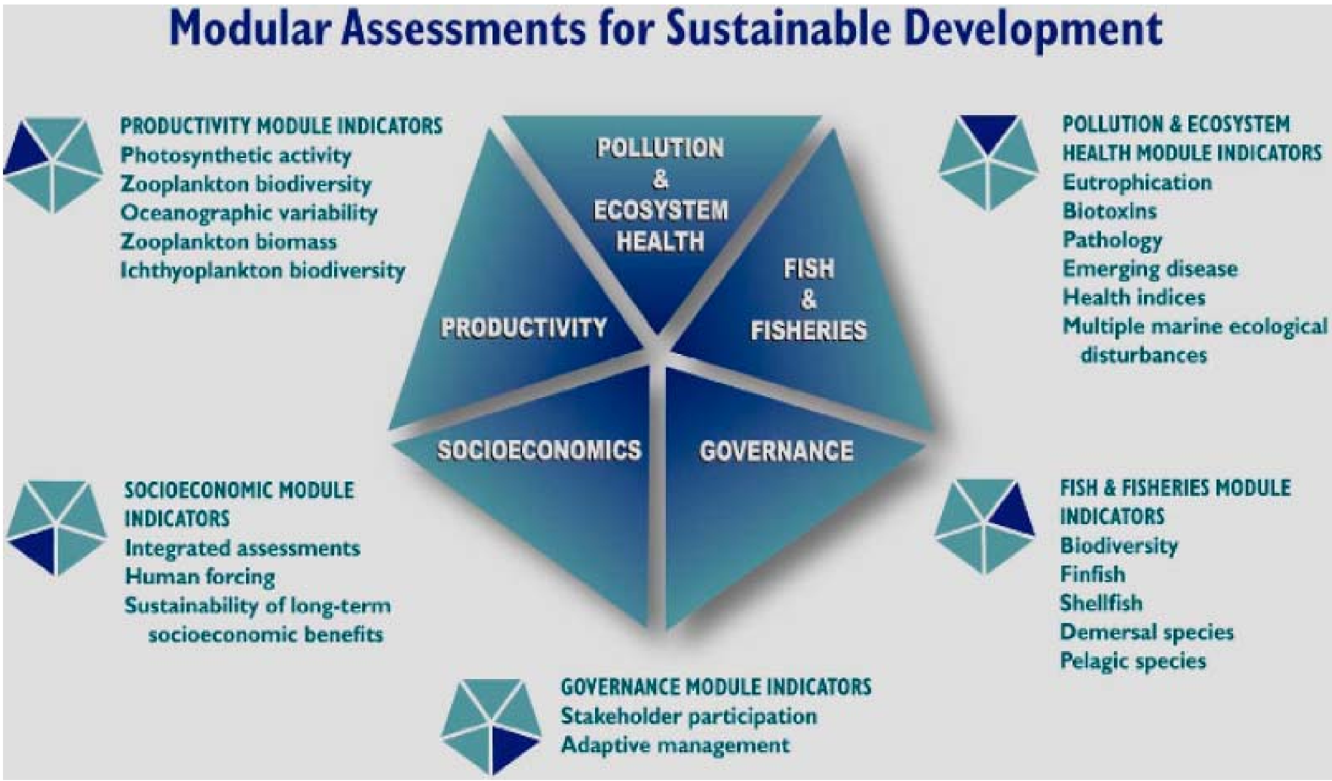
1. East Bering Sea
2. Gulf of Alaska
3. California Current
4. Gulf of California
5. Gulf of Mexico
6. Southeast U.S. Continental Shelf
7. Northeast U.S. Continental Shelf
8. Scotian Shelf
9. Newfoundland-Labrador Shelf
10. Insular Pacific-Hawaiian
11. Pacific Central-American
12. Caribbean Sea
13. Humboldt Current
14. Patagonian Shelf
15. South Brazil Shelf
16. East Brazil Shelf
17. North Brazil Shelf
18. West Greenland Shelf
19. East Greenland Shelf
20. Barents Sea
21. Norwegian Shelf
22. North Sea
23. Baltic Sea
24. Celtic-Biscay Shelf
25. Iberian Coastal
26. Mediterranean
27. Canary Current
28. Guinea Current
29. Benguela Current
30. Agulhas Current
31. Somali Coastal Current
32. Arabian Sea
33. Red Sea
34. Bay of Bengal
35 Gulf of Thailand
36. South China Sea
37. Sulu-Celebes Sea
38. Indonesian Sea
39. North Australia
40. Northeast Australia
41. East-Central Australia
42. Southeast Australia
43. Southwest Australia
44. West-Central Australia
45. Northwest Australia
46. New Zealand Shelf
47. East China Sea
48. Yellow Sea
49. Kuroshio Current
50. Sea of Japan
51. Oyashio Current
52. Sea of Okhotsk
53. West Bering Sea
54. Chukchi Sea
55. Beaufort Sea
56. East Siberian Sea
57. Laptev Sea
58. Kara Sea
59. Iceland shelf
60. Faroe Plateau
61. Antarctic
62. Black Sea
63. Hudson Bay
64. Arctic Ocean

LME Modules

A five-module approach to the assessment and management of LMEs has been proven to be useful in ecosystem-based projects. The modules are customized to fit the situation within the context of the transboundary diagnostic analysis (TDA) process and the strategic action plan (SAP) development process for the group of nations sharing the particular LME based o available information and capacity. These processes are critical for integrating science into management in a practical way and for establishing governance regimes appropriate for the particular situation.

The five modules (Figure 2) consist of three science-based activities focused on: productivity, fish and fisheries, and pollution and ecosystem health; and two other activities: socio-economics and governance. The last two activities are focused on socioeconomic benefits to be derived from a more sustainable resource base, and, on implementing governance mechanisms for providing stakeholders and stewardship interests with legal and administrative support for ecosystem-based management practices. The first four modules support the TDA process while the governance module is associated with periodic updating of the SAP. [Sherman, 2005, in Levner et al., 2005, Strategic Management of Marine Ecosystems, NATO Science Series]

Figure 2. LME Modules and Indicators



II – Nutrient Loading and Eutrophication – A Watershed Perspective

Over the past 30+ years, scientists, coastal managers, and public decision-makers have come to recognize that coastal ecosystems suffer a number of environmental problems that can, at times, be attributed to the introduction of excess nutrients from upstream watersheds. Rivers are the major pathway by which nutrients are transported from watersheds to coastal systems. In many watersheds, nutrient delivery by rivers to coastal waters has been increasing as a result of human activities, related to food and energy production, such as increased use of synthetic fertilizer in agriculture, population growth, cultivation of legumes, and fossil fuel combustion [e.g., *Carpenter et al*., 1998; *Galloway et al*., 2004; *Vitousek et al*., 1997].

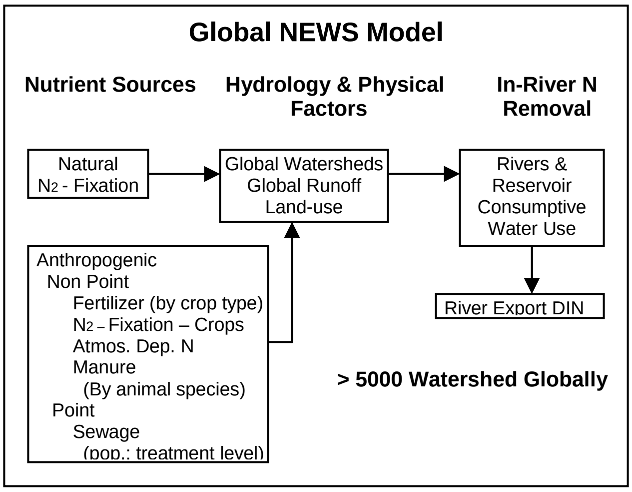
The resulting nutrient enrichment has contributed to changes in coastal ecosystems. These deteriorations include the formation and increased extent of coastal ‘‘dead zones” (anoxic and hypoxic water), loss of habitat (e.g., seagrasses), decreases in coastal biodiversity and distribution of species, increased frequency and severity of harmful and nuisance algae blooms and coral reef degradation, among others [*Diaz et al*., 2001]. One of the most common effects of over-enrichment is the acceleration of a natural process known as eutrophication. Eutrophication represents one of the central themes of aquatic ecology, and defines the excessive richness of nutrients in a body of water, frequently due to runoff from the land, which causes a dense growth of plant life and can lead to death of animal life from lack of oxygen [*Gomes et al., 2006*].

Natural or man-made enrichment with nutrient elements, mainly nitrogen and phosphorus, beyond the maximum critical level of the self-regulatory capacity of a given system for a balanced flow and cycling of nutrients, contributes considerably to coastal eutrophication. One of the most important nutrients in this respect is nitrogen (N), because nitrogen is often the most limiting nutrient [*Justic et al.*, 1995; *Turner and Rabalais*, 1994; *Vince and Valiela,* 1973]. Dissolved inorganic nitrogen (DIN) is often the most abundant and bioavailable form of nitrogen, and therefore contributes significantly to coastal eutrophication [*Veuger et al.,* 2004].

What are the Sources of N from Watersheds?

The total DIN exported to the coast by rivers is the result of the sum of N inputs from the point sources fraction, the non-point sources fraction and removal processes (sinks) in the rivers (Scheme 1). These are all important components of the NEWS-DIN model, as will be discussed in more detail in the next chapter.

Scheme 1. Sources and Sinks

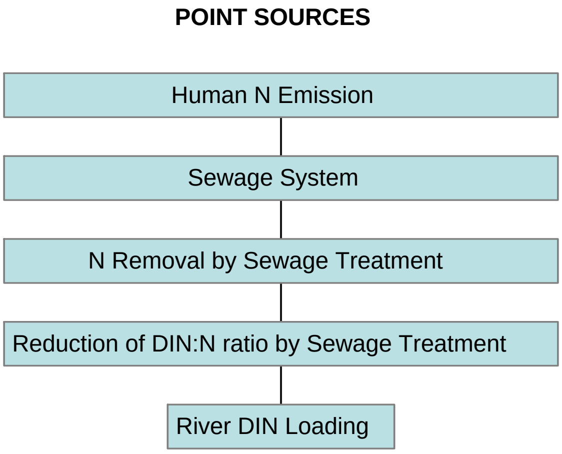


Point Sources

The principal N point source to surface waters is human sewage. In some regions, sewage treatment facilities can greatly reduce the amount of DIN entering surface waters from point sources. However, in many regions sewage treatment is minimal. Diet, population density, and sewage connectivity can all affect the amount of DIN entering surface waters from point sources. Diets with higher amounts of protein tend to result in higher per capita rates of DIN loading from sewage.

Higher population density also results in higher rates of DIN loading. Sewage connectivity (the degree to which municipalities are connected directly to surface waters via sewage systems) also has an impact on DIN loading to surface waters, with highly connected systems leading to relatively high rates of DIN loading (Scheme 2).

Scheme 2. Point Sources

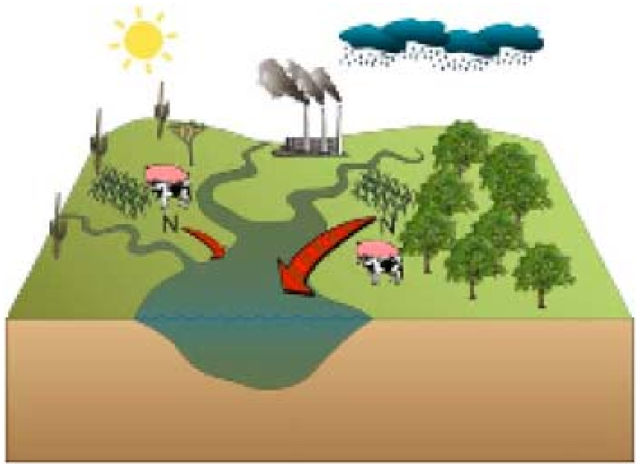


Non-point sources

Non-point sources very often greatly exceed point sources of DIN to coastal systems. Important non-point sources of DIN to surface waters include inorganic N fertilizers, manure, N deposition, and N_2-fixation (both natural and anthropogenically enhanced) (Figure 3). These DIN sources are referred to as “non-point sources” because they do not enter surface waters at well defined points such as outfall pipes, but rather are more evenly dispersed sources on the landscape. Water runoff is an important factor controlling the proportion of non-point sources making it into flowing surface waters.

The effect of human activities on the global cycling of nitrogen is vast, and the rate of change in the pattern of use is extremely rapid. The single largest change in the nitrogen cycle comes from increased reliance on synthetic inorganic fertilizer, which was invented and became widely used in the last century. The National Academy of Science of the USA [2000] estimated that inorganic fertilizers account for more than half of the human alteration of the nitrogen cycle, and approximately half of the inorganic nitrogen fertilizer ever used on the planet was used in the last 15 years. It is not only the direct use of synthetic fertilizer that contributes DIN loading in rivers, but the crops harvested from those fields are fed to animals and eaten by people which contribute an additional portion of fertilizer N as DIN to rivers from the manure (non-point) and sewage (point), respectively, produced.

Figure 3. Conceptual Model – Non-Point Sources



In the same way, other human controlled processes contribute to the problem by converting atmospheric nitrogen into biologically available forms of nitrogen, such as by combustion of fossil fuels and production of N_2-fixing crops in agriculture. Overall, human fixation of nitrogen increased globally some 2- to 3- fold from 1960 to 1990, and continues to grow. Over the next 50 years, human population, agricultural production, and industrialization are predicted to increase especially rapidly in many developing regions of the world, leading to increased nutrient (nitrogen and phosphorus) inputs to the coastal zone [*Kroeze and Seitzinger* 1998].

Dams and Diversions (DIN sinks)

Several pathways for DIN loss from rivers and streams can affect the amount of DIN reaching coastal waters. In general, factors that increase the residence time of water in a watershed or decrease the amount of water flowing downstream tend to reduce the amount of DIN reaching coastal waters. Increasing residence time increases the chance that DIN will be converted to N_2 gas and lost to the atmosphere via denitrification before reaching coastal waters. (Denitrification is the reduction of nitrate (DIN) to N_2 gas by bacteria naturally occurring in the environment.) For example, dams can increase the residence time of water in rivers, thereby increasing the likelihood that DIN will be lost to the atmosphere before it is transported to coastal waters

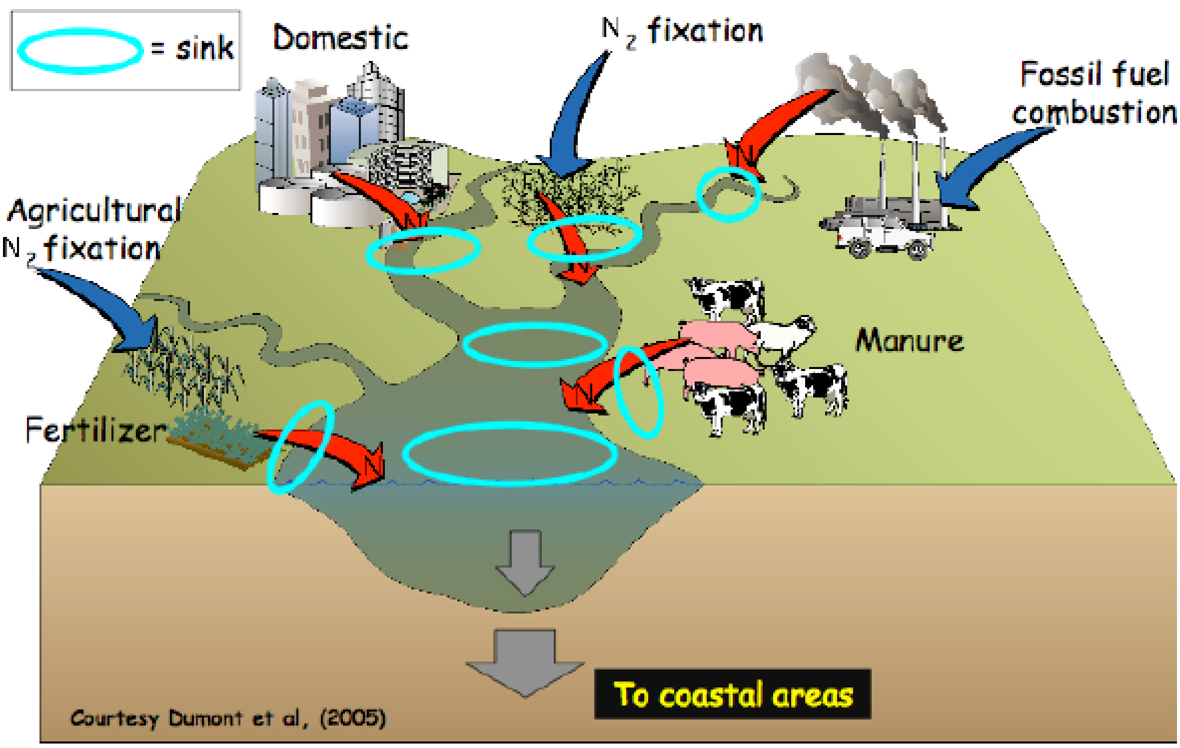
Water extraction for irrigation or other consumptive uses also removes DIN, and therefore prevents it from being input to coastal systems. NEWS-DIN accounts for both denitrification and extractive losses of DIN from surface waters as illustrated below.

The DIN transported from watersheds by rivers can result in a wide range of environmental problems once it enters coastal ecosystems including:

- Increased algal productivity
- Shifts in community structure
- Harmful algal blooms
- Degradation of seagrass and algal beds
- Formation of nuisance algal mats
- Coral reef destruction
- Increased oxygen demand and hypoxia
- Increased nitrous oxide (greenhouse gas)
- Disease and pathogen increases
- Socio-economic impacts

In order to optimize use of land for food and energy production while at the same time conserving coastal habitats, it is important to understand the links between land-based activities and nutrient inputs to coastal systems. The NEWS-DIN model was formulated for that purpose. Nutrient sources, sinks, and controlling factors in watersheds are explicit components of the model, and the effect of a range of scenarios on DIN river export can be explored.

Figure 4. DIN Export Conceptual Model



III – Global NEWS-DIN Model

The GEF/LME Nutrient Export Modelling Workshops used the NEWS-DIN model (*Dumont et al.*, 2005) for predicting dissolved inorganic nitrogen (DIN) export by rivers to coastal waters in each of the seven analyzed large marine ecosystems (LMEs). The NEWS-DIN model was developed as part of a multi-investigator effort to model river export of multiple bioactive elements and element forms (particulate/dissolved, organic/inorganic) called Global Nutrient Export from WaterSheds (Global NEWS) (Table 2). The NEWS model has been applied to watersheds globally. Over 4500 watersheds are delineated and included in the global application.

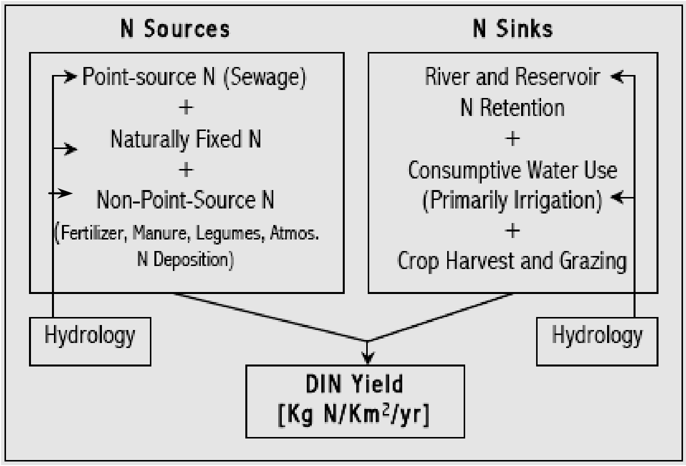
Table 2.

Global NEWS Models River Export			
	Dissolved		Particulate
	Inorganic	Organic	
N (Nitrogen)	**DIN**	DON	PN
P (Phosphorus)	DIP	DOP	PP
C (Carbon)		DOC	PC

The NEWS-DIN model estimates annual DIN export at the mouth of rivers (just before discharging to coastal ecosystems) for medium to large river basins. N inputs to watersheds that contribute to river DIN export include synthetic fertilizer use (by crop type), manure production (by animal type), biological N_2-fixation by natural vegetation and by leguminous crops, atmospheric DIN deposition, and sewage (Scheme 3). A portion of this N is removed within the watershed before entering the river due to N export by crop harvesting and grazing and N removal in sewage treatment, for example. Not all the N entering the river is exported to the coast. During river transport, a portion of the N is removed by biological processes such as denitrification in the river and in dammed reservoirs, as well as by physical processes (e.g., water removal for irrigation).

The application of NEWS-DIN allows the prediction of river DIN export to coastal zones under past and current conditions, and future DIN export under a range of scenarios, as well as the contribution of individual source and sink types to river DIN export.

Scheme 3. DIN Sources and Sinks in NEWS-DIN



Details of Methodology, Model Form and Input Data[2]

The highest level equation of NEWS-DIN can be described as follows:

DINymod = FE_{riv} . [PS+ (FE_{ws} . DS)], (1)

where DINymod is modeled DIN yield per river basin (kg N km^{-2} yr^{-1}), *PS* is DIN from sewage point sources (kg N km^{-2} yr^{-1}) and *DS* is total nitrogen (TN) from diffuse sources that is mobilized from the watershed soils and sediments (kg N km^{-2} yr^{-1}). FE_{riv} is a river export fraction representing the fraction (0 – 1) of total point and diffuse DIN inputs to the river that is exported as DIN, FE_{ws} is a watershed export fraction representing the fraction (0 – 1) of TN from diffuse sources in the watershed that

[2] NEWS-DIN is based on the research presented by, Dumont, E., J. A. Harrison, C. Kroese, E. J. Bakker, and S. P. Seitzinger (2005), in, Global distribution and sources of dissolved inorganic nitrogen export to the coastal zone: Results from a spatially explicit, global model, *Global Biogeochem. Cycles, 19*, GB4S02, doi:10.1029/2005GB002488.

leaches to rivers as DIN. To estimate total DIN export per basin (kg N basin^{-1} yr^{-1}) DIN yield is multiplied by basin area (km^2, derived from *Vörösmarty et al.,* [2000a, 2000b]).

OVERVIEW OF CALCULATIONS

$$DINymod = FE_{riv} \cdot [PS + (FE_{ws} \cdot DS)]$$

DIN	= Modeled DIN yield per river basin (kg N km^{-2} yr^{-1})
DS	= N from diffuse sources that is mobilized from basin soils and sediments
FE_{ws}	= Fraction of N from diffuse sources leaching to rivers as DIN
PS	= DIN from point sources
FE_{riv}	= Fraction of total point and diffuse DIN inputs to the river that is exported as DIN

Most input data were available as a 0.5 X 0.5° grid and were selected to be representative of the years between 1990 and 1997. Before using this gridded data in the model, it was averaged over river basins delineated from an updated version of the 0.5 X 0.5° STN30-p global river network [*Vörösmarty et al.*, 2000a, 2000b].

Point Sources

Point source DIN inputs to rivers originate primarily in emissions from human sewage; these emissions are subsequently modulated and attenuated by the extent of sewage system connectivity and wastewater treatment levels. Emissions in areas not connected to sewage systems (rural and non-sewered urban) occur in a diffuse (non-point) manner throughout a watershed, but are assumed to be retained or lost from the watershed and therefore do not reach streams. Sewage system connectivity and removal in wastewater treatment plants vary widely regionally and globally and are estimated based on national and regional sanitation statistics, including the level of treatment available.

More specifically, total human waste emission (per capita) is estimated as summarized by Bouwman et al., [2005a],

$$TN_{sew} = H \, . \, (1 - T_N) \, . \, I \, . \, E_N \, , \qquad (2)$$

where TN_{sew} is the annual sewage of total nitrogen (TN) discharged to surface water per km^2 of basin (kg N km^{-2} yr^{-1}), *H* is population density (individuals km^{-2}) from the *United Nations* (UN) [1998], the *Food and Agriculture Organization* (*FAO*) [2001] and the World Bank [2001], T_N is a country by country fraction of TN removed by wastewater treatment compiled by *Bouwman et al*., [2005a], *I* is a country by country fraction of population connected to sewer systems compiled by *Bouwman et al*., [2005a], and E_N is the per capita human TN emission estimated as described by *Bouwman et al.,* [2005a] (kg N km^{-1} yr^{-1}). For those countries where *I* and T_N were not available on a country by country basis, regional estimates were used according to *Bouwman et al.,* [2005a].

Sewage effluent DIN emitted to rivers is estimated as

$$PS = TN_{sew} \cdot \left[0.485 + \frac{T_N}{\max(T_N)} \cdot 0.255 \right] , \quad (3)$$

where *PS* is DIN in sewage effluents for a basin (kg N km^{-2} yr^{-1}), max is the maximum of all countries for which T_N is known (max(T_N) = 0.8 in Finland), 0.485 is an estimate of the fraction of TN that is DIN in sewage effluent without treatment [*Seitzinger*, 1995], and 0.255 is the maximum increase in DIN to TN ratio that can be achieved by sewage treatment [*Seitzinger*, 1995] (See Scheme 2 in Chapter II).

Diffuse Sources

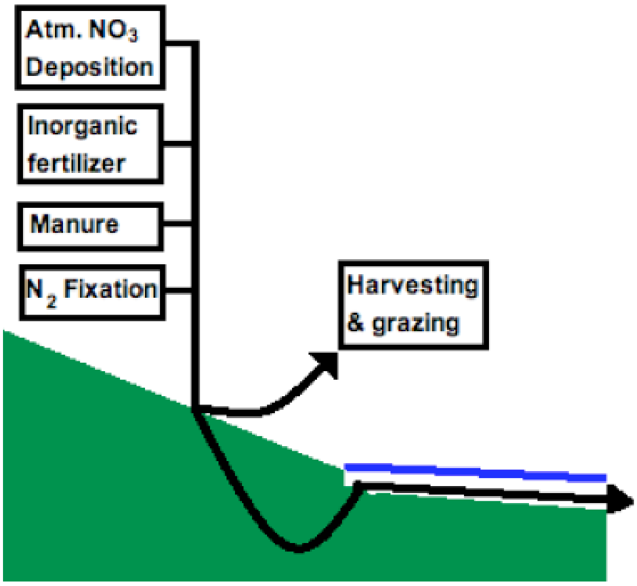
The total amount of N applied to the landscape that is potentially available as input to the river as a diffuse source (*DS*) (kg N km^{-2} yr^{-1}) is estimated in NEWS-DIN as follows,

$$DS = TN_{am} + TN_{fe} + TN_{dep} + TN_{fix} - TN_{exp} \, , \qquad (4)$$

where TN_{am} is animal manure N addition (kg N km^{-2} yr^{-1}), TN_{fe} is fertilizer N addition (kg N km^{-2} yr^{-1}), TN_{dep} is atmospheric NO_y deposition (kg N km^{-2} yr^{-1}), and TN_{fix} is biological N_2 fixation (kg N km^{-2} yr^{-1}). TN_{exp} is N in crops and grassland that is removed from the land by harvesting and grazing (kg N km^{-2} yr^{-1}). This term is subtracted from the inputs in order to avoid double counting of N inputs, since afterwards this N is available for leaching to surface water following reapplication as animal manure or as point source from human sewage.

Considerable detail is included in all the terms in Equation (4). For example, TN_{am} is calculated as a function of animal species and includes seven different species ranging from camels to cows. TN_{fe} is calculated as a function of specific crop type. TN_{am}, TN_{fe}, *and* TN_{exp} were calculated as by *Bouwman et al.* [2005b]. TN_{dep} is the annual average deposition of atmospheric NO_y-N modeled for 1995 [*Lelieveld and Dentener, 2000*]. TN_{fix} includes both natural and agricultural biological N_2 fixation as developed by *Green et al*., [2004].

Figure 5. Contribution of Diffuse Sources



Equation (4) was applied to each 0.5 X 0.5° grid cell. Then *DS* for each grid cell in a basin was averaged over the basin and this average *DS* was used in equation (1).

Watershed Export

Not all N applied to the landscape enters into the river. A portion is removed in crops and grazing as noted above. The remaining TN transported as DIN from soils to rivers is defined as the watershed export fraction, FE_{ws}, in equation (1). Hydrology, specifically water runoff from the land to the river, is an important factor controlling the portion of the N applied to the land that enters the river.

In NEWS-DIN, FE_{ws} is calculated as

$$FE_{ws} = e \, . \, R, \quad (5)$$

where R is runoff (m yr^{-1}) and, e, the watershed export coefficient, is a calibrated parameter that defines the slope of the assumed linear relationship between R and FE_{ws} obtained from *Fekete et al.,* [2000], and has a maximum value of 1. This formulation is consistent with previous studies that also have identified water runoff as an important predictor of DIN transport through soils, brooks and small river reaches [*Behrendt and Opitz*, 2000; *Goolsby et al*., 2000].

Aquatic Retention

Not all N that enters the river from point and diffuse sources is exported to the coast; a portion of N is lost in route due to the process of denitrification in the river and in dammed reservoirs, and from consumptive water use primarily associated with irrigation. This loss is calculated as the aquatic retention, which is expressed as $(1 – FE_{riv})$ meaning the retention of DIN (0 – 1) in reservoirs and in the STN-30 basin river network developed by *Vörösmarty et al.,* [2000a, 2000b].

The fraction of river DIN inputs exported to the coastal zone as DIN, FE_{riv}, is defined as

$$FE_{riv} = (1 – L_{den}) \, . \, (1 – Q_{rem}) \, . \, (1 – D), \quad (6)$$

taking into account the fraction of DIN not retained in: river reaches $(1 – L_{den})$, dammed reservoirs $(1 – D)$, or diverted to other basins or removed for irrigation $(1 – Q_{rem})$.

Details of the approach used to estimate each of the terms in Equation (6) is included in Dumont et al. (2005). Briefly, the DIN loss by denitrification during transport all the way through entire river networks was estimated according to *Seitzinger et al.,* [2002]. The impact of anthropogenic removal of river water (containing DIN) was estimated in NEWS-DIN based on the water discharge before any direct human manipulations on the river system, the amount of discharged water lost from the river by anthropogenic transfer of water out of the basin, and the amount of discharge removed for irrigation minus the amount of irrigation water that ultimately flows back into the river.

DIN retention in reservoirs within a river basin was modelled by *Dumont et al.,* [2005] according to *Seitzinger et al.,* [2002] as a function of reservoir depth and water residence time for each identified reservoir. The retention in each reservoir of a river basin was aggregated to a basin average by taking a weighted arithmetic average of the retention in reservoirs. The modeled retention in a reservoir was weighted by the fraction of total basin discharge that the reservoir intercepts.

Source Contributions to DIN Export

One of the strengths of NEWS-DIN is that the contributions of the various N sources in the watershed to river DIN export can be evaluated, thus providing important information for watershed managers and policy makers. The contributions of point sources, atmospheric NO_y deposition from fossil fuel combustion, fertilizer addition, manure addition and agricultural and non-agricultural biological N_2 fixation to DIN export can be separately estimated using the model equations as described in *Dumont et al.,* [2005].

Measured DIN Export from Watersheds

The NEWS-DIN model was calibrated and then validated by *Dumont et al.,* [2005] using discharge, DIN concentration, and basin surface area data for 61 basins compiled from several sources. Together, these 61 basins account for 33% of global exoreic discharge and include a broad range of sizes, land uses, climates, topographies, and ecosystems (Figure 6). *Dumont et al.,* [2005] restricted the data set to include only long-term (>4 years) annual averages with at least 85% of the measurements taken between 1990 and 1997. Basins encompassing fewer than 11 grid cells owing to uncertainties associated with smaller basins were also excluded [*Harrison et al.*, 2005a; *Vörösmarty et al.*, 2000b].

Data on DIN yield have an interannual variation ranging from a factor 2 to 13 [*USGS,* 2003].

Measured DIN yield was obtained as follows:

$$DIN_{meas} = ([NO_3^-] + [NH_4^+]) \cdot \frac{Q}{A}, \quad (7)$$

DIN_{meas} is DIN yield near the river mouth (kg N km^{-2} yr^{-1}). $[NO_3^-]$ and $[NH_4^+]$ are measured NO_3^--N and NH_4^+-N concentrations, respectively, measured near the river mouth (kg N km^{-3}). Q is measured basin discharge (km^3 yr^{-1}) and A is basin area (km^2).

Figure 6. Data subset of Validation basins (From *Dumont et al.,* [2005])

Calibration and Model Analyses

Two indicators of model fit were used in the development of the model by *Dumont et al.,* [2005]: model efficiency and model error. The quality of the one to one linear relationship between the logarithm of measurements and model estimates was expressed as model efficiency (R^2, distinct from r^2, the coefficient of determination) [*Nash and Sutcliffe*, 1970].

Model error, ME (%), was expressed for the *i*th basin according to *Alexander et al*., [2002],

$$ME_i = \frac{Mod_i - Obs_i}{Obs_i} \cdot 100 \,, \qquad (8)$$

where *Obs* is observed DIN export for a basin and *Mod* is modeled DIN export for the same basin (*Dumont et al.,* [2005]).

Model Calibration and Validation

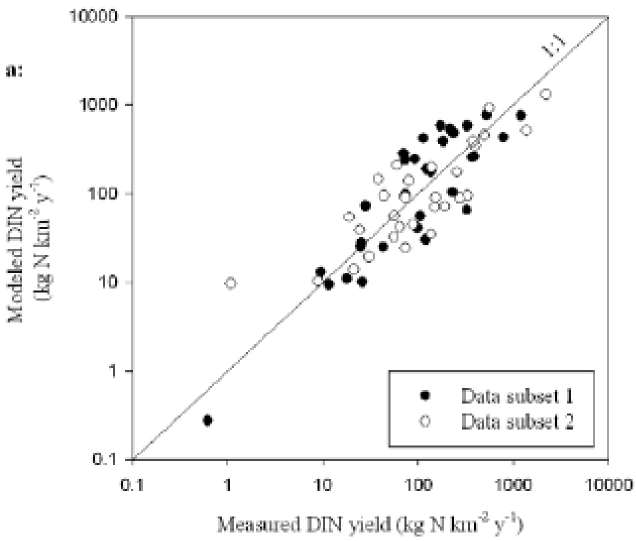
Equation (5) contains calibrated parameters. The watershed export coefficient (*e*; equation (5)) was calibrated by *Dumont et al.,* [2005] Parameter *e* in equation (5) was calibrated by optimizing the linear one to one relation between log measurements and log model outputs for 61 basins. To validate, *Dumont et al.,* [2005] split randomly the set of available DIN export measurements into two representative subsets of 31 and 30 measurements (Figure 6), sequentially recalibrating on one subset and validating on the other.

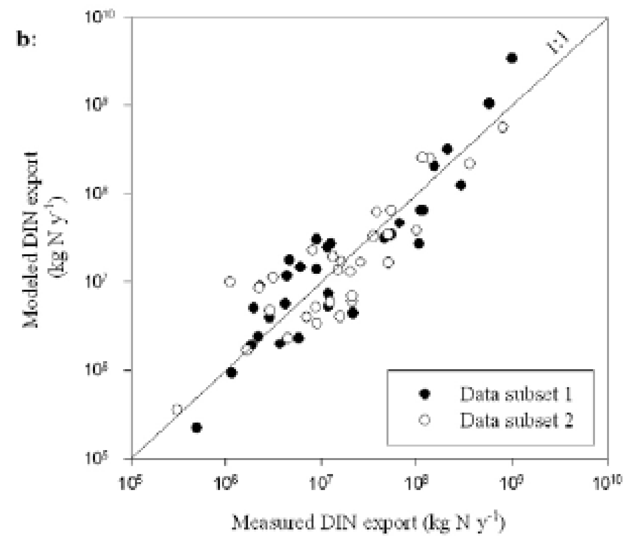
Fit, precision and bias obtained during calibration on all measured basins are similar to those obtained during validation, indicating that the uncertainty parameter *e* is low. Parameter *e* was calibrated to 1.1. 70% of the variability in DIN yield (kg N km^{-2} yr^{-1}) (Figure 7a), and 79% of DIN export (kg N basin^{-1} yr^{-1}) (R^2 = 0.79) (Figure 7b) was explained. The distribution of residuals and a median percent error of 7% suggest that NEWS-DIN yield and export estimates are relatively unbiased. Finally, the validation procedure indicated that NEWS-DIN's predictive capacity is quite high.

Model Efficiency and Sensitivity Analyses

Dumont et al., [2005] conducted a model efficiency analysis, in order to test the relative contribution of NEWS-DIN's model parts in explaining DIN export as yield. In this analysis, the change in model efficiency (R^2) was evaluated when individual model parts, such as *D* or TN_{dep}, were removed sequentially. Changes in R^2 were used to calculate the fraction of otherwise unexplained variation that is explained by inclusion of the removed model part. *Dumont et al.,* [2005] found that the largest decrease in model efficiency (up to 87%) took place when runoff or river network retention terms were removed. They concluded that future improvements to NEWS-DIN may depend much upon a better understanding of these factors.

Figure 7. (**a**) Modeled versus measured DIN yield (kg N km^{-2} yr^{-1}). R^2 = 0.70. (**b**) Same as Figure 7a, but for DIN export (kg N yr^{-1})). R^2 = 0.79. (From *Dumont et al.,* [2005])





While the change in model efficiency after removal of the water withdrawal term was low, *Dumont et al.*, [2005] considered that at a local scale, anthropogenic river water removal can have an important impact on DIN export. For example, in the Colorado (southwestern United States) and the Eastmain (eastern Canada), anthropogenic river water removal accounts for 99.5% and 93% of DIN retention, respectively.

To evaluate model sensitivity *Dumont et al.,* [2005] calculated the change in modeled DIN yield for each basin resulting from 5% changes in model inputs and parameters. The effect of these changes on the mean percent change in DIN yield ranged from 0.4 to 9.6%. Sensitivity analysis suggests that NEWS-DIN predictions are quite sensitive to treatment of its retention terms, which is consistent with results of the efficiency analyses [*Dumont et al.,* 2005].

Dumont et al. [2005] cautioned that the sensitivity of NEWS-DIN to parameters and inputs in individual basins can be much larger than the average sensitivity of DIN export in all basins of the world.

IV – Workshop Goals and List of Participants

Individuals from seven LME regions who were interested in the effect of land-use in their local watersheds on nutrient export to their LMEs were invited to participate in two training workshops held at IOC. The first workshop was held 23-26 January 2006, and the second workshop was held 18-20 September 2006. At the workshops, participants learned to use the Global Nutrient Export from Watersheds (NEWS) DIN river nutrient export model under current and future conditions and apply it to their particular LME region. The participants also met and exchanged information with other workshop participants.

In addition to attending the workshops, participants developed science-based summary documents for their home region. Inter-workshop activities were implemented through electronic communication of an IOC-UNESCO IT Eutrophication Network of participating scientists. In the same order, the participating scientists continue communicating and taking part in eutrophication-related activities.

Accomplishments

LME participants whose expertise would be strengthened with detailed training in the use of the Global NEWS-DIN nutrient export model were identified and invited to attend the training workshops. In preparation for the workshops, the LME participants were networked, modeling materials were prepared, and reference resources for participant use during and after the workshops were developed.

During the first workshop participants were trained to use the nutrient export model to develop LME model output. During the second workshop participants were trained in more advanced features of the nutrient export model to develop current and future LME model output. After the workshops, the model results were communicated to LME directors through summary documents. It is important to highlight that mechanisms for long-term communication with the participants have been established for further activities and research. Details of these accomplishments can be summarized as:

1. Identification and networking of workshop participants from 7 LMEs.
2. Preparation of workshop modeling materials:
    a. Delineated watersheds with export to LMEs, reconfigured the model for application to LMEs and ease of use by workshop participants.
    b. Acquired software licenses for all LME participants.
    c. Developed model input databases for future (2030) conditions and reconfigured the model for 2030 conditions for application to LMEs.

3. Development of resources for instruction and reference during the workshop:
    a. Agenda
    b. Presentations
    c. DIN model publication
    d. DIN model posters
    e. Workshop manual

4. Participant model investigation and communication of nutrient export results for 7 LMEs:
    a. Were trained in GIS and model use.
    b. Produced model output for each LME under current (1990's) and future (2030) conditions.
    c. Drafted and finalized summary documents.
    d. Communicated total DIN export and watershed source contribution results to LME Directors and in many cases to local government officials.

5. Long-term communication among IOC Eutrophication Network participants.

Identification and networking of workshop participants from 7 LMEs

For the first workshop, eight individuals (LME Associates) with the appropriate background, expertise, interests and leadership qualities were identified and invited to participate. These individuals represented seven LMEs, which had been identified for potential participation in this project, based on discussions with Dr. Kenneth Sherman. The LMEs include: Baltic Sea, Bay of

Bengal, Benguela Current, Guinea Current, Gulf of Mexico, Humboldt Current, and Yellow Sea.

Three participants identified for the first workshop were unable to attend the second workshop. However, those original participants worked with Dr. Sybil Seitzinger and Dr. Rosalynn Lee, and the Heads or Coordinators of their LME regional coordinating project units (CPUs) to identify additional participants from their LMEs (* in list below). This produced a positive effect resulting in a larger number of people trained in the use of the model. The original participants that were unable to attend the second workshop trained the new participants in the modeling skills developed in the first workshop. The new participants also shared the results and skills developed in the second workshop with the original participants from their LMEs upon their return.

List of participants that were trained during the UNESCO-IOC workshops in order of LME Region

Baltic Sea LME

- Bärbel Müller-Karulis
  Baltic Sea Regional Project
  Local Project Manager for the Productivity Coordination Center
  Institute of Aquatic Ecology
  University of Latvia, Latvia

- Ainis Lagzdins*
  Latvian University of Agriculture, Latvia

Bay of Bengal LME

- Dr. G.V.M. Gupta
  Integrated Coastal and Marine Area Management Project
  Directorate
  Department of Ocean Development
  NIOT Campus, India

Benguela Current LME

- Anja van der Plas
  Physical & Chemical Oceanography Section
  National Marine Information & Research Centre
  Ministry of Fisheries and Marine Resources, Namibia

- Bomba Sangolay*
  Marine Research Institute
  Instituto de Investigacao Marinha
  Ministerio das Pecas, Eambiente Ilha de Luanda
  Angola

Guinea Current LME

- Dr. George Wiafe
  Department of Oceanography & Fisheries
  University of Ghana, Ghana

- Dr. Samuel Anurigwo
  The Office of Secretary to the State Government, Cabinet Office
  Nigeria

Gulf of Mexico LME

- Dr. Jorge Herrera-Silveira
  CINVESTAV-IPN
  Mexico

Humboldt Current LME

- Dr. Sandor Mulsow
  Instituto de Geociencias
  Facultad de Ciencias
  Universidad Austral de Chile
  Chile

Yellow Sea LME

- Dr. Daoming Guan
  National Marine Environmental Monitoring Center, SOA
  China

- Dr. Qilun Yan*
  National Marine Environmental Monitoring Center, SOA
  China

***** *New participants trained and identified by original LME participants to attend the second workshop*

Project participants were linked via the Internet, thereby creating the “virtual center” required both for dialog between project participants and their engagement in project development and results. The communication among the IOC-UNESCO Eutrophication Network of participating scientists continued to build, leading up to the second workshop.

In preparation for the workshops, 1) project objectives and background information were provided and/or reiterated to current or new project participants; 2) LME-specific information was requested from all project participants; and 3) multi-direction dialog was established among all participants. More specifically, new project participants were provided with general background information on coastal eutrophication, on land based sources of nutrients causing coastal eutrophication, and on specific information about the modeling approach they were to use to identify rates and sources of coastal N loading.

For the first workshop, input from participants was requested on the current status of knowledge of eutrophication as an environmental problem in their LME region and what were known, or considered to be, the major sources of nutrient pollution in their coastal systems at present and in the future. Therefore, for the second workshop, all participants were requested to assemble existing current or future (2030) LME region-specific input data (e.g., population, sewage, fertilizer, manure, biological N2 fixation, atmospheric deposition, and hydrology terms such as discharge, water runoff, and consumptive water use) to verify or challenge the model predictions.

To facilitate communication among the participants, a participant website (http://www.marine.rutgers.edu/globalnews/LMEworkshop.htm; username: LMEworkshop; password: export) was developed to post workshop logistics, participant contact information, model background and resources, and participant-developed model output. A listserv was also created as a forum for participant communication of modeling challenges and results via email (lmeworkshop@marine.rutgers.edu).

Preparation of workshop modeling materials

In preparation for the first workshop, the model was reconfigured to be easily run on PC-based GIS software. The watersheds with export to the 7 LMEs were delineated and input databases necessary for model use under 1990's conditions for the 7 LMEs were developed. For the second workshop, the model was reconfigured for future conditions, also running on GIS software. The input databases necessary for model use under 2030 conditions for the 7 LMEs were also developed. In both workshops, the nutrient export model was refined to facilitate ease of use by workshop participants.

During the first year of the project, GIS software for project participants was selected (ESRI ARC-GIS 9), and 1-year software licenses for each of the 7 LME participants were acquired. During the second year, participants were encouraged to acquire GIS software for their own institution for use of the model after the expiration of these licenses. Each participant's LME Director was notified of their interest in extended use of the software to aid in finding additional funds to support extension of their licenses. During the process, local ESRI-GIS software distributors were also identified for each participant, in order to facilitate pricing of the licenses.

Workshop facility details were finalized with UNESCO-IOC, which handled all the room scheduling, computer rentals, internet connections, and travel arrangements for the workshop.

Development of resources for instruction and reference during the workshops

Written and graphical resources for instruction and reference were developed and distributed to the project participants in order to achieve the workshop objectives, which were to:

Workshop 1

1. Introduce participants to the model structure, input parameters and their formulation, and model outputs.

2. Introduce ArcMap GIS software features that are relevant to the model use, such as to: a) define watershed, country or regional boundaries of the model domain; examine the distribution of land-use and human activities within those boundaries; b) calculate nutrient export to the coastal zone; c) calculate the relative contribution of different land-based sources to the nutrient export; and d) display model results in tabular and graphical form.
3. Apply the model to participants' particular LME regions and analyze the model output.
4. Compare the model inputs and predictions to local data that the participants brought to the workshop.
5. Change input values for watershed parameters so that participants could explore the effect of changing land-use on nutrient export in their region.

Workshop 2

6. Develop more in-depth knowledge of the current effect of land-use, human activities and natural processes on nutrient transport from watersheds to coastal systems.
7. Explore the potential effects of future (2030) conditions of human activities on nutrient transport to participants' LME regions through various model scenario runs.
8. Develop individual expertise by independent exploration of model sensitivity and the effect of changing model inputs on coastal nutrient enrichment.
9. Discuss project results, in particular implications for optimizing food and energy production while minimizing water quality degradation in rivers and coastal marine ecosystems.
10. Finalize participants' LME region-specific summary documents for LME Directors and regional policy makers based on their findings from the two workshops.

Five members of the Global NEWS workgroup: Dr. Sybil Seitzinger, Rutgers University, USA; Dr. Lex Bouwman, Netherlands Environmental Assessment Agency, The Netherlands; Mr. Egon Dumont, Wageningen University, The Netherlands; and Dr. Rosalynn Lee, Rutgers University, USA; and Dr. John Harrison, University of California, USA; were directly involved in conducting the first and the second training workshops thereby providing extensive direct interaction between the workshop participants and the larger group of individuals who developed the models and databases that the participants used.

The workshop overview, eutrophication background, and nutrient export model details were presented in ten Powerpoint presentations. The titles of these presentations and their presenters are listed below:

- Overview of Workshops.
  Sybil Seitzinger
- Coastal N Over-enrichment.
  John Harrison
- NEWS-DIN Model Overview.
  Egon Dumont
- NEWS-DIN Model Equations.
  Egon Dumont
- NEWS-DIN Model Sinks.
  Egon Dumont
- NEWS-DIN Nonpoint Sources.
  Lex Bouwman
- NEWS-DIN Point Sources.
  Lex Bouwman
- N Effluent from Sewerage Systems, N Inputs, Land Cover.
  Lex Bouwman
- Major Needs from a "Global" Perspective
  Lex Bouwman
- Millenium Assessment Scenarios
  Lex Bouwman

Additional instruction and reference materials were provided in the training manual prepared and printed for the participants which contained specific examples of each step illustrated in the training manual through text and images. In addition to the GIS tutorial which presented software features relevant to model use, such as step-by-step directions for polygon and tabular data import, manipulation and spatial display, the printed manual also contained a copy of the publication describing the DIN model and the four model conceptual posters displayed at the workshop.

The DIN model paper “Global distribution and sources of dissolved inorganic nitrogen export to the coastal zone: Results from a spatially explicit, global model” was published in the peer-reviewed journal Global Biogeochemical Cycles (December 2005) and provided background and explicit details of the nutrient export model (see Section III). The four model conceptual posters highlighted the overview, point sources, non-point sources and dams and diversions (sinks) of the nutrient export model.

Participant model investigation and communication of nutrient export results for 7 LMEs

During the first workshop, participants learned how to use the new and innovative GIS-based NEWS model that relates land-use, human activities, and hydrology in watersheds to dissolved inorganic N (DIN) export by rivers to the coast. In the second workshop, participants focused on more advanced features of the model, ran and evaluated model scenarios for forecasted 2030 conditions, and continued to work on a short summary document with their LME region-specific information for potential future conditions.

Throughout the workshops, specific information regarding the model input databases for participants’ regions was provided and feedback was requested from participants regarding the accuracy of the databases for their regions (e.g., current and future conditions for the distribution of population, fertilizer use and atmospheric N deposition, and water runoff). Participants were assisted in comparing model predictions of N export with measurements available in particular watersheds. This information was incorporated into the model input. Additionally, participants were guided in exploring model sensitivity and changing model inputs on coastal nutrient enrichment in their LMEs.

Within each LME, DIN export and dominant sources were predicted for current and 2030 conditions. Spatial variability among watersheds was also examined. Summarized results of each participant’s exploration of the model for their LME are included in the following Section V. These graphically and textually presented results include the total DIN load from watersheds to each LME for current and future conditions as well as the contribution of DIN export from sewage, fertilizer, manure, atmospheric deposition and biological N_2 fixation.

V – Nutrient DIN Loads and Source Apportionment in the 7 LMEs Represented at the Workshop

(Baltic Sea, Bay of Bengal, Benguela Current, Guinea Current, Gulf of Mexico, Humboldt Current, and Yellow Sea LMEs)

1990s DIN export to LMEs

Total DIN load to the 7 LMEs, the Baltic Sea, Bay of Bengal, Benguela Current, Guinea Current, Gulf of Mexico, Humboldt Current, and Yellow Sea, modeled under 1990s conditions varied both across the different LMEs and by watershed within each LME (Figures 8-14; note the differences in scale). The magnitude of DIN export was highest in watersheds from the Bay of Bengal LME and decreased across orders of magnitude from the Guinea Current, Gulf of Mexico, and the Yellow Sea to the Baltic Sea, Benguela Current and Humboldt Current LMEs.

Figure 8. Modeled total DIN export by rivers from watersheds to the Baltic Sea LME under 1990s conditions.

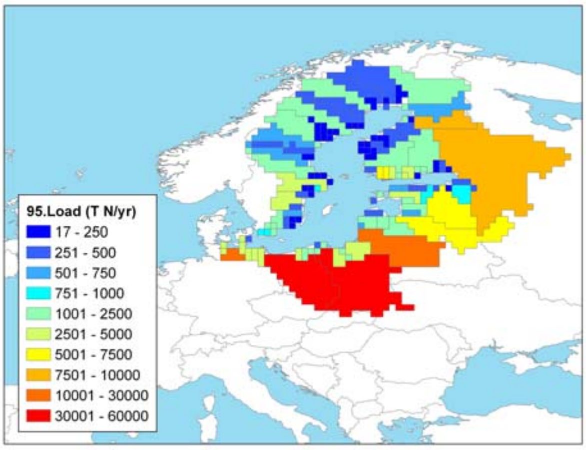


Figure 9. Modeled total DIN export by rivers from watersheds to the Bay of Bengal LME under 1990s conditions.

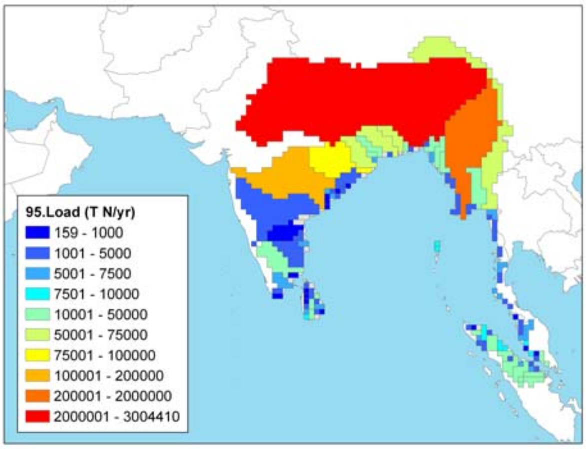


Figure 10. Modeled total DIN export by rivers from watersheds to the Benguela Current LME under 1990s conditions.

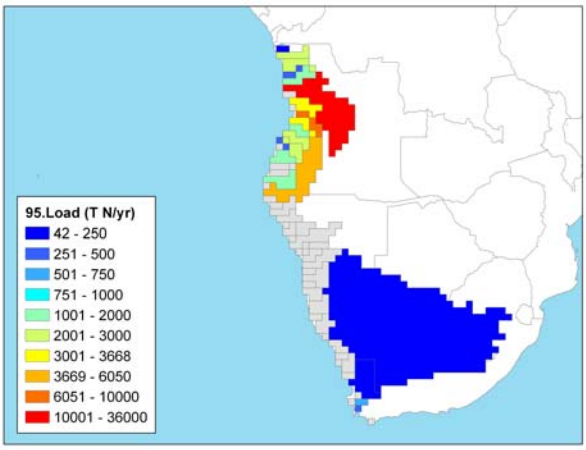
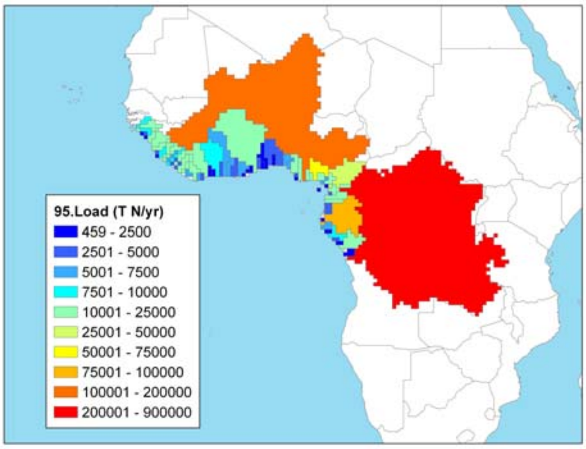


Figure 11. Modeled total DIN export by rivers from watersheds to the Guinea Current LME under 1990s conditions.



The spatial variability of DIN export also varied over many orders of magnitude within LMEs. The watersheds within an LME with the largest DIN export often contained the largest river systems, such as the Ganges River to the Bay of Bengal LME (Figure 9), the Mississippi River to the Gulf of Mexico LME (Figure 12), and the Yellow River to the Yellow Sea LME (Figure 14).

Figure 12. Modeled total DIN export by rivers from watersheds to the Gulf of Mexico LME under 1990s conditions.

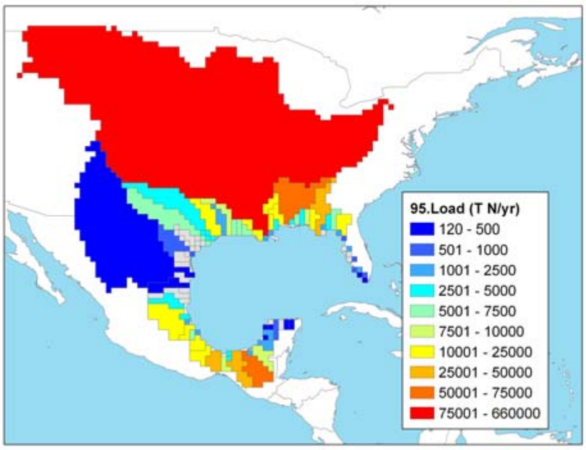


Figure 13. Modeled total DIN export by rivers from watersheds to the Humboldt Current LME under 1990s conditions.

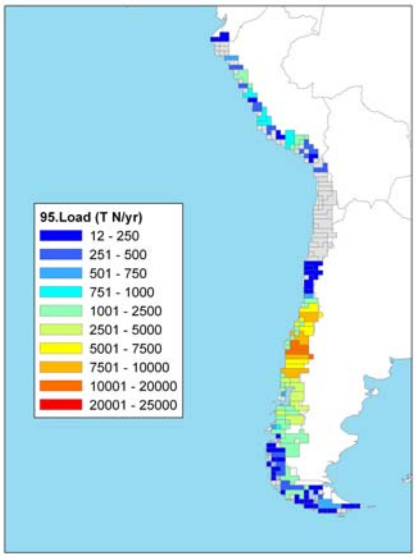
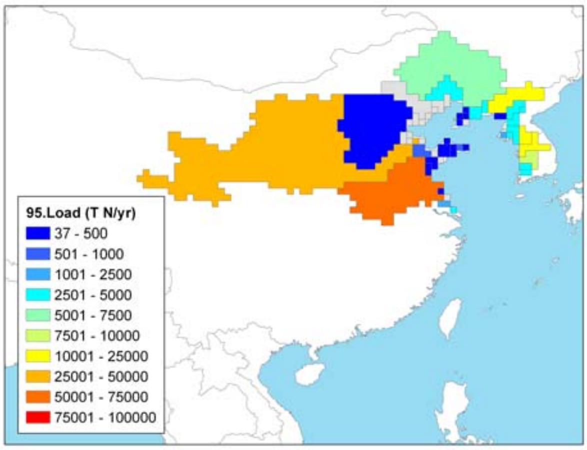


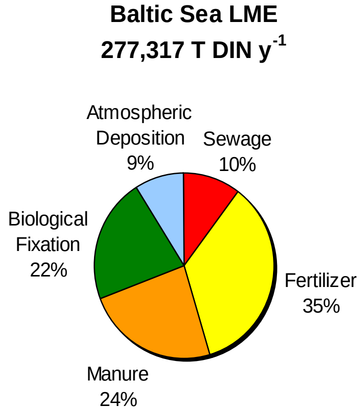
Figure 14. Modeled total DIN export by rivers from watersheds to the Yellow Sea LME under 1990s conditions.



1990s DIN export source apportionment

The sources of DIN export to the 7 LMEs included sewage, fertilizer, manure, biological fixation and atmospheric deposition. The contribution of these different sources to total DIN export varied among LMEs (Figures 15-21).

Figure 15. Source apportionment of DIN export by rivers from watersheds to the Baltic Sea LME under 1990s conditions.



In all 7 LMEs, biological fixation was a significant source to total DIN export ranging from ~20% to the Baltic Sea (Figure 15) and Yellow Sea (Figure 21) LMEs to almost 80% to the Benguela Current (Figure 17) and Guinea Current (Figure 18) LMEs. In these two African LMEs, the remaining DIN load was attributed primarily to atmospheric deposition and manure inputs. In contrast, fertilizer was a major source of DIN to the Baltic Sea (Figure 15), Bay of Bengal (Figure 16), Gulf of Mexico (Figure 19), Humboldt Current (Figure 20) and Yellow Sea (Figure 21) LMEs. Sewage was an important source of DIN (10-18%) to the Baltic Sea and Yellow Sea LMEs. These large contrasts in source apportionment indicate the very different approaches necessary to manage DIN export from watersheds to different LME regions.

Figure 16. Source apportionment of DIN export by rivers from watersheds to the Bay of Bengal LME under 1990s conditions.

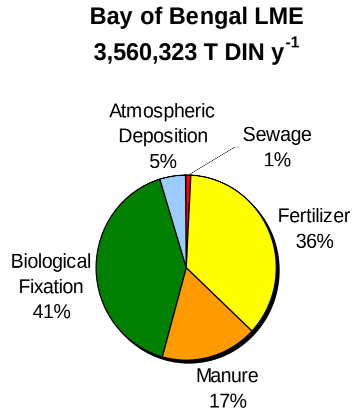


Figure 17. Source apportionment of DIN export by rivers from watersheds to the Benguela Current LME under 1990s conditions.

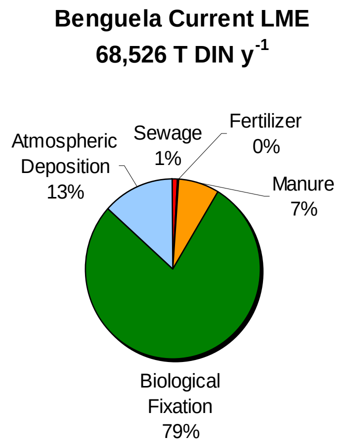


Figure 18. Source apportionment of DIN export by rivers from watersheds to the Guinea Current LME under 1990s conditions.

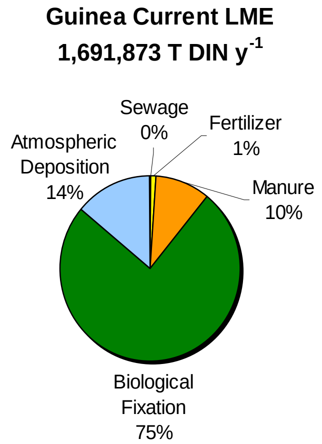


Figure 19. Source apportionment of DIN export by rivers from watersheds to the Gulf of Mexico LME under 1990s conditions.

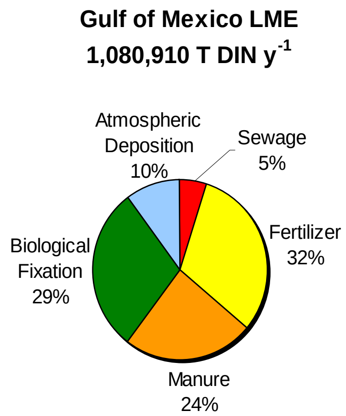


Figure 20. Source apportionment of DIN export by rivers from watersheds to the Humboldt Current LME under 1990s conditions.

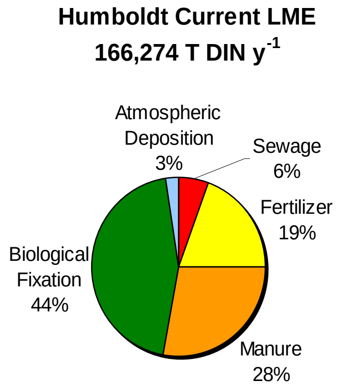
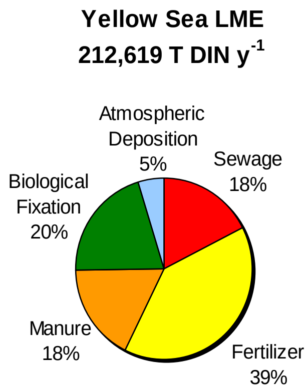


Figure 21. Source apportionment of DIN export by rivers from watersheds to the Yellow Sea LME under 1990s conditions.



2030 DIN export to LMEs

In order to explore how nutrient inputs in the future might change, input databases for the DIN model were developed for a business-as-usual scenario for 2030. The business-as-usual scenario assumes current trajectories will continue into the future based on country - and regionally - specific projections of inputs (e.g., population, fertilizer use, and atmospheric deposition) while other parameters were assumed to remain at their 1990s levels (e.g., water runoff).

Under 2030 business-as-usual conditions, modeled DIN load across the LMEs exhibited higher overall magnitudes than under 1990s conditions (Figures 22-28; note the differences in scale). The relative export of DIN across the LMEs was similar to 1990s conditions, with the highest individual watershed loads to the Bay of Bengal, Guinea Current, and Gulf of Mexico LMEs. The spatial distribution of DIN export from watersheds within LMEs was also similar between 2030 business-as-usual and 1990s conditions, but in some watersheds DIN loading increased, while in other watersheds, DIN loading decreased.

Figure 22. Modeled total DIN export by rivers from watersheds to the Baltic Sea LME under 2030 business-as-usual conditions.

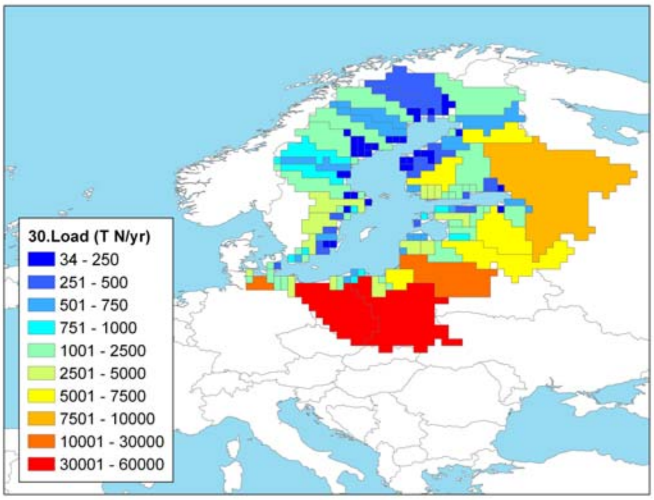


Figure 23. Modeled total DIN export by rivers from watersheds to the Bay of Bengal LME under 2030 business-as-usual conditions.

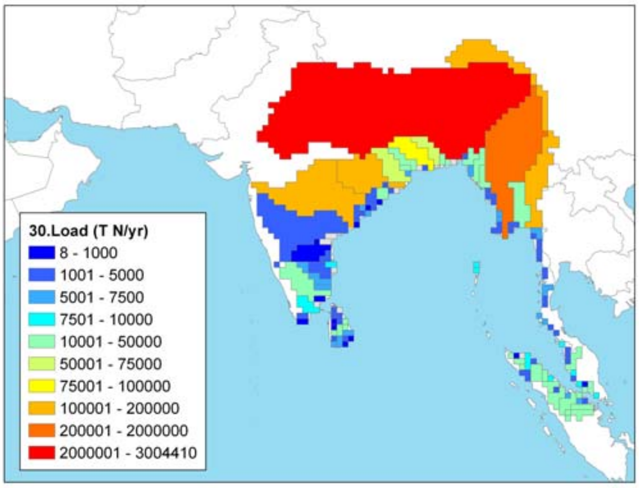


Figure 24. Modeled total DIN export by rivers from watersheds to the Benguela Current LME under 2030 business-as-usual conditions.

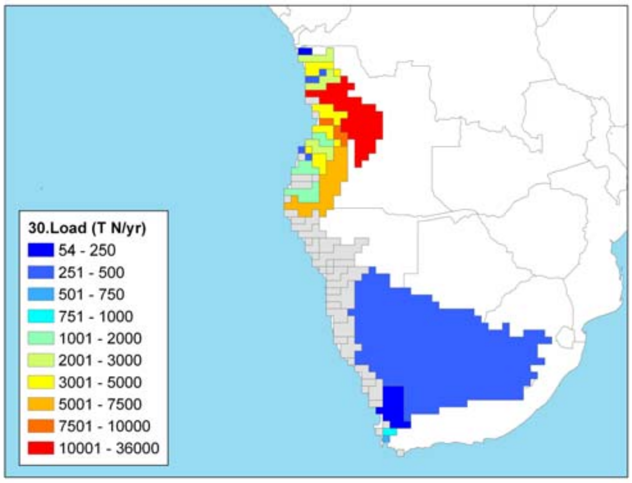


Figure 25. Modeled total DIN export by rivers from watersheds to the Guinea Current LME under 2030 business-as-usual conditions.

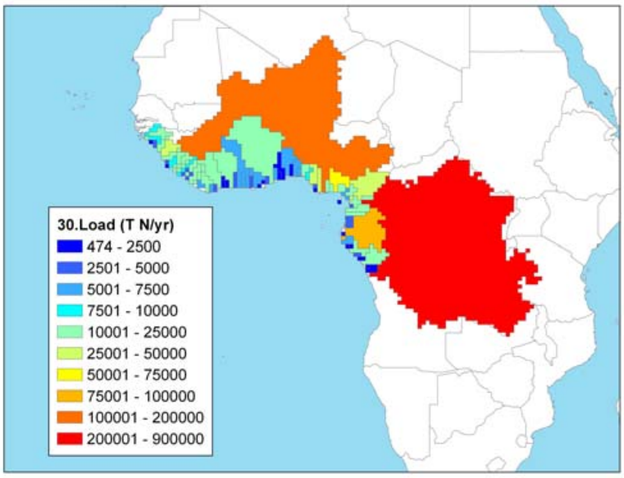


Figure 26. Modeled total DIN export by rivers from watersheds to the Gulf of Mexico LME under 2030 business-as-usual conditions.

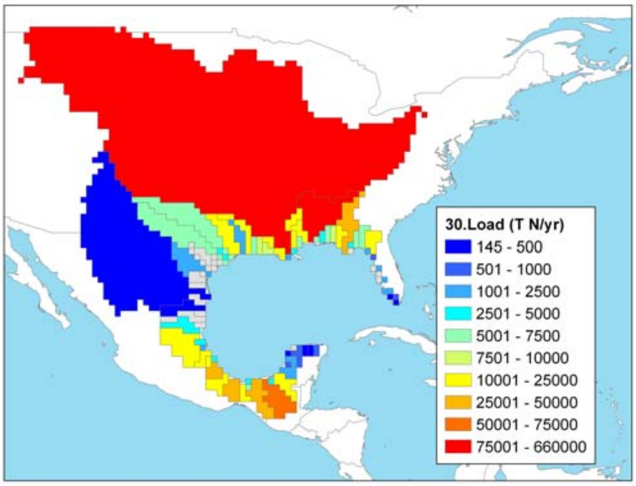


Figure 27. Modeled total DIN export by rivers from watersheds to the Humboldt Current LME under 2030 business-as-usual conditions.

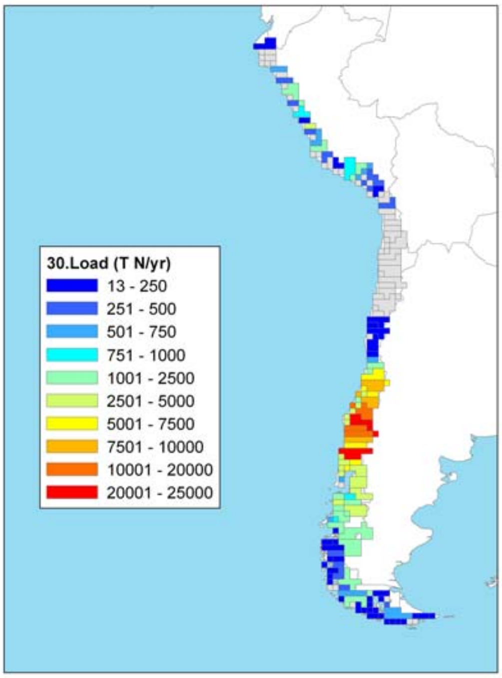
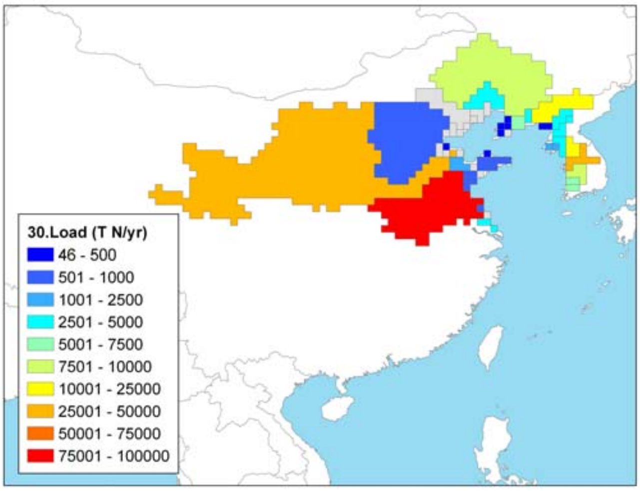


Figure 28. Modeled total DIN export by rivers from watersheds to the Yellow Sea LME under 2030 business-as-usual conditions.



2030 DIN export source apportionment

The modelled contribution of different sources of DIN export to the 7 LMEs in 2030 under business-as-usual conditions was somewhat similar in relative magnitude to that under 1990s conditions (Figures 29-35). Biological fixation was still the dominant source of DIN to the Benguela Current (Figure 31) and Guinea Current (Figure 32) LMEs, but at ~10% less than in the 1990s. Fertilizer application continued to be a major source of DIN to the Baltic Sea (Figure 29), Bay of Bengal (Figure 30), Gulf of Mexico (Figure 33), and Yellow Sea (Figure 35) LMEs, though at slightly different proportions both higher and lower. The relative contribution of manure application to DIN load was also similar to 1990s conditions with the highest proportion (34%) to the Humboldt Current LME (Figure 34).

A large increase in the contribution of sewage to total DIN load to LMEs from 18% in the 1990s to 28% under 2030 business-as-usual conditions was exhibited in the Yellow Sea due to population density increases and changes in sewerage infrastructure, whereas the contribution of sewage to DIN export to the other LMEs remained approximately the same. In contrast, a major change in the contribution of atmospheric deposition to total DIN load to LMEs was exhibited only in the Baltic Sea LME, increasing from 9% under 1990s conditions to 17% in 2030 under business-as-usual conditions as a result of increased fossil fuel burning from industrialization. Better estimates of future projections of total loads and types of sources of DIN export to LMEs are critical for achieving current management strategies that can be applicable to potential future conditions.

Figure 29. Source apportionment of DIN export by rivers from watersheds to the Baltic Sea LME under 2030 business-as-usual conditions.

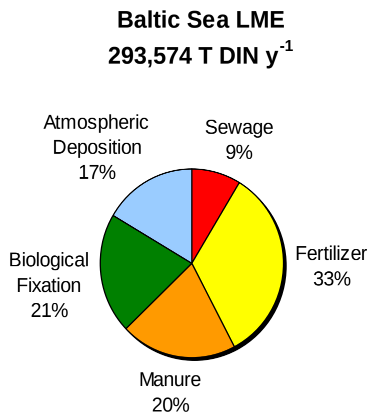


Figure 30. Source apportionment of DIN export by rivers from watersheds to the Bay of Bengal LME under 2030 business-as-usual conditions.

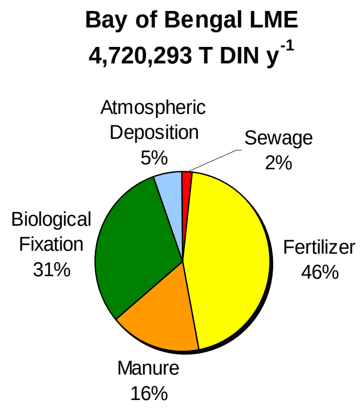


Figure 31. Source apportionment of DIN export by rivers from watersheds to the Benguela Current LME under 2030 business-as-usual conditions.

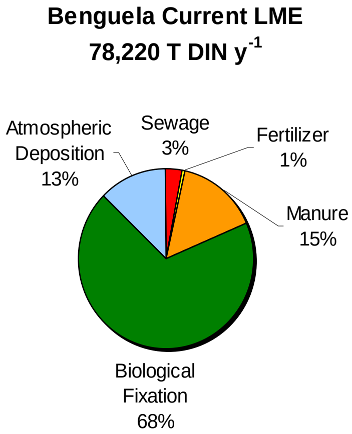


Figure 32. Source apportionment of DIN export by rivers from watersheds to the Guinea Current LME under 2030 business-as-usual conditions.

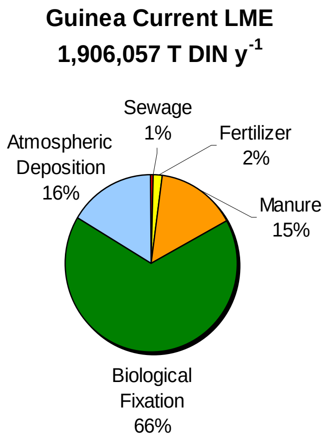


Figure 33. Source apportionment of DIN export by rivers from watersheds to the Gulf of Mexico LME under 2030 business-as-usual conditions.

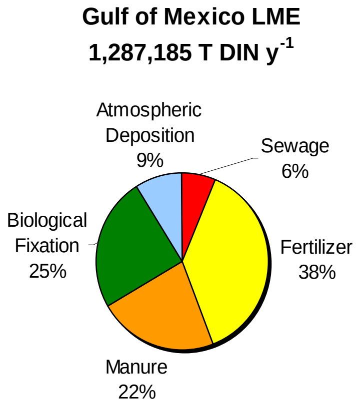


Figure 34. Source apportionment of DIN export by rivers from watersheds to the Humboldt Current LME under 2030 business-as-usual conditions.

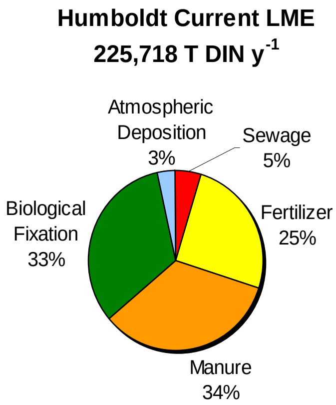
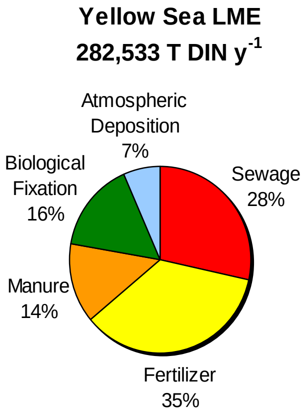


Figure 35. Source apportionment of DIN export by rivers from watersheds to the Yellow Sea LME under 2030 business-as-usual conditions.



VI – Example Case Studies: Baltic Sea and Yellow Sea LMEs

BALTIC SEA LME

Contributed by workshop participants: Bärbel Müller-Karulis and Ainis Lagzdins

Nutrient export from the catchment area is of prime concern for Baltic Sea environmental management, as it leads to pronounced eutrophication effects. Eutrophication was first noticed as an environmental problem when extensive oxygen deficiency occurred in the bottom water of the central Baltic Basins. Periodic anoxia is a natural phenomenon in the deep areas of the Baltic, caused by the intermittent oxygen input to the bottom water with salt-water inflows from the North Sea. The prolonged oxygen deficiency observed in the 1960s was a new phenomenon, which was finally linked to both low inflow intensity as well as increased organic matter production, leading to higher sedimentation and consequently increased sediment oxygen consumption [*Fonselius*, 1969, cited in *Elmgren*, 2001].

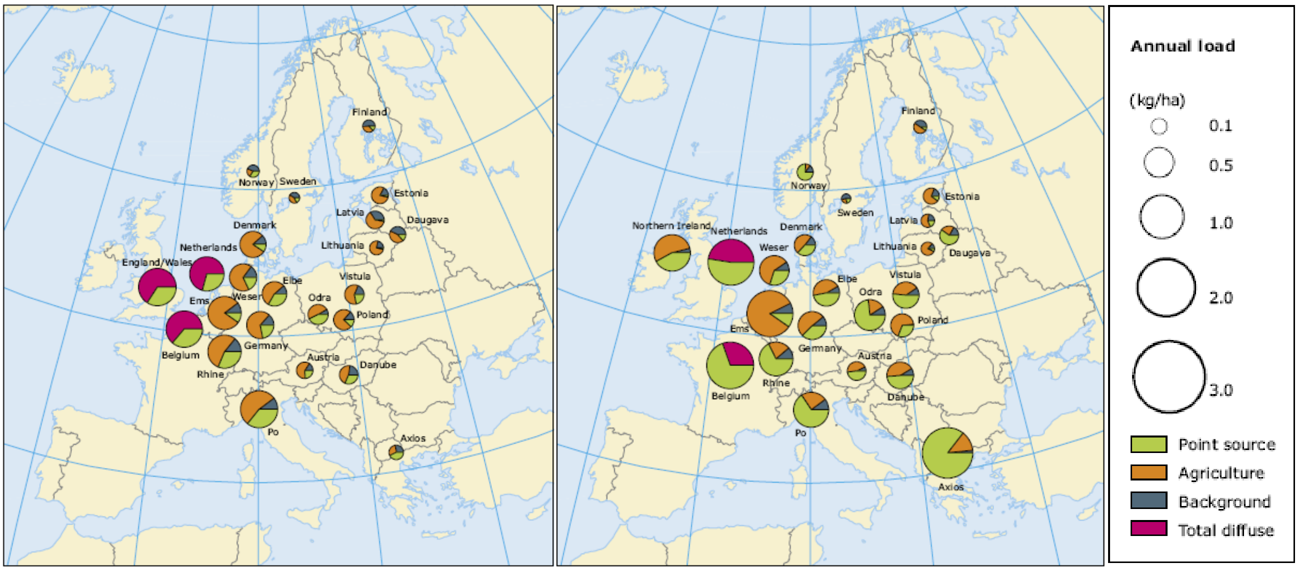
Today, more than 35 years after Fonselius' publication and more than 30 years after the Baltic Sea drainage basin countries signed the Convention on the Protection of the Baltic Marine Environment commonly known as HELCOM, eutrophication is still recognized as one of the key issues to be addressed by Baltic ecosystem management. A "Baltic Sea unaffected by eutrophication" is therefore one of the four strategic goals to be achieved by the new HELCOM Baltic Sea Action plan, which was adopted by the HELCOM contracting parties in November 2007. The Baltic Sea Action Plan will be a major marine policy planning document for the Baltic Sea drainage basin countries, mandating to "achieve a Baltic Sea in good environmental status by 2021" (*HELCOM*, 2007).

Generally, there is a lack of quantitative information on both nutrient loads to the Baltic Sea prior to the mid-1970s as well as to the state of the ecosystem itself. Systematic observations of riverine nutrient concentrations started in the 1970s in most riparian countries [*Stalnacke et al.*, 1999]. Only for some European rivers outside the Baltic Sea drainage basin like the Rhine (Germany/Netherlands) or the Tisza (Hungary) time-series reach back as far as the 1950s [*Grimvall et al*., 2000], indicating that riverine nutrient loads had started to rise already during the 1950s. Paleolimnologic techniques indicate that nitrogen load increases have been especially pronounced in areas with intensive agriculture, whereas growth in urban areas due to sewage has been less drastic and was successfully reduced by wastewater treatment [Clarke et al., 2006]. Overall, nitrogen loads to the Baltic are believed to have increased by four times compared to the beginning of the 20th century, while phosphorus loads have intensified by eight times [*Elmgren*, 2001].

Nitrogen and phosphorus enter the Baltic Sea mainly from land. Atmospheric deposition to the sea itself is only significant for nitrogen and contributes approximately one fourth of the total load [*HELCOM*, 2006]. However, within the Baltic Sea internal nutrient loading by biological or geochemical pathways (e.g., nitrogen fixation, recycling of nitrogen and phosphorus from bottom sediments) is high, leading to long response times to nutrient abatement measures, especially in the central Basin, the Baltic Proper [*Savchuk*, 2005, *Savchuk and Wulff*, 2001, *Savchuk and Wulff*, 1999].

Even though nutrient inputs to the Baltic Sea cause severe eutrophication problems, loads are low in comparison to Western European catchments, where more intensive agriculture and higher population density lead to even higher N and P export (Figure 36). The limited water exchange with the North Sea obviously makes the Baltic Sea more susceptible to eutrophication than truly marine systems.

Figure 36. N and P Nutrient Export From European Catchments (Source: EEA, 2005)



HELCOM has started a routine monitoring programme of nutrient discharges to the Baltic Sea, summarized in the pollution load compilations (Scheme 4). Reporting obligations by the HELCOM contracting parties include the nutrient loads of all major rivers and load estimates for unmonitored rivers on an annual basis, as well as loads from major point sources discharging directly to the sea. Starting with PLC 4 for the year 2000, every 6th year the reporting obligations are supplemented by a source oriented approach, where contracting parties estimate the magnitude of nutrient losses to watercourses in the drainage area, using source apportionment methods to identify natural background losses, as well as anthropogenic point and diffuse sources [*HELCOM*, 2003]

So far, the HELCOM contracting parties have not applied a common methodology for estimating the components of the source oriented approach. While the natural background load is mostly estimated from remote, relatively pristine catchments, the inputs to watercourses from diffuse sources (agriculture, scattered dwellings) are calculated either by empirical relationships or field-scale models, which can either be coupled to hydrological models or to semi-empirical routines that describe the nutrient retention within rivers, lakes and wetlands (HELCOM guidelines for PLC-WATER). There are several models in use for European catchments, and a comparison of nine nutrient load models has recently been done within the EU-funded EUROHARP project (http://www.euroharp.org).

The DIN-submodel of the global NEWS model [*Dumont et al., 2005*] was used to simulate riverine DIN export to the Baltic Sea under current (1990s) and future (2030) business-as-usual conditions.

In order to analyze the DIN yield predicted by NEWS-DIN, the catchments modeled were aggregated into 11 subregions according to their DIN yield and geographical location (Figure 37). Germany Northeast, Sweden South, Poland North, and Finland South are coastal regions with relatively intensive agriculture, while Bothnia West, Finland North and Finland Central comprise the Scandinavian boreal regions. Gulf of Finland East represents the Russian-Estonian part of the Gulf of Finland catchment, a transition area to slightly higher agricultural intensity in the Baltic States and Kaliningrad as well as Poland Central.

Scheme 4. Source oriented and load oriented approach in the HELCOM pollution load compilation (Source, HELCOM 2003)

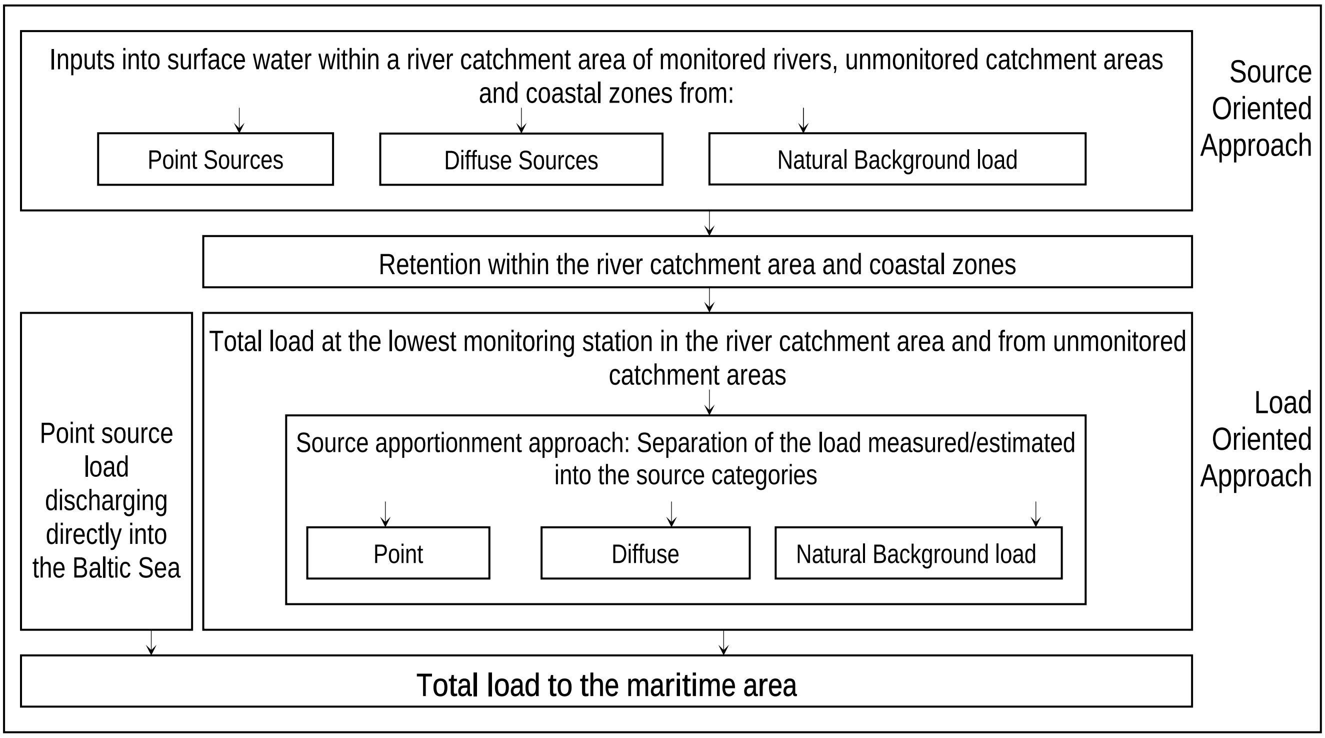
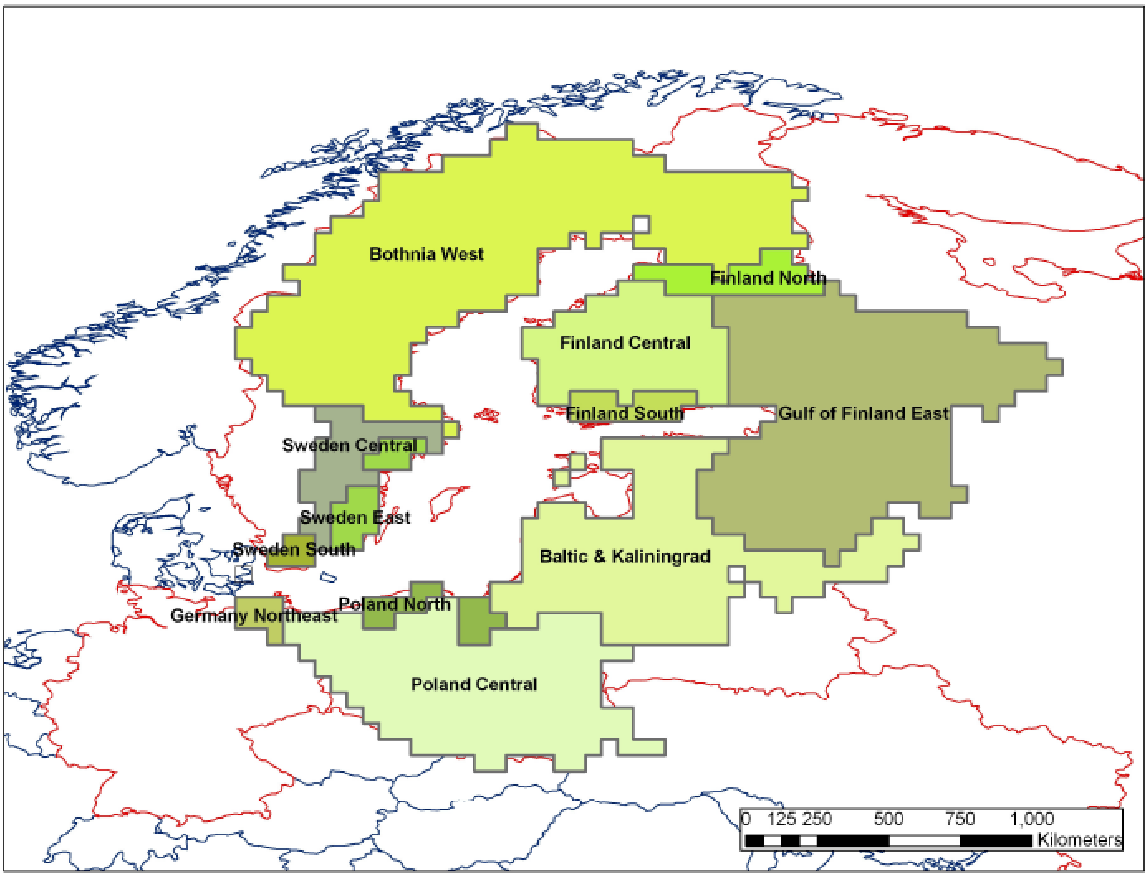


Figure 37. Subregions defined for NEWS-DIN output analysis



Results for current (1990s) conditions

The DIN yield predicted by NEWS-DIN for the subregions in the Baltic catchment area under current conditions varied by two orders of magnitude, with averages as low as 30 kg km^{-2} year^{-1} for the boreal Bothnia West region to 1230 kg km^{-2} year^{-1} in the intensively farmed Southern Finland (Figure 38).

In all subregions, diffuse sources widely dominated the DIN input into river systems, while point sources – the sewage load after treatment – contributed only 4 – 10 %. Diffuse inputs are therefore, according to NEWS-DIN, by far the major DIN source within the Baltic catchment. Further data analysis therefore focuses on the diffuse DIN yield.

Fertilizer use provides the most important source of DIN to the landscape in Baltic catchments, followed by manure application. Nitrogen fixation – both natural and agricultural – and atmospheric N deposition are far less important (Figure 39). Regional differences, especially between the intensively farmed areas in Southern Sweden and Finland, intermediate levels in Poland and the Baltic States, and the boreal regions are pronounced. Diffuse N inputs from the Eastern Gulf of Finland region appear to be very low, considering the high population density in the St. Petersburg area and climatic similarities to the adjacent Finish and Baltic State regions.

Figure 38. DIN yield estimated by NEWS-DIN

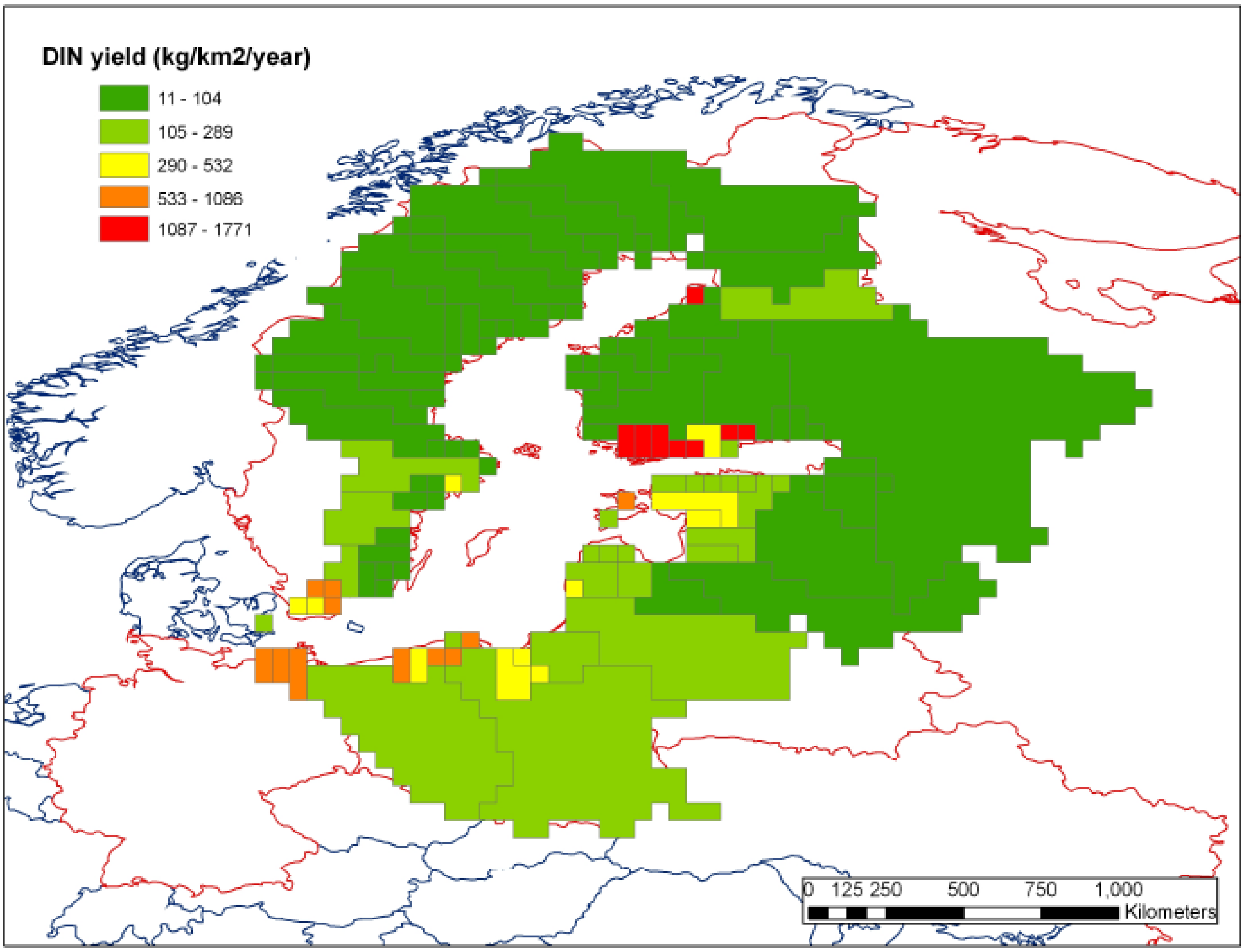
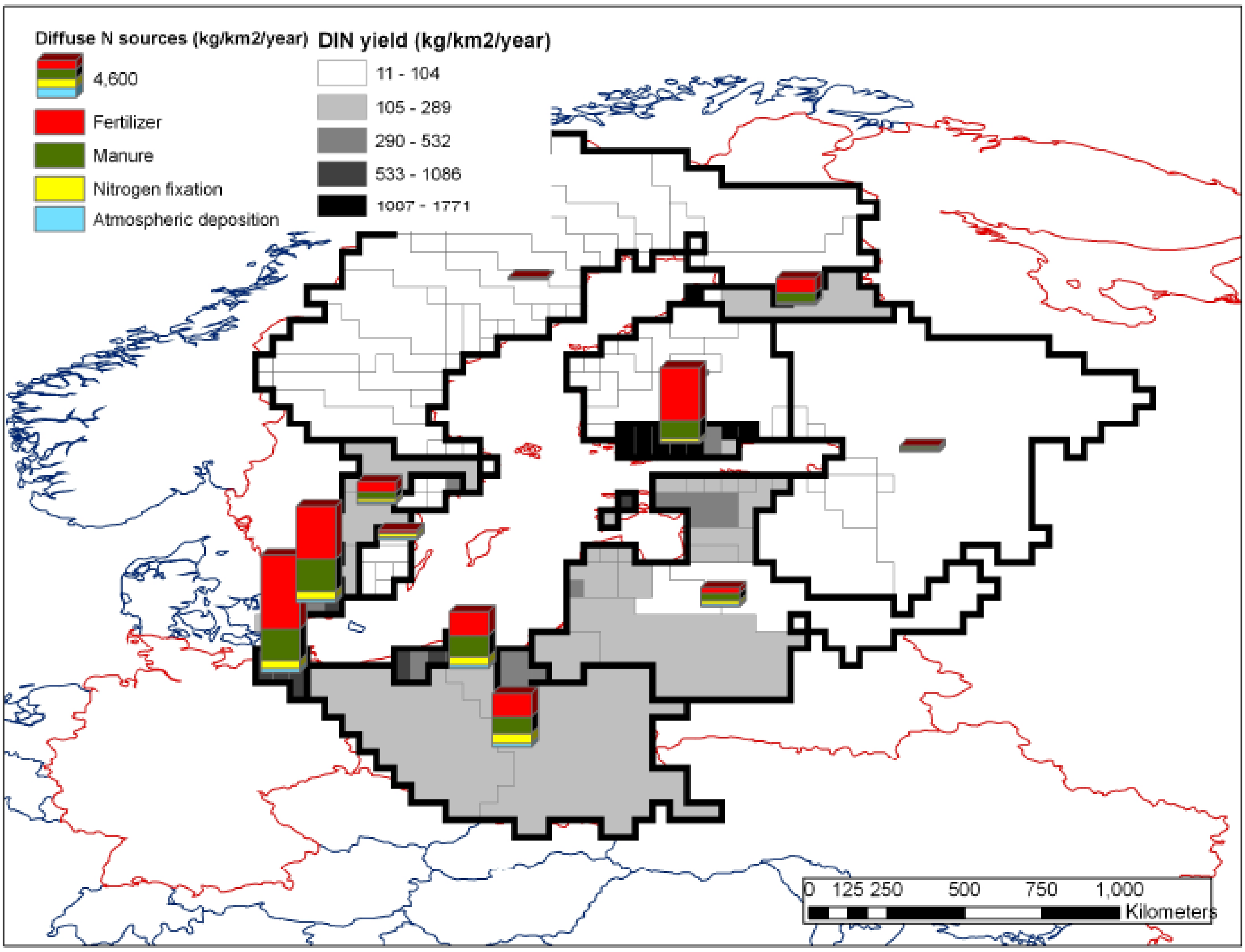


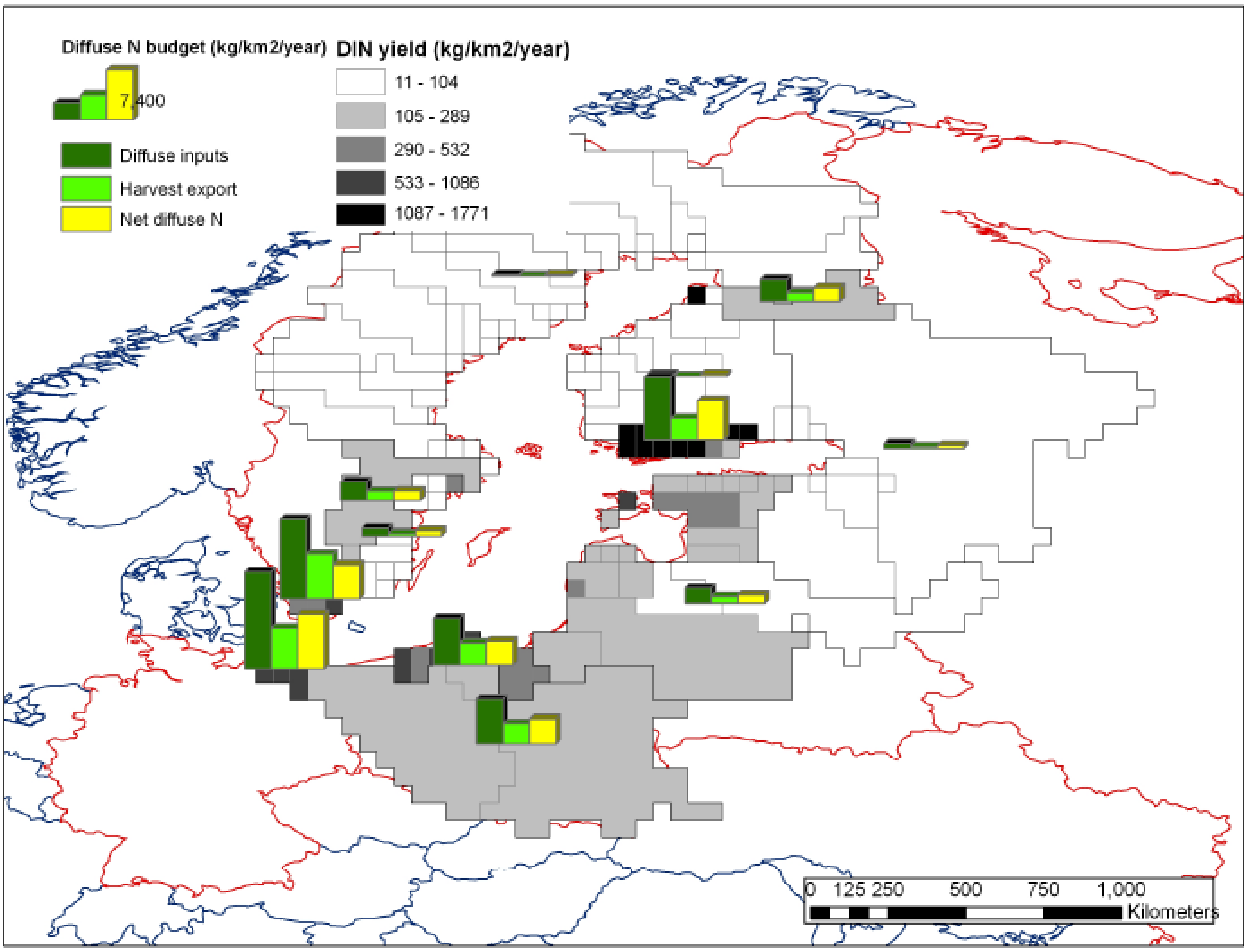
Figure 39. Nitrogen inputs to Baltic watersheds in NEWS-DIN



Export with the harvest partially removes nitrogen inputs from the watersheds. The difference between diffuse sources and harvest export forms the net diffuse N input, i.e. the DIN pool potentially available for leakage from the root zone (Figure 40). In predominantly agricultural regions the harvest removes about 40 % of landscape N inputs and around 10% in forested boreal regions. Net diffuse N inputs show the same spatial patterns as diffuse nitrogen sources, indicating that the additional N input from agriculture is by far more important than the different magnitude of harvest N removal.

Because denitrification and leakage from the root zone occur in soils at all times, harvest removal percentages below 100 % do not mean per se that agriculture is inefficient in Baltic catchments. On the other hand, since agriculture is the dominant nitrogen source for the Baltic Sea, nitrogen application should be optimized not only to maximize the harvest, but economic incentives should also be provided to reduce the leakage of nitrogen from the root zone.

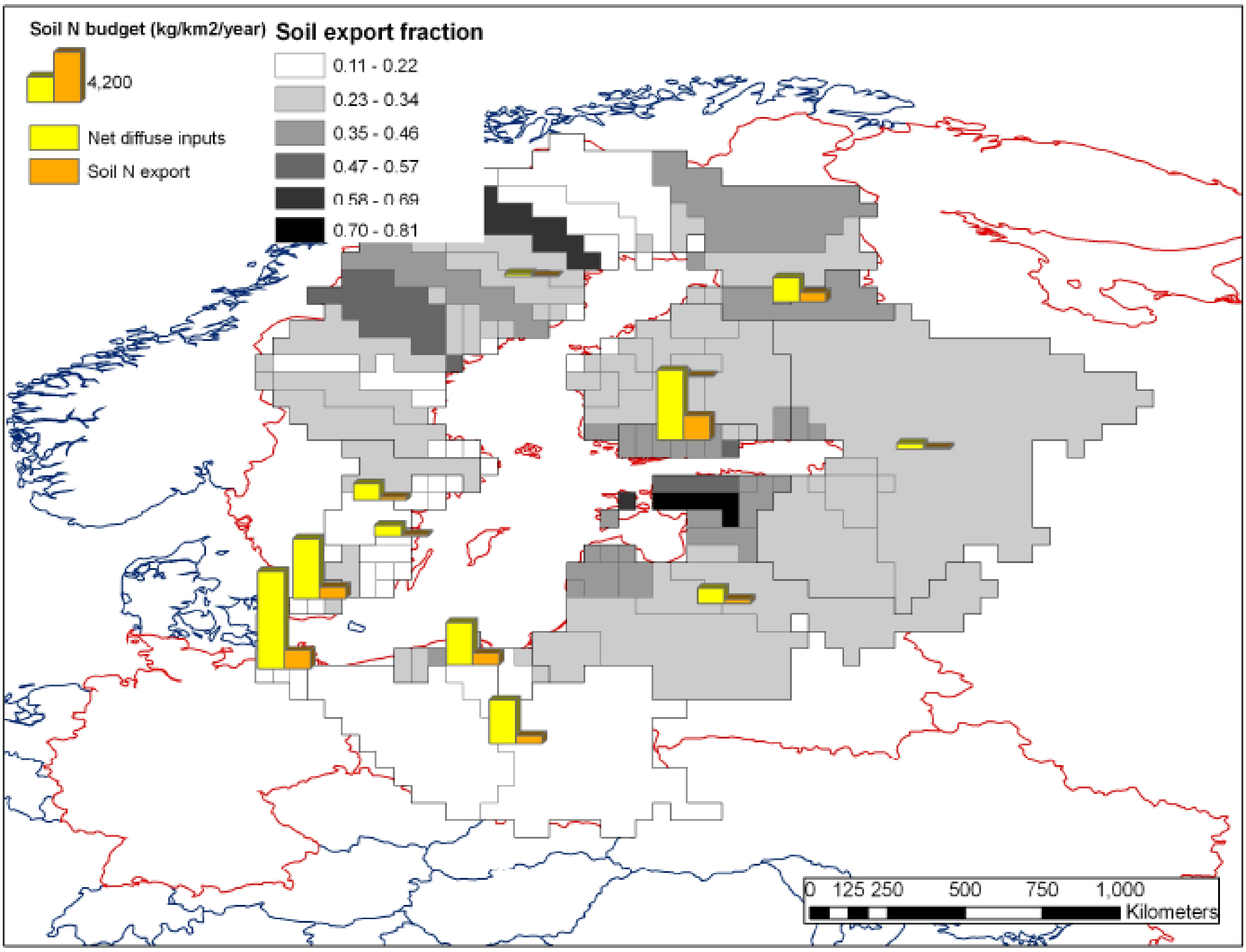
Figure 40. Soil diffuse N budget in NEWS-DIN



DIN removal in soils and along groundwater flow pathways is considerable, therefore mostly only 20 – 30 % of the net diffuse N input reaches watercourses (Figure 41). Soil export is lower in the loamy areas of Poland and Southern Sweden and significantly higher (50 – 80 %) in several other catchments. Though the magnitude of diffuse inputs is still clearly visible, soil properties distinctly influence the spatial distribution of soil nitrogen export. For example even though the net diffuse N input in Northeast Germany is larger than in Southern Finland, soil export shows the opposite trend.

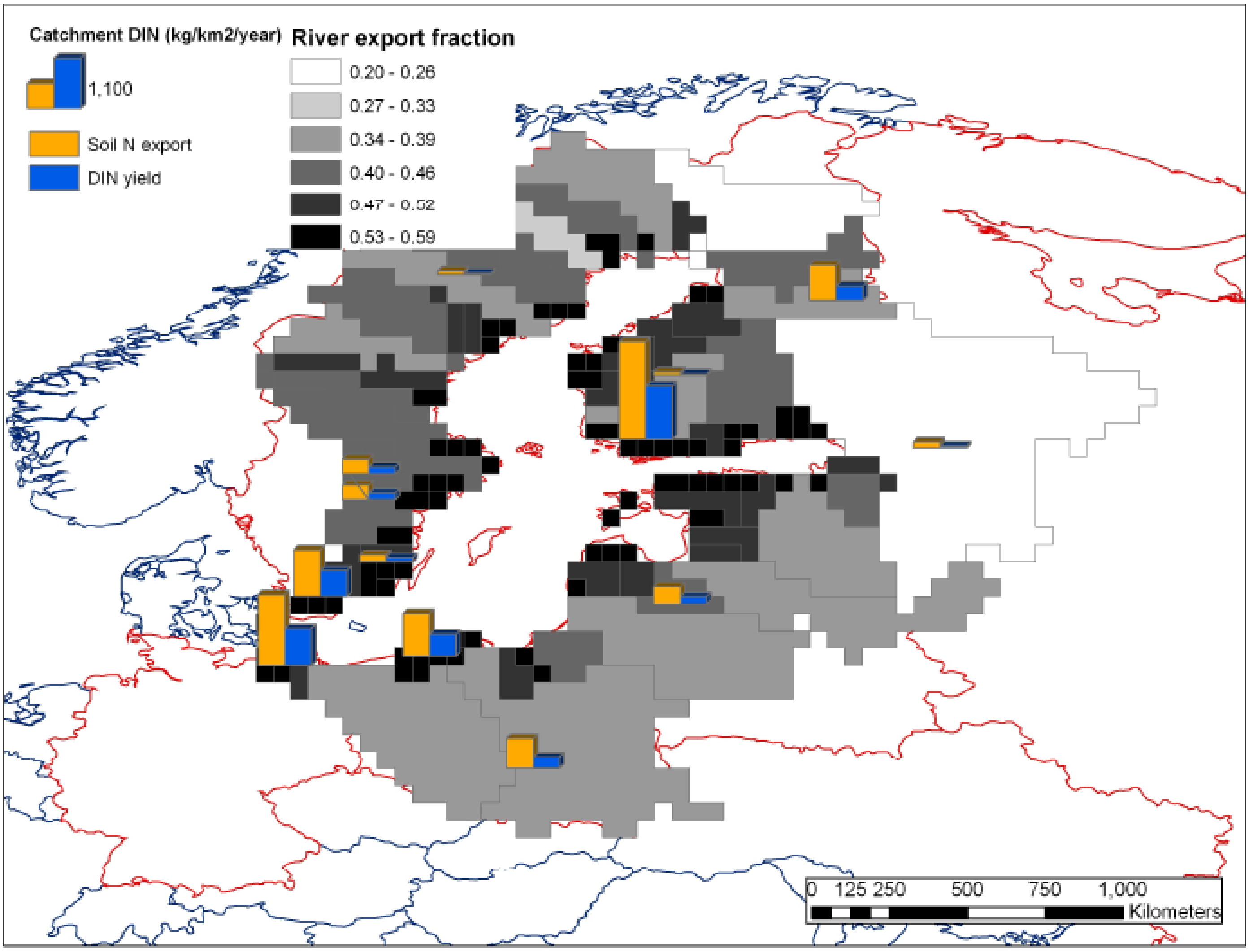
NEWS-DIN predicted between 20 – 60 % of DIN leached from soils to watercourses is further exported to the sea (Figure 42). The river export fraction is generally high in coastal catchments with short watercourses and lowest in catchments with a high proportion of lakes and wetlands, for example the drainage area of the Eastern Gulf of Finland. Still, the nitrogen input signal from agricultural land use is clearly visible in the spatial distribution of the DIN yields.

Figure 41. Export of net diffuse N from soils in NEWS-DIN



According to NEWS-DIN, agricultural inputs are the single most important source for DIN loads to the Baltic Sea. This finding agrees well with the results of the 4th Baltic Sea Pollution Load Compilation [HELCOM, 2003] and with the source apportionment conducted by the European Environment Agency [EEA, 2005]. Spatial patterns predicted by NEWS-DIN also suggest, that coastal catchments are more susceptible to nitrogen export as compared to regions distant from the sea.

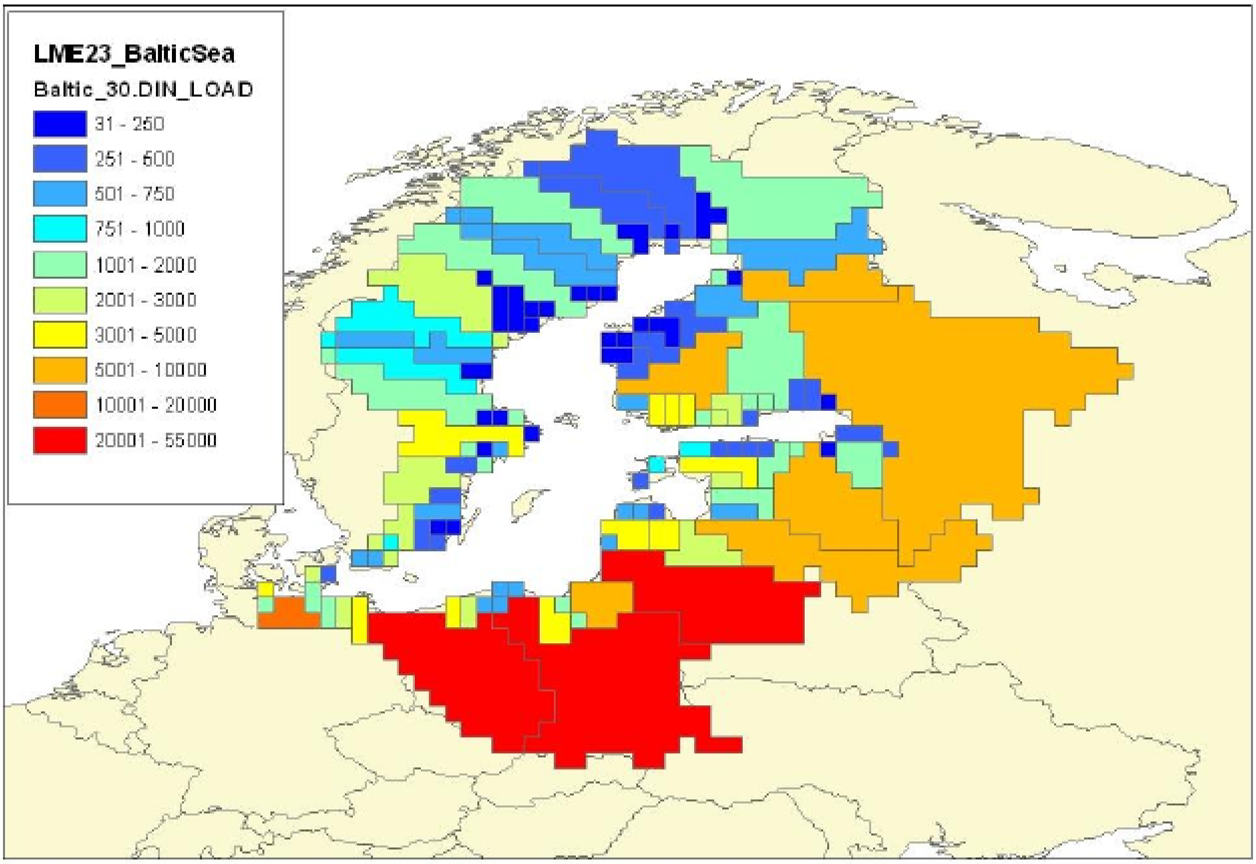
Figure 42. DIN delivery and retention in watercourses modeled by NEWS-DIN



Results for future (2030) business-as-usual conditions

Predicted dissolved inorganic nitrogen (DIN) export for each basin draining into the Baltic Sea for year 2030 (Figure 43), as well as the contribution of each DIN source was calculated during the second workshop. According to NEWS-DIN calculations, in year 2030 under business-as-usual conditions southern regions contribute more DIN to coastal zones than northern Baltic regions. The Nemuna, Wisla and Odra river basins demonstrate some of the highest N-export values, which is consistent with their high population densities and high levels of agricultural activity.

Figure 43. Model predicted dissolved inorganic nitrogen (DIN) export values for Baltic river basins (Ton- N/basin/year).



In accordance with the NEWS-DIN model prediction for 1995 and 2030 under business-as-usual conditions, in most subregions DIN yield in time will be reduced (Figure 44). Increases in DIN yield are associated with highly-populated areas – Stockholm (Sweden), Kohtla – Jarve (Estonia), Kaliningrad oblastj (Russia), Gdansk (Poland). Small decreases in DIN yield (green cells) are a result of implementation European Union Common Agricultural Policy.

Nitrogen and phosphorus enter the Baltic Sea either as waterborne or airborne inputs. In 2000, these inputs amounted to 1,009,700 tonnes of nitrogen and 34,500 tonnes of phosphorus. About 75 % of the nitrogen entering the Baltic Sea is as waterborne input and 25 % as airborne input.

Agriculture and managed forestry contributed almost 60 % of the waterborne nitrogen inputs to the sea (Figure 45 and 46), while 28 % entered from natural background sources and 13 % came from point sources. The airborne nitrogen input has been calculated as direct atmospheric deposition on the Baltic Sea. It originated from emissions to the air from inside as well as outside the Baltic Sea catchment area and from ship traffic from *HELCOM*, [2005]. The intensively farmed areas in southern Sweden and Finland and intermediate levels in Poland and the Baltic States are reasons for increases of fertilizer and manure DIN.

Figure 44. Comparisons of DIN yield (kg N km^{-2} yr^{-1}) for Baltic Sea LME basins.

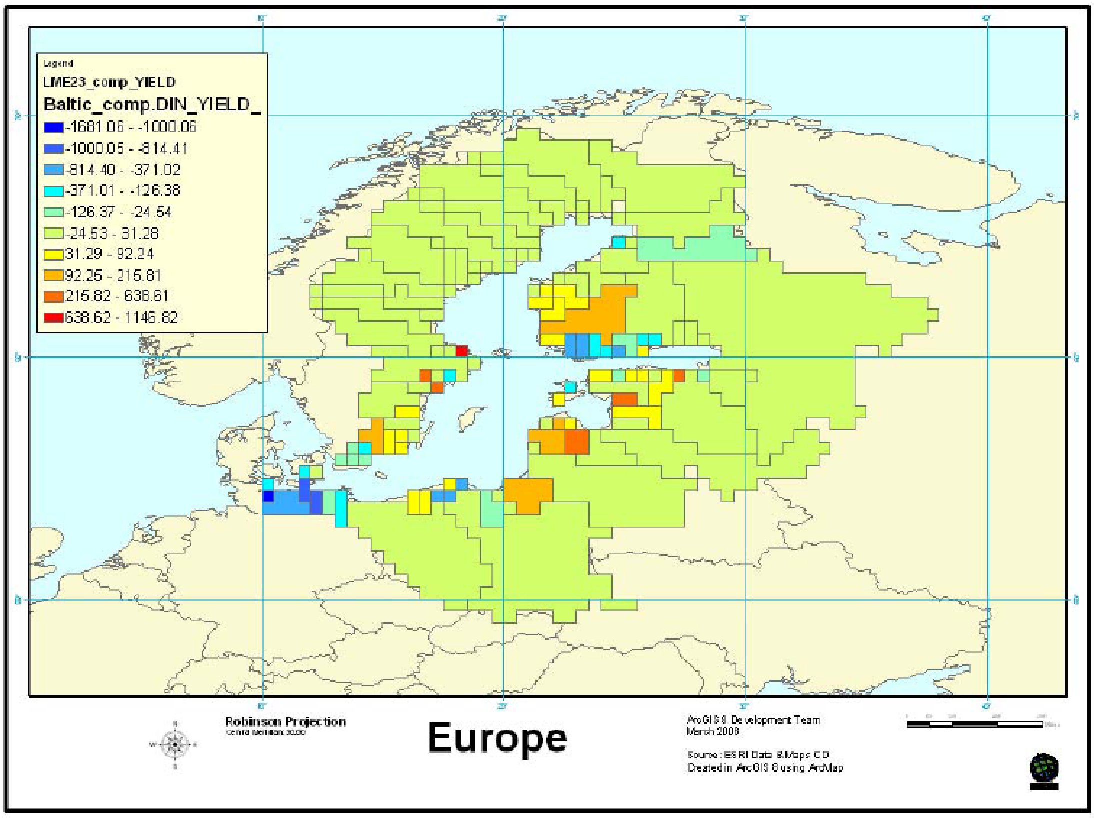


Figure 45. Comparisons of DIN export from fertilizer use (kg N km^{-2} yr^{-1}) for Baltic Sea LME basins.

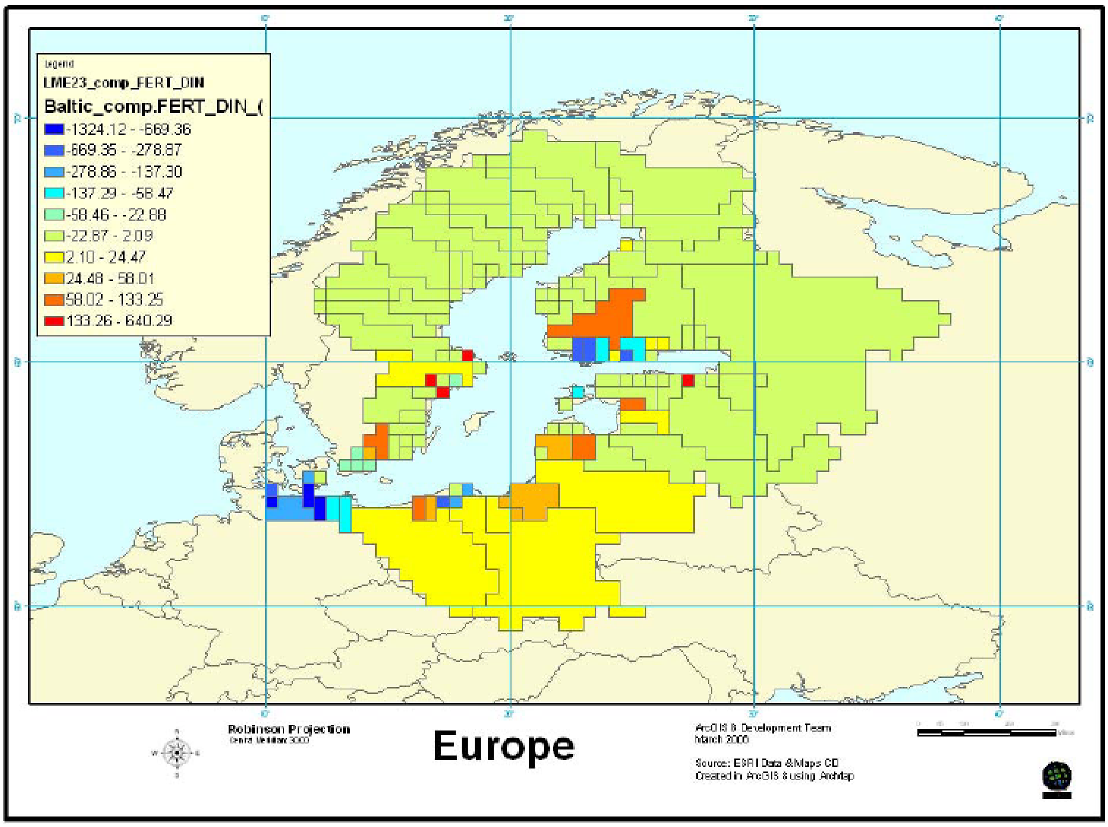
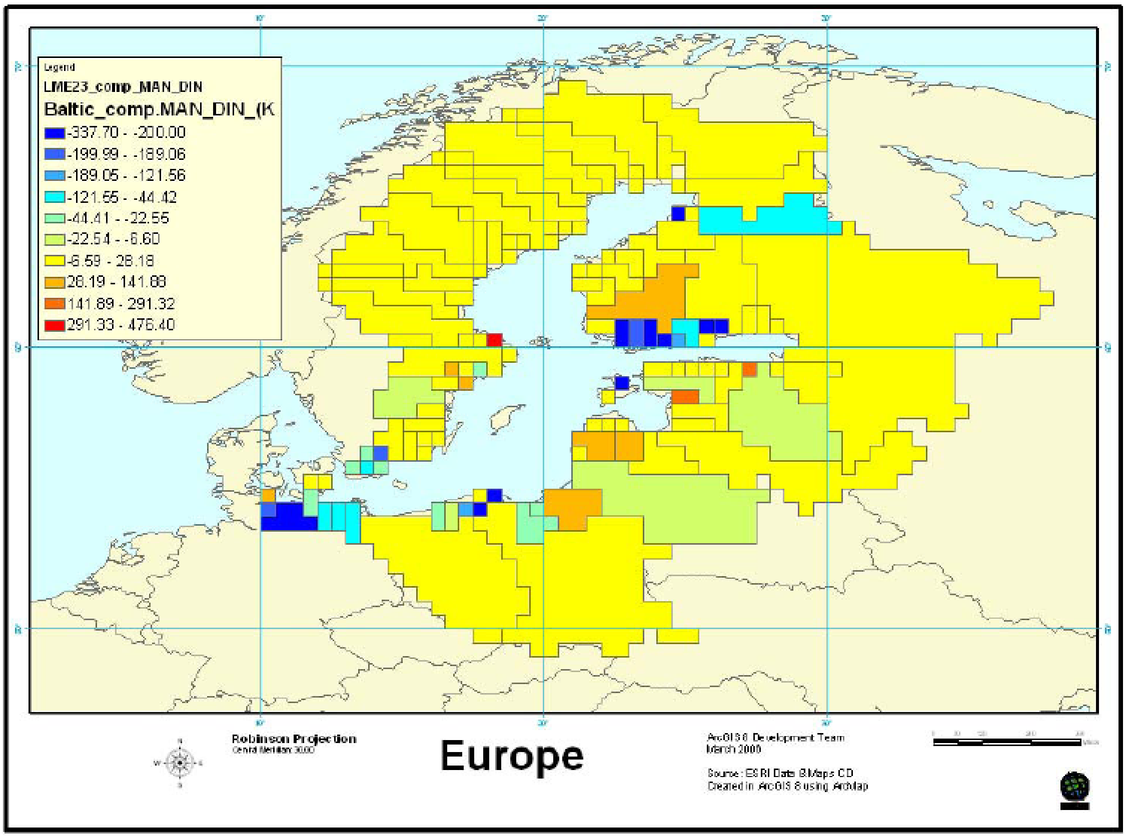


Figure 46. Comparisons of DIN export from manure use (kg N km^{-2} yr^{-1}) for Baltic Sea LME basins.



EU regulations have contributed to stricter controls on industry and municipal wastewater treatment plants. The goal of the EU investments is to ensure that all wastewater is collected, treated and disposed of in accordance with EU Directive 91/271/EEC, Urban Wastewater Treatment Directive. These goals can be attained by building new wastewater treatment plants and reconstruction, extension and/or rehabilitation of existing wastewater systems. As a result nutrient pollution from point sources has decreased significantly especially in former Soviet Union countries such as Latvia, Lithuania, Estonia and Poland (Figure 47).

Comparison of model predictions of DIN export for Baltic Sea river basins (Figure 48) shows trends that can be observed between 1995 and 2030 under business-as-usual conditions. Because DIN export from basins is calculated taking into account a variety of parameters, it is difficult to explain values. In general, decreased DIN export is related to improved functioning of wastewater treatment plants, and increased DIN load is related to agricultural activities that do not yet fulfill EU legislation requirements.

Figure 47. Comparisons of DIN export from sewerage use (kg N /km^{-2} yr^{-1}) for Baltic Sea LME basins.

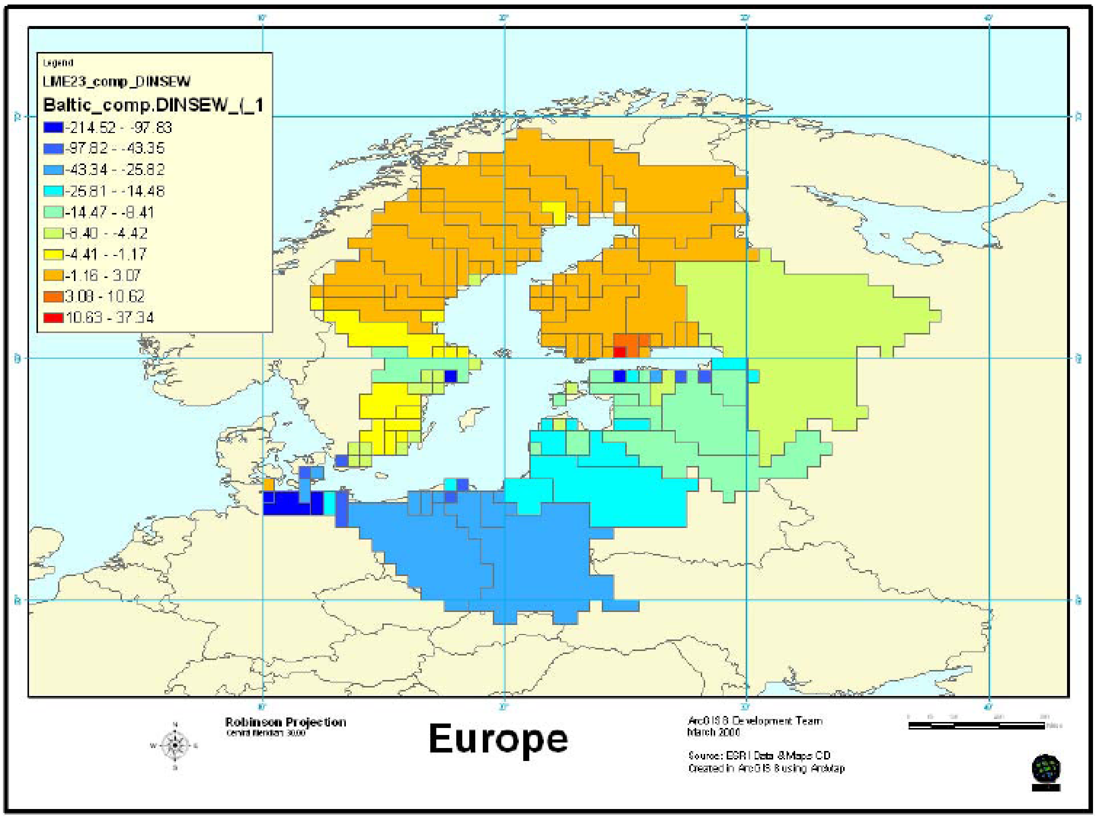
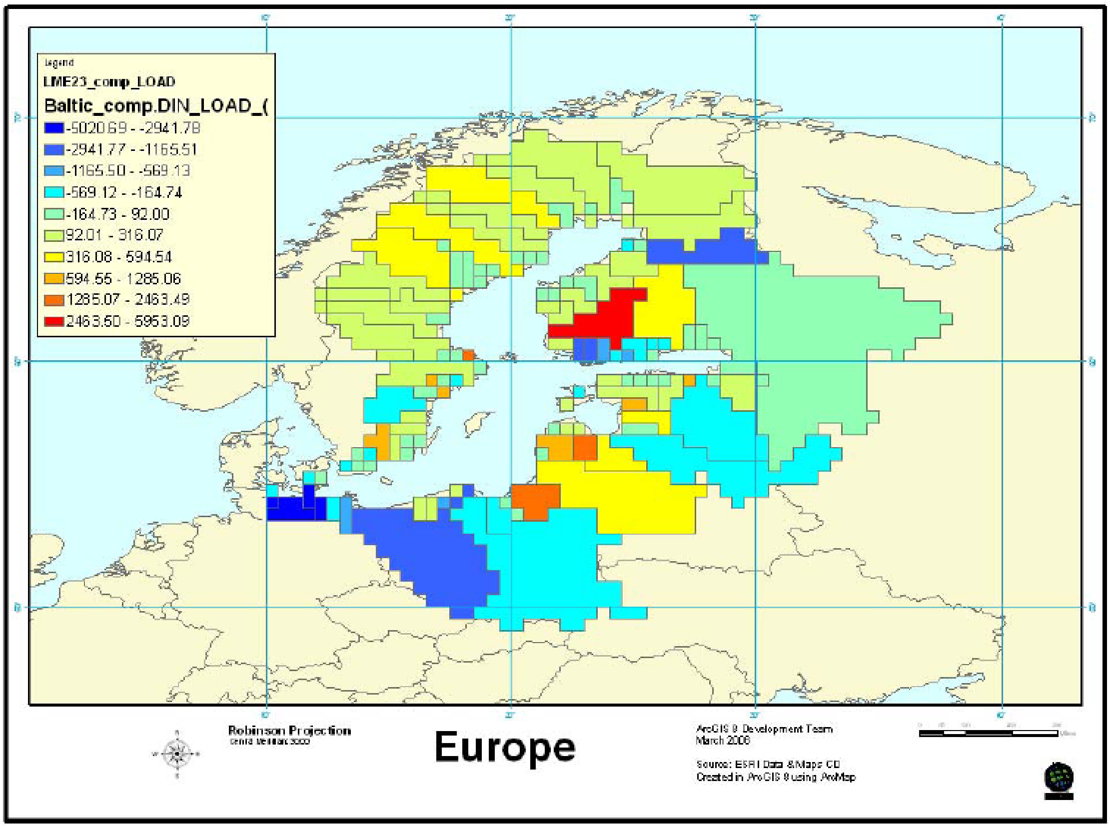


Figure 48. Model predicted DIN export for Baltic river basins (Ton-N/basin/year).



Baltic Sea LME nutrient load reduction strategies

There is no clear consensus among Baltic scientists whether nutrient load reduction strategies should focus on nitrogen, phosphorus or both nutrients [*Naturvårdsverket*, 2006]. Even though the Baltic Sea is generally considered nitrogen limited, both nitrogen and phosphorus loads affect its environmental quality. Summer blooms of toxic cyanobacteria benefit from water column phosphorus surplus [*Bianchi et al.*, 2000] and will decrease only with improved balance between N and P pools [*Kiiriki et al.*, 2001].

Further, coastal regions under freshwater influence are often phosphorus limited; therefore their ecological status requires phosphorus input reductions. Long-term eutrophication effects in the Gulf of Riga, a subbasin of the Baltic with high freshwater input, appear to be more related to phosphorus accumulation than nitrogen dynamics [*Aigars et al.*, 2008]. Experience from the Stockholm Archipelago shows that the region benefited both from initial phosphorus removal as well as from subsequent nitrogen abatement [*Naturvårdsverket*, 2006].

Even though the effects of nutrient load reductions seem to vary spatially and are difficult to predict, there is a growing consensus that load reductions should be achieved in a cost-efficient way. Initially, nutrient load reduction efforts in the Baltic started from a 50 % load reduction goal proclaimed by the Ministers of the Environment of the Baltic Sea countries in the 1988 HELCOM Ministerial Declaration. The reduction goal was achieved only in the Baltic countries, primarily due to extremely low runoff in the target year compared to the “wet” baseline year. It also became evident, that marginal abatement costs differ between Baltic Sea riparian countries and therefore the 50 % reduction goal in each country should be replaced by a cost-efficient strategy [*Ollikainen and Honkatukia*, 2001].

However, cost-efficient allocation of nutrient abatement also changes the spatial pattern of desired impacts as well as undesired side-effects, e.g., the distribution of cyanobacteria blooms [*Schernewski and Neumann,* 2002]. A decision- support system has been developed as a scientific base for cost-effective measures to reduce nutrient loads to the Baltic Sea within the Swedish MARE project [*Wulff et al.*, 2001, http://www.mare.su.se].

With the adoption of the Baltic Sea Action Plan, the 50 % reduction goal was replaced by scientifically justified targets. Water transparency during summer was chosen as an integrative indicator of eutrophication effects and its desired status was defined allowing a 25 % deviation from conditions before the onset of eutrophication. Permissible nutrient loads to achieve the desired water transparency levels were further estimated by biogeochemical modelling. Consequently, for each of the Baltic Sea subbasins and each of the HELCOM countries, the Action Plan defines phosphorus and nitrogen load reduction targets, which must be reached by 2016.

The socio-economic costs of nutrient load reductions are region specific and depend among others on types of measures that have not been implemented yet. Initially, phosphorus load reductions are easier to achieve and involve lower abatement costs than nitrogen reduction, since about 20 % of the phosphorus load originates from point sources, which can be easily removed by improved waste water treatment [*Gren et al.*, 1997]. Water and nutrient transport between Baltic Sea subbasins principally allow allocation of Baltic Sea nutrient abatement measures between the riparian countries, especially between countries sharing a Baltic subbasin [Gren and Wulff, 2004].

At the same time, local eutrophication effects in estuaries, semi-enclosed bays and coastal areas might demand strict local nutrient reduction targets, especially where local sources impair water quality beyond the ecological quality criteria set by the Water Framework Directive or where local uses, especially tourism, demand high water quality [*Schernevski and Neumann*, 2002].

Initial (mechanical and biological) waste water treatment as well as some agricultural abatement measures reduce nitrogen and phosphorus load simultaneously, e.g., reductions in livestock, change of manure spreading time and wetland restoration [*Gren et al.*, 1997]. A Finnish scenario calculation [*Helin*, 2006] showed that phosphorus loads from agriculture mostly decrease simultaneously with nitrogen runoff, but reductions are much smaller. Constrained by a limited nitrogen load, farmers would maximize their profit by reducing fertilizer use, implementing buffer strips, and replacing cultures leading to high nutrient leakage by less demanding crops. Predicted loss of profit for a typical Finnish farm at 50 % reduction in nitrogen leakage is on the order of 20 %, while the associated phosphorus load reduction is estimated to be about 5 %.

Currently, the discussion of nutrient load reduction to the Baltic Sea focuses on the load to the sea itself. However, it has to be kept in mind that in many cases, the protection of inland waters and groundwater bodies may also require load reductions. Lakes, especially, are more likely to be phosphorus limited than marine waters. Relevant EU legislation governing the permissible loads to inland regions and groundwaters are the Urban Wastewater Directive, Nitrates Directive and the Water Framework Directive, which includes also the ecological state of marine coastal waters.

With respect to agriculture, the EU Common Agricultural Policy (CAP) and its subsidy system is a powerful driver in the European Union, which, after the accession of Poland, Lithuania, Latvia, and Estonia in 2004, covers the majority of the Baltic catchment area. The 2003 reform of the CAP, whose implementation started in 2005/2006, continues to decouple subsidies from the amount produced, contains agri-environmental measures and introduces “cross-compliance” requirements to maintain public, animal and plant health, environment and animal welfare. The cross-compliance requirement foresees subsidy cuts when existing legislation is violated. Implementation of cross-compliance control is the responsibility of the EU member states (EC 796/2004).

Existing legislative tools as well as economic incentives provided by the EU and on the national level should be coordinated to reduce nutrient inputs to inland and marine waters. On the drainage basin level, implementation of abatement measures will appear on the political agenda after the first water quality assessment cycle under the Water Framework Directive is completed with submission of River Basin Management Plans in 2009. For coastal waters it is expected that the good ecological quality target will not be met in many areas of the Baltic. River Basin Management Plans will contain measures suggested to improve water quality, together with an estimate of their economic costs.

NEWS-DIN results suggest that parts of the Baltic Sea drainage basin are more susceptible to nutrient export. Spatially explicit models, which are already in use in several Baltic Sea countries, could help in identifying sensitive areas and in focusing abatement measures. In parallel with improved scientific justification of permissible loads to water and groundwater bodies, spatially disaggregated modeling of nutrient export – pending the availability of input and calibration data – should become a powerful spatial planning tool.

YELLOW SEA LME

Contributed by workshop participant: Qilun Yan

Among the 64 Large Marine Ecosystems (LMEs) in the world, the Yellow Sea LME has been one of the most significantly affected by human development [*Vander Molen and Boers* 1998, *Duan and Zhang* 1999]. Nearly 30 rivers drain to the Yellow Sea from the west and east, so these rivers bring many nutrients and pollutants from the land into the ocean [*Li and Yang* 2004, *Xia et al.*, 2001]. As the population and economy quickly develops, the environmental problems of the Yellow Sea become more and more serious. The increase in nitrogen export has been related to decreases in coastal biodiversity and increased frequency and severity of harmful and nuisance algal blooms. Therefore, the Yellow Sea LME is increasingly threatened by increases in the export of nutrients.

Figure 49. NEWS-DIN predicted DIN export in 1995 (top) and 2030 under business-as-usual conditions (bottom left) and the difference between 2030 and 1995 (bottom right) for Yellow Sea Basins.

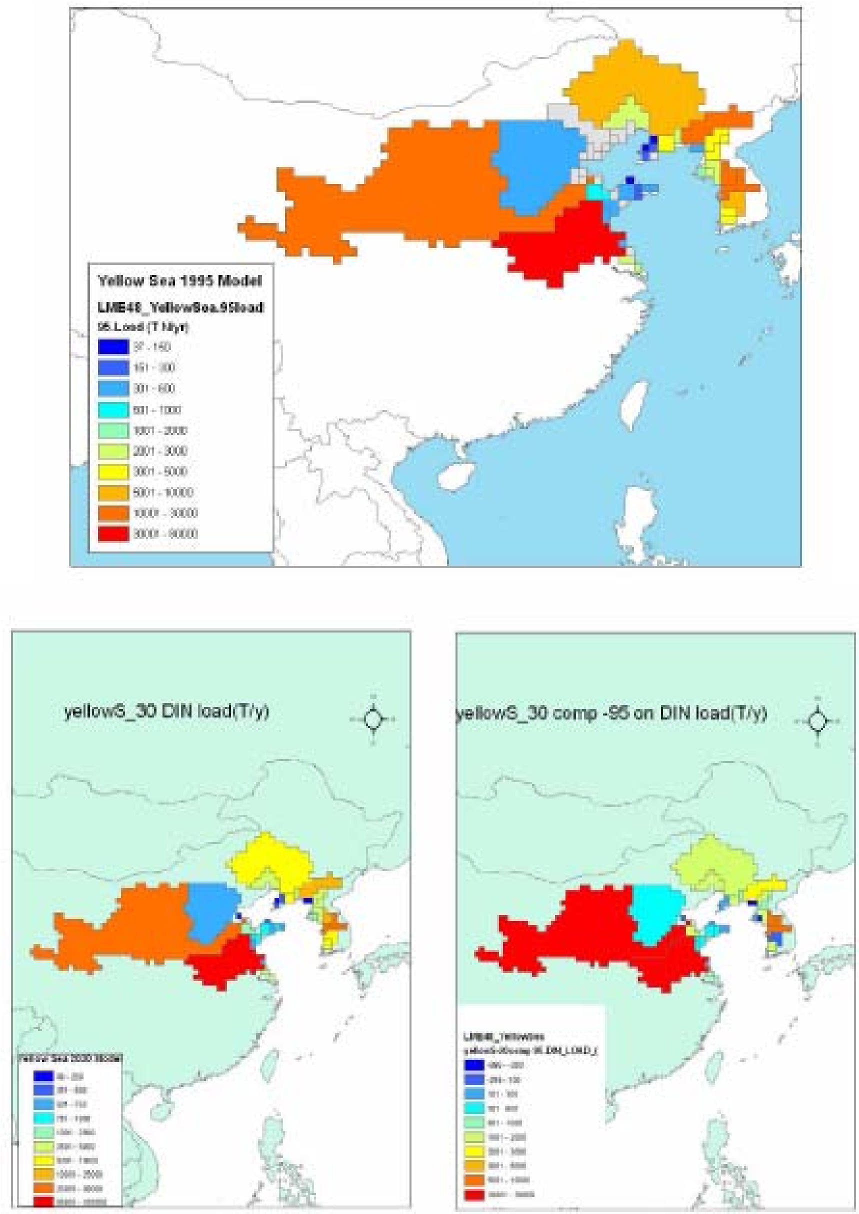
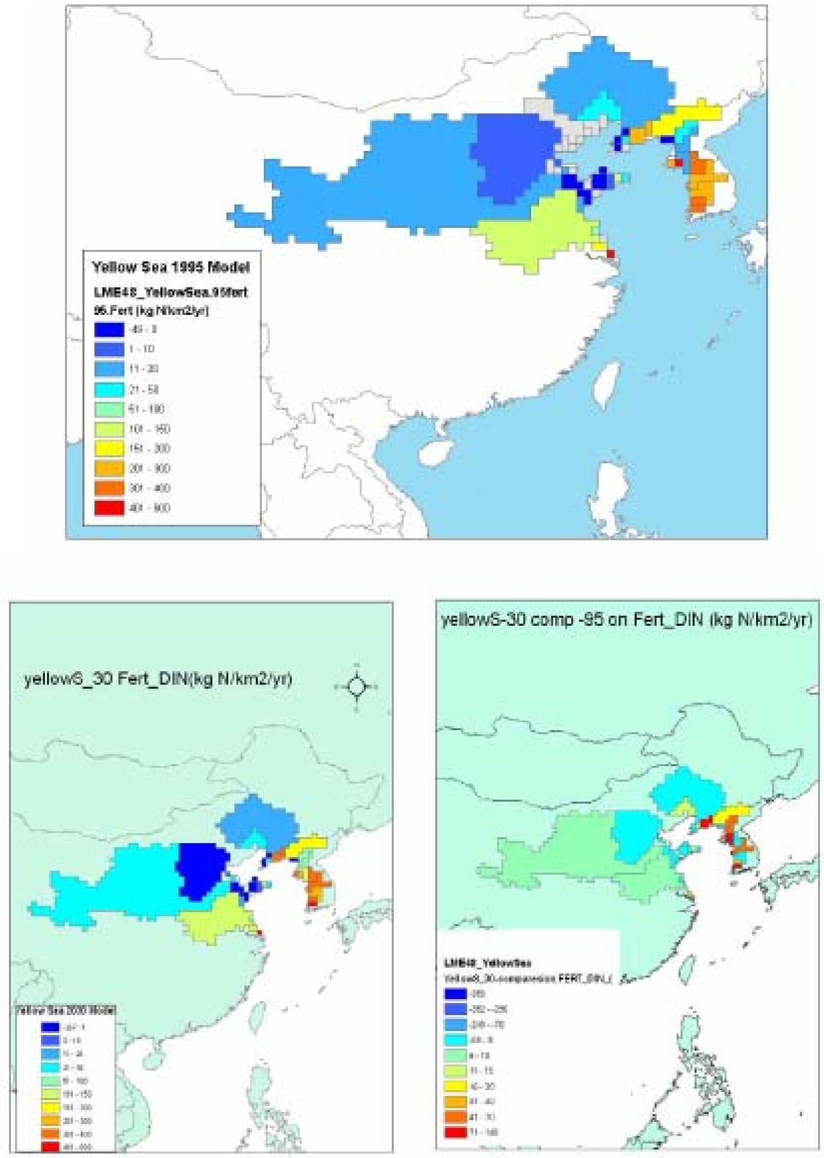


Figure 50. NEWS-DIN predicted fertilizer export in 1995 (top) and 2030 under business-as-usual conditions (bottom left) and the difference between 2030 and 1995 (bottom right) for Yellow Sea Basins.



Dissolved Inorganic Nitrogen (DIN) export from each basin draining into the Yellow Sea was estimated using the Global News-DIN model for 1995 and 2030 under business-as-usual conditions. The total load and contribution of several main sources of export in both years (Figure 49-52) was compared. From the model results, current DIN export to the Yellow Sea mainly comes from fertilizer application and manure excretion, but in the next twenty years, the sewage input will increase. According to NEWS-DIN calculations, the southern Yellow Sea regions contribute more DIN to coastal areas than northern Yellow Sea regions (Figure 49). This is because the southern Yellow Sea regions contain more agricultural land than the north, and population density is greater than in the north.

The model results demonstrate high DIN export values for the Yellow River basins (Figure 49), which may be caused by high-density agricultural activities, lower efficiency fertilizer utilization and large areas of soil erosion in these regions. NEWS-DIN suggests that fertilizer and manure N is the dominant source in most Yellow Sea basins, especially in southern Yellow Sea regions. In northern Yellow Sea regions, the NEWS-DIN model predicts that most inorganic nitrogen input is from the Yalu River.

Based on NEWS-DIN model predictions, the amount of DIN exported to the Yellow Sea LME will increase greatly from 1995 to 2030 under business-as-usual conditions. According to the National 11th Five Year Plan of China, the amount of DIN exported to the coast will be decreased at least 10 percent in the next year. This goal will be difficult based on the results of the NEWS-DIN model. To be successful, the amount of DIN exported to the Yellow Sea LME must be reduced for the Yellow Sea LME to improve by 2030 under business-as-usual conditions.

As urbanization increases and more and more people move to coastal areas, although sewage treatment efficiency increases, sewage DIN input to the Yellow Sea LME does not decrease from 1995 to 2030 under business-as-usual conditions. More work is necessary to control sewage N input to the Yellow Sea LME. It is also necessary to improve the efficiency of fertilizer use and manure production.

Figure 51. NEWS-DIN predicted sewage export in 1995 (top) and 2030 under business-as-usual conditions (bottom left) and the difference between 2030 and 1995 (bottom right) for Yellow Sea Basins.

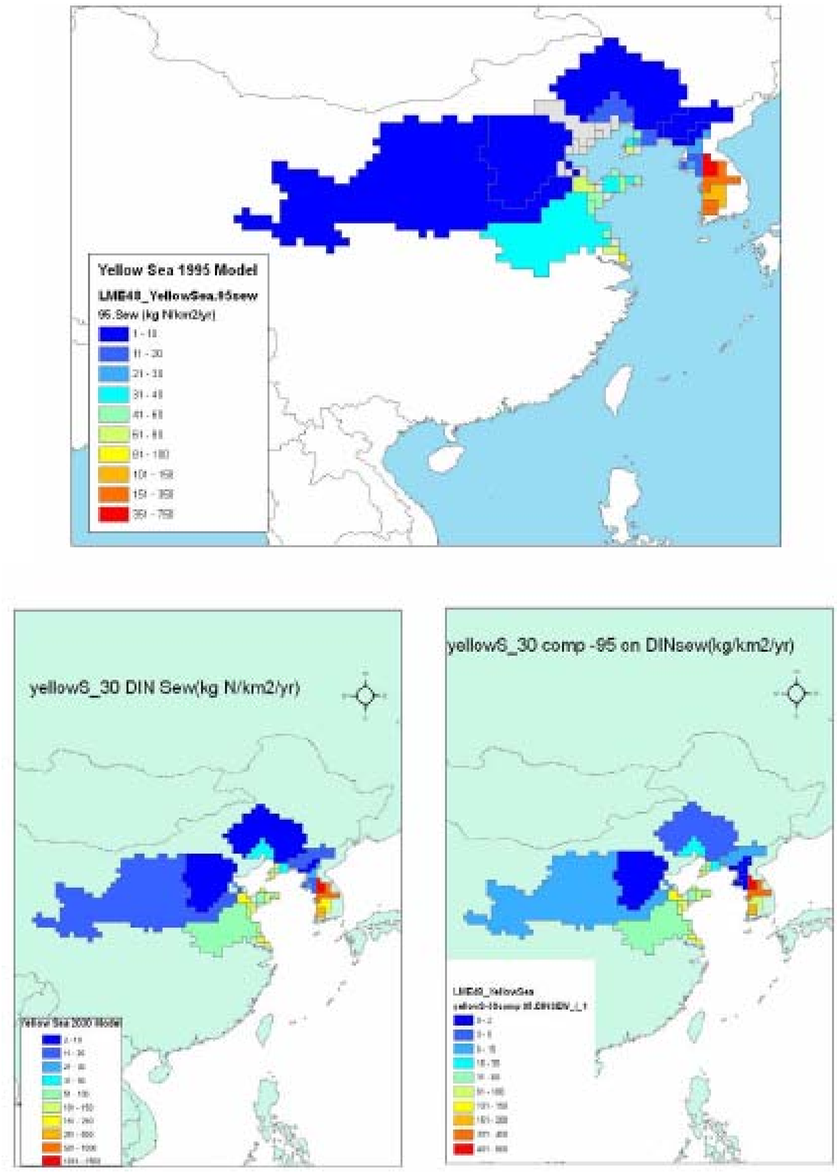
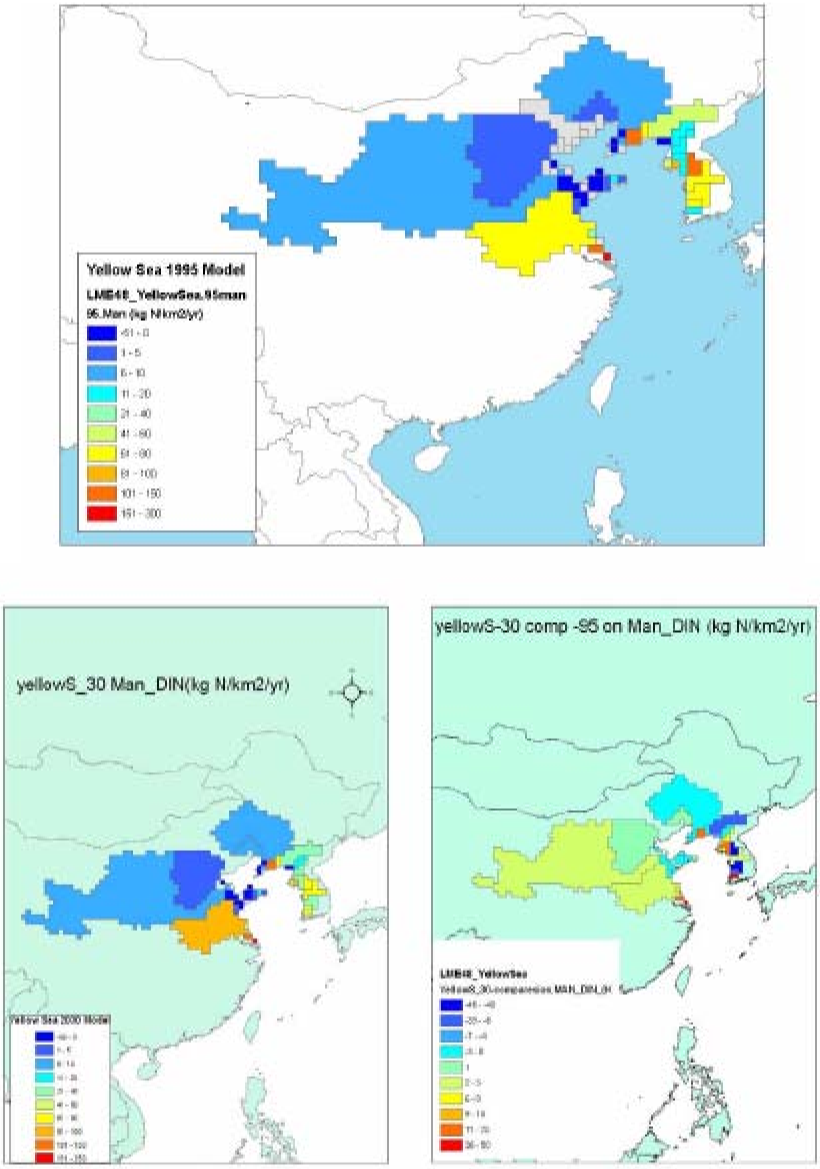


Figure 52. NEWS-DIN predicted manure export in 1995 (top) and 2030 under business-as-usual conditions (bottom left) and the difference between 2030 and 1995 (bottom right) for Yellow Sea Basins.



VII – Long-term Activities of the Workshop Participants Enabled by the Training Workshops

As highlighted in section IV, mechanisms for long-term communication among UNESCO-IOC Eutrophication Network participants were established. Consequently, participants have been able to integrate themselves into a broader network of scientists working on eutrophication related issues around the world.

As a result of this long-term communication, six major activities with the workshop participants developed after the conclusion of the UNESCO-IOC workshops, specifically:

1) Manuscripts

Two manuscripts were identified by workshop participants to be developed as a group. Mr. Jorge Herrera-Silveira (Gulf of Mexico LME) is leading a framework paper based on the 1995 vs. 2030 business-as-usual model scenarios, while Mr. Sandor Mulsow (Humboldt Current LME) is leading a paper based on LME ecosystem services. These activities are strengthening the collaboration among the workshop participants and developing their independence from the workshop trainers.

2) Proposals

Mr. Jorge Herrera-Silveira (Gulf of Mexico LME) and Mr. Sandor Mulsow (Humboldt Current LME) have also been included as working group members for a proposal to the Scientific Committee on Oceanic Research (SCOR) to link nutrient inputs to coastal harmful algal blooms. This proposal has now been funded and the first workshop will be held July 2008.

3) Other Workshops

Dr. Sybil Seitzinger informed Mr. G. V. M. Gupta (Bay of Bengal LME) of the Sustained Indian Ocean Biogeochemical and Ecological Research (SIBER) workshop in Goa, India, 3-6 October 2006 and encouraged his participation. Mr. Gupta attended the workshop and is developing a manuscript from the workshop on river nutrient transport from watersheds to Indian Ocean coastal systems.

4) Nitrogen Initiative Conference

An International Nitrogen Initiative (INI) conference was held in Brazil in October 2007. Individuals from academia, government and NGOs participated from diverse disciplines such as agronomy, ecology, biogeochemistry, oceanography, and atmospheric science as well as other sciences dealing with agriculture, animal husbandry, forestry, fishery, and energy production.

Workshop participants were informed of this meeting and encouraged to submit abstracts. This also strengthened collaboration among the workshop participants and continued to integrate them into the broader scientific and policy community. Mr. Sandor Mulsow (Humboldt Current LME) presented his results in a talk entitled "Open Ocean DIN exports to coastal zones from salmon farming in Southern Chile: a GLOBAL-NEWS model evaluation and prediction" and participated in a policy workshop organized as part of a UNEP activity.

5) Networking

Workshop participants' contact information was forwarded to their International Nitrogen Initiative (INI; http://www.initrogen.org) regional centers (i.e., Africa, Asia, Latin America, and Europe Regional Centers) to facilitate direct communication of INI activities and documents, such as a recent (24 April 2007) non-technical review of nitrogen entitled "Human alternation of the nitrogen cycle: Threats, benefits and opportunities" developed by INI/UNESCO/SCOPE.

6) Future Research

A continued interaction with the participants encouraged them to follow through with the above activities. Beyond the current project, their participation in future activities will be considered. A significant overall outcome of these two workshops is the interaction between participants and their local and national government officials.

The integration and exchange between regional scientists and policy-makers is critical for the application of local and advanced knowledge in informed policy decisions.

VIII – Nutrient DIN Loads and Source Apportionment in the 64 LMEs – A Global Perspective

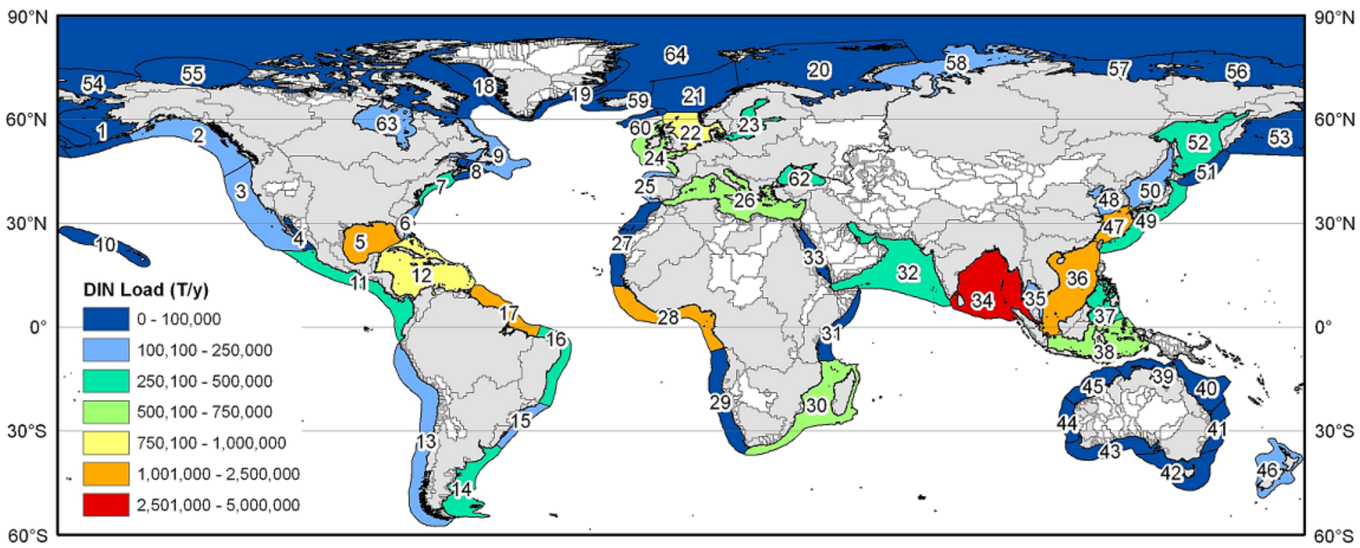
To bridge the gap between land-based activities and LME waters globally, the relative magnitudes and distribution of DIN loading from watersheds to LMEs were examined. Land-based DIN loading to LMEs was evaluated using the spatially-explicit Global NEWS river export model for 1990s conditions with recent updates for LMEs with large watershed basins. DIN loading to each LME was attributed to diffuse and point sources including natural biological fixation, agricultural biological fixation, fertilizer, manure, atmospheric deposition and sewage. Dominant sources of DIN to LMEs were also identified which may be useful for the management of land-based nutrient loading to LMEs. Finally, the relationship between DIN loading rates and primary productivity estimates was examined to evaluate the role of DIN on phytoplankton production in LMEs.

Global patterns of total DIN loading to LMEs

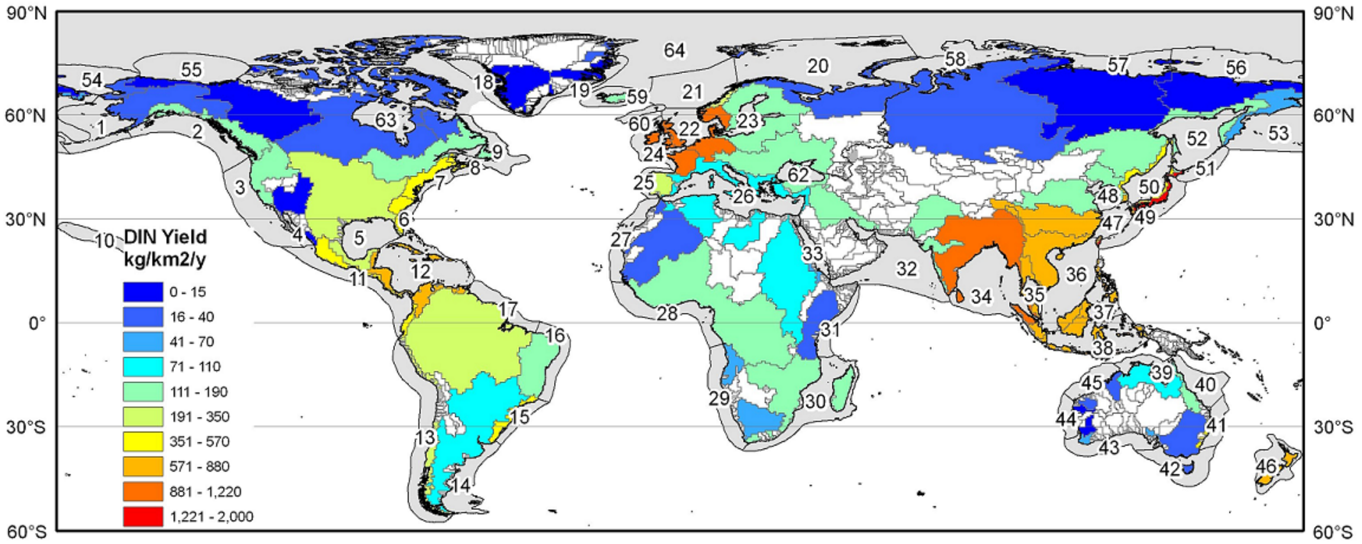
DIN export from watersheds to LMEs varies globally across a large range of magnitudes (Figure 53a). The smallest loads are exported to many polar and Australian LMEs, while the largest loads are exported to northern tropical and subtropical LMEs. While these global patterns of DIN loading to coastal waters are generally known [*Dumont et al.,* 2005], their contribution on a LME level and relationship with marine systems has not been examined previously. The LMEs receiving the largest loads of land-based DIN are the Bay of Bengal, North Brazil Shelf, South China Sea, East China Sea, Guinea Current and Gulf of Mexico LMEs (3.56, 2.01, 1.67, 1.51, 1.16 and 1.08 MT y-1, respectively). Riverine discharge plays a significant role in the export of DIN to LMEs as rivers with the highest coastal discharge drain into these LMEs including the Amazon, Congo and Ganges Rivers.

Figure 53. (**a**). Modeled DIN load to LMEs in T yr-^{1}. Watersheds discharging to LMEs are grey; watersheds with zero coastal discharge are white. *[Lee and Seitzinger, submitted]* (**b**). Modeled watershed DIN yield to LMEs in kg km-2 yr-^{1}.

(**a**)



(**b**).



DIN yields from watersheds discharging to LMEs demonstrate the impact of basin size in combination with anthropogenic nitrogen sources on DIN loading to LMEs (Figure 53b). For example, while the DIN load to the North Brazil Shelf LME is among the highest globally, the watershed drainage area is also large and anthropogenic nitrogen sources in the watershed are quite low, so therefore the areal DIN yield is relatively low. In contrast, a number of LMEs with smaller drainage areas but with large anthropogenic nitrogen sources, such as in northern Europe, the Caribbean, East and Southeast Asia, have relatively more intense DIN yields than their absolute loads to LMEs.

Source Apportionment

Across the 64 LMEs, natural biological fixation, fertilizer, and manure are the dominant primary and secondary sources of DIN (Figure 54). The primary source of land-based DIN export to most polar, sub-Saharan African, and northern Australian LMEs is natural biological fixation, while fertilizer is the primary source to many northern temperate and Southeast Asian LMEs. Manure is the dominant source to the most Central and South American LMEs, and is important as a primary or secondary source to a variety of LMEs globally.

Atmospheric deposition is important in regions where there are few other land-based inputs (e.g., in polar regions such as the West and East Greenland Shelf LMEs), where fossil fuel combustion from development is extreme (e.g., in the North- and Southeast U.S. Continental Shelf LMEs), or where extensive landscape burning occurs (e.g., the Guinea Current LME which is fed by savannah fires in Western Central African watersheds; [*Barbosa et al.*, 1999]).

Sewage is an important source of DIN to only a few LMEs (as a primary source to the Kuroshio Current, Red Sea, West-Central Australian Shelf, and Faroe Plateau LMEs), while agricultural fixation plays an even lesser role globally as a primary source to only the Southwest Australian Shelf LME and a secondary source to the Benguela Current, North Australian Shelf, and West-Central Australian Shelf LMEs.

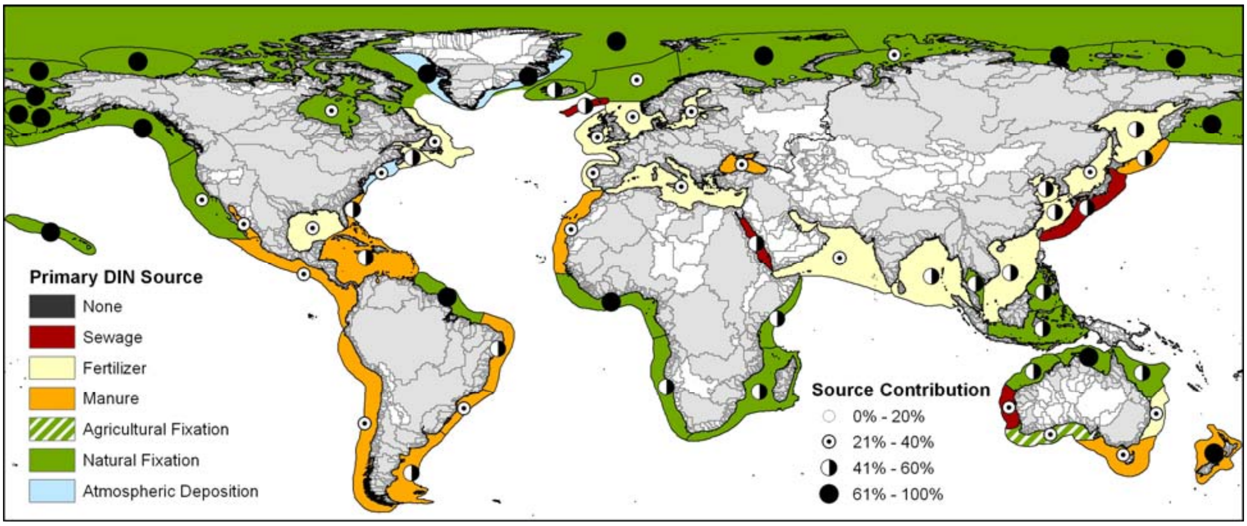
In watersheds draining to LMEs, anthropogenic activities, such as fossil fuel burning and agriculture, contribute to over half of the total DIN load in 73% of LMEs (data not shown). These anthropogenic DIN dominant LMEs are distributed across most continents, except sub-Saharan Africa and most polar regions. Some of the highest proportions (> 90%; *Lee and Seitzinger submitted*) of anthropogenic DIN loads are to European LMEs, such as the North Sea and Mediterranean LMEs, and East Asian LMEs, such as the Yellow Sea and East China

Sea LMEs. In these and the other LMEs receiving DIN from watersheds in developed and developing regions, human activities control the amount of export to LMEs.

Agriculture is a major source of the anthropogenic DIN export to LMEs (data not shown; *Lee and Seitzinger submitted*). There is no agricultural export to most polar LMEs, but in 91% of the LMEs with agriculture occurring in their related watersheds, over half their anthropogenic export is due to agricultural sources such as agricultural biological fixation, manure, and fertilizer. Attribution of agricultural DIN export to these three sources reveals the predominance of fertilizer and manure over biological fixation (data not shown). For example, LMEs with the largest agricultural loads have less than 20% of the total DIN load due to biological fixation and over 50% due to either fertilizer (e.g., Bay of Bengal, East China Sea and South China Sea LMEs), to manure (e.g., Caribbean and North Brazil Shelf LMEs) or to a combination of both (e.g., North Sea and Celtic-Biscay Shelf LMEs) due to local agricultural practices.

Figure 54. (**a**) Primary sources of DIN exported to LMEs; (**b**) secondary sources of DIN exported to LMEs. [*Lee and Seitzinger, submitted*]

(**a**)



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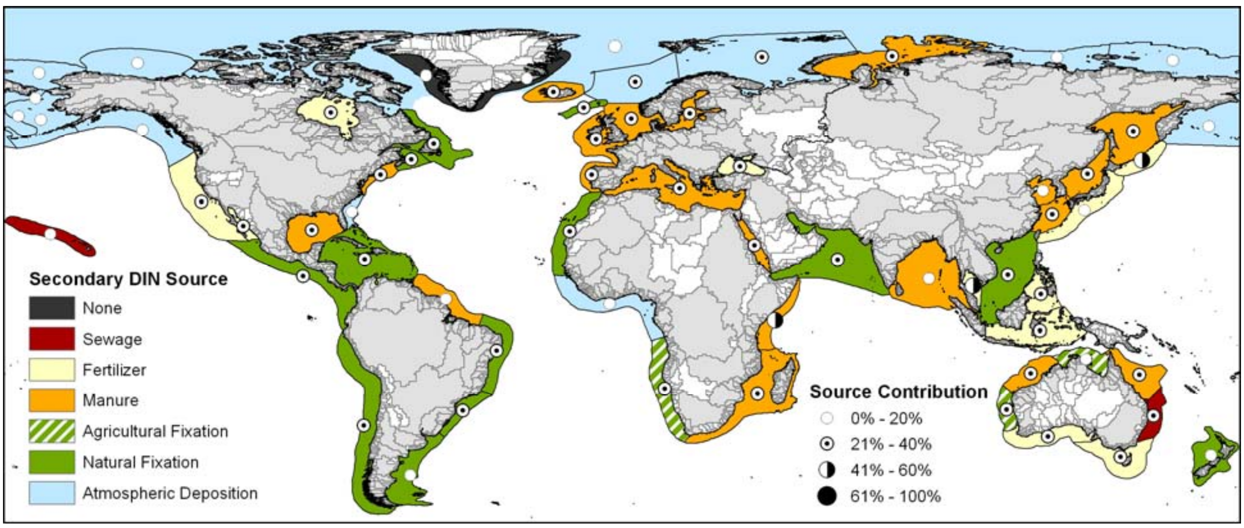
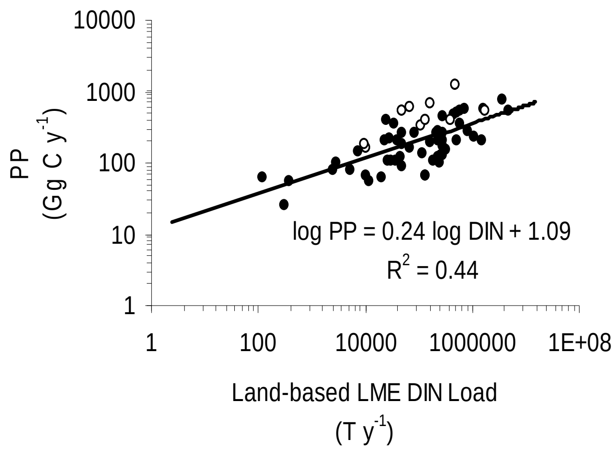


Ecosystem-level Implications

The relationship between land-based DIN load and LME primary production based on modeled SeaWiFS data from the Sea Around Us Project [2007] (Figure 55) suggests that land-based DIN export supports coastal primary production. In areas with upwelling, nutrient-rich bottom waters is an important source of nitrogen for high rates of photosynthetic production, and thus higher primary productivity than predicted by the regression solely with land-based DIN inputs occurs in LMEs characterized by upwelling (Guinea Current, Arabian Sea, Pacific Central-American, Humboldt Current, California Current, Gulf of Alaska, Benguela Current, Canary Current, Northwest Australian, and Southwest Australian LMEs). Nitrogen loading is well-correlated with primary production in a variety of marine ecosystems around the world [*Smith,* 2006, *Cloern,* 2001, *Nixon et al*., 1996] and because of the positive relationship between fisheries production and primary productivity in marine systems [*Nixon*, 1988], DIN loading is potentially an important factor controlling fisheries yield in LMEs.

Figure 55. Logarithmic relationship between primary production in LMEs (from Sea Around Us Project estimates of modeled SeaWiFS data) and land-based DIN load to LMEs. Variance without upwelling-characterized LMEs (open symbols) is 0.51. [*Lee and Seitzinger, submitted*]



– Conclusions –
Response of the GEF/LME Project to Societal Imperatives

Eutrophication of coastal and marine waters is an increasing concern in many world regions. Nutrient pollution causing coastal and marine eutrophication is primarily related to food and energy production in upstream watersheds. The watersheds of ecologically-delineated large marine ecosystems, LMEs, span multiple countries and thus eutrophication issues are transboundary in nature.

This technical report demonstrates how advances in watershed nutrient modelling can improve information on loads and source apportionment of nutrients entering LMEs by rivers. The project focused on dissolved inorganic nitrogen (DIN) modelling using the NEWS-DIN model, which employs multiple inputs at a spatially explicit scale. Such advances result in better understanding, and potentially more effective monitoring and policy development in LMEs. This report also provides valuable information about the structure, performance, and scenario analysis capabilities of the NEWS-DIN model.

The magnitude and sources contributing to DIN export to seven LMEs were explored during two training workshops. Participants included scientists from academia and government agencies within these LMEs. The 7 LMEs included developing countries and countries with economies in transition in Africa, Asia, Latin America and Eastern Europe. There was considerable variation in the magnitude and relative contribution of different sources of DIN across the 7 LMEs. The results of these workshops help to identify areas sensitive to nutrient loading and focus abatement strategies in these LMEs. In parallel with improved scientific assessment of permissible loads to water and groundwater bodies, spatially disaggregated modeling of nutrient export – pending the availability of input and calibration data – should become a powerful spatial planning and management tool.

In view of the fact that the source of the nutrient pollution is primarily related to food production (fertilizer use and animal production) and consumption (sewage) and energy production, which are essential to support the needs of the large human population, it is imperative to improve understanding with updated information. This is an activity that requires urgent attention in each LME. Intensive data generation efforts need to be pursued to fill the gaps of information and update the present model perspective of the DIN input scenarios. In the same order, the development and implementation of best environmental practices and best available techniques for agriculture to reduce discharge of nutrients is deemed necessary. Future measurement, modelling, and synthesis activities at many scales and in many world regions, in concert with policy and economic analyses, will be required to minimize environmental degradation while at the same time meet the food and energy demands of society [*Galloway and Cowling*, 2002].

In some geographical regions, population explosion in the coastal zones has not been accompanied by the requisite expansion in basic facilities and services such as those for water and sanitation. Coastal zone planning has been inadequate or absent in most coastal areas. Consequently, many coastal urban areas lack adequate waste collection, treatment and disposal facilities. Most wastes are therefore discharged into water bodies or onto beaches and river banks.

Based on NEWS-DIN model predictions, the amount of DIN exported to different LMEs is expected to increase significantly from 1995 to 2030, under a business-as-usual scenario. The results suggest the potentially large increases in DIN export in the future in many world regions, particularly in Eastern and Southern Asia. In order to avoid future large increases in N export to coastal systems, a multiplicity of innovative approaches will likely be required. As urbanization increases and more and more people move to coastal areas, although sewage treatment efficiency increases, sewage DIN input to LMEs does not necessarily decrease from 1995 to 2030. Additional approaches are necessary to control sewage DIN input to LMEs. As food needs increase for the growing population, improved efficiency of fertilizer use and manure management are also necessary to control DIN loading to LMEs in the future.

Environmental resource protection and restrictions for nutrient discharge must be considered under the impact of future technological and economic activities. It is particularly important to be able to predict increases in nutrient loading to coastal areas. It should be stressed that the task of specialists at present is not only to calculate the quantity of nutrients that can be discharged to coastal areas, but also to assess the possible effects of nutrient over-enrichment in the coasts. Such effects include increased algal growth, increase in Harmful Algal blooms, loss of habitat for fish and shellfish, decrease in species diversity, and increased water turbidity, among others. Therefore, policy makers should recommend, when necessary, special measures to minimize negative consequences of eutrophication. Existing legislative tools as well as economic incentives provided by international institutions should be coordinated to reduce nutrient inputs to inland and marine waters.

To conclude, it is significant to highlight that one of the strengths of the NEWS-DIN model is that the contributions of the various N sources in the watershed to river DIN export can be evaluated, thus providing important information for watershed managers and policy makers. One key event through the development of the workshops has been the opportunity for interaction among individuals from these 7 functionally-different LMEs around the globe: each representing a wide range of conditions with respect to current and potential future DIN export and the impacts in the watersheds and coastal waters of the region. The workshops have also provided the opportunity for a number of these individuals to participate in international conferences, thus increasing their integration into the global network of eutrophication science.

In addition, this part of component 3 of the GEF/LME Project has made great progress in training traditional fisheries scientists to understand and move towards a more integrated ecosystem-based approach to fisheries management, where fisheries scientists are now cognizant of interactions between 'land use in watersheds, eutrophication and adverse impacts on fish habitat, for example. For the first time, model estimates for nitrogen loadings have been determined for all 64 LMEs, and in many of these regions, workshops and model results produced by local scientists have been transmitted to appropriate government sectors for integration into management decisions. Nevertheless this work is just one step towards meeting the challenge.

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66	Bruun Memorial Lectures, 2003: Energy from the Sea: the potential and realities of Ocean Thermal Energy Conversion (OTEC). 2003	E only
67	Interdisciplinary Geoscience Research on the North East Atlantic Margin, Mediterranean Sea and Mid-Atlantic Ridge (12^{th} training-through-research cruise, June-August 2002). 2003	E only
68	Interdisciplinary Studies of North Atlantic and Labrador Sea Margin Architecture and Sedimentary Processes (13^{th} training-through-research cruise, July-September 2003). 2004	E only
69	Biodiversity and Distribution of the Megafauna / Biodiversité et distribution de la mégafaune. 2006 Vol.1 The polymetallic nodule ecosystem of the Eastern Equatorial Pacific Ocean / Ecosystème de nodules polymétalliques de l'océan Pacifique Est équatorial Vol.2 Annotated photographic Atlas of the echinoderms of the Clarion-Clipperton fracture zone / Atlas photographique annoté des échinodermes de la zone de fractures de Clarion et de Clipperton	E F
70	Interdisciplinary geoscience studies of the Gulf of Cadiz and Western Mediterranean Basin (14^{th} training-through-research cruise, July-September 2004). 2006	E only
71	Indian Ocean Tsunami Warning and Mitigation System, IOTWS. Implementation Plan, July-August 2006. 2006	E only
72	Deep-water Cold Seeps, Sedimentary Environments and Ecosystems of the Black and Tyrrhenian Seas and the Gulf of Cadiz (15^{th} training-through-research cruise, June–August 2005). 2007	E only
73	Implementation Plan for the Tsunami Early Warning and Mitigation System in the North-Eastern Atlantic, the Mediterranean and Connected Seas (NEAMTWS), 2007–2011. 2007 *(electronic only)*	E only
74	Bruun Memorial Lectures, 2005: The Ecology and Oceanography of Harmful Algal Blooms – Multidisciplinary approaches to research and management. 2007	E only
75	National Ocean Policy. The Basic Texts from: Australia, Brazil, Canada, China, Colombia, Japan, Norway, Portugal, Russian Federation, United States of America. (Also Law of Sea Dossier 1). 2008	E only
76	Deep-water Depositional Systems and Cold Seeps of the Western Mediterranean, Gulf of Cadiz and Norwegian Continental margins (16^{th} training-through-research cruise, May–July 2006). 2008	E only
77	Indian Ocean Tsunami Warning and Mitigation System (IOTWS) – 12 September 2007 Indian Ocean Tsunami Event. Post-Event Assessment of IOTWS Performance. 2007	E only
78	Tsunami and Other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (CARIBE EWS) – Implementation Plan 2008. 2008	E only
79	Filling Gaps in Large Marine Ecosystem Nitrogen Loadings Forecast for 64 LMEs – GEF/LME global project Promoting Ecosystem-based Approaches to Fisheries Conservation and Large Marine Ecosystems. 2008	E only