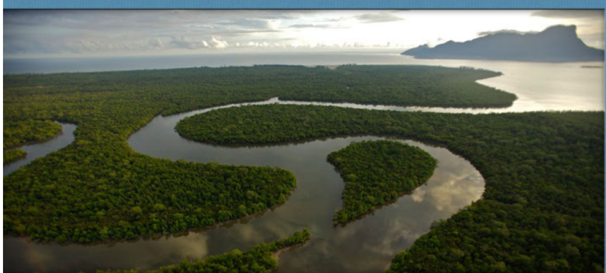
Bay of Bengal Large Marine Ecosystem Project



Understanding nutrient loading and sources in the Bay of Bengal Large Marine Ecosystem

BOBLME-2014-Ecology-18

BOBLME contract: LOA/RAP/2013/97

For bibliographic purposes, please reference this publication as:

BOBLME (2014) Understanding nutrient loading and sources in the Bay of Bengal Large Marine Ecosystem BOBLME-2014-Ecology-18

Understanding nutrient loading and sources in the Bay of Bengal Large Marine Ecosystem

Prepared by: S.P. Seitzinger[1], S. Pedde[2], C. Kroeze[2], E. Mayorga[3]

[1]International Geosphere-Biosphere Program, Stockholm, Sweden
[2]University Wageningen, Environmental Systems Analysis Group, Wageningen, The Netherlands
[3]University Washington, Applied Physics Laboratory, Seattle, Washington, USA

Summary

River inputs of nitrogen (N), phosphorus (P) and dissolved silica (DSi) from watersheds draining in to the Bay of Bengal Large Marine Ecosystem (BOBLME) for contemporary conditions, and for one future scenario for the years 2030 and 2050 as calculated by the Global NEWS model are presented. The major N and P sources are identified, and the Indicator of Coastal Eutrophication (ICEP) is calculated for rivers draining into the BOBLME. In 2000, a total of 7.1 Tg N and 1.5 Tg P was transported to the mouth of rivers in the BOBLME. Three rivers (Ganges, Godavari, Irrawaddy) account to approximately 75-80% of the total river transport of N and P. Based on the scenario analysis, by 2050 the river N load is projected to increase to 8.6 Tg, while the P load is not expected to change much. This is the net effect of increasing loads for dissolved N and P, and decreasing loads for particulate N and P.

Rivers draining into the western BOBLME generally have higher N and P export compared to eastern BOBLME rivers. The dominant sources of the different forms of N and P differ across basins; however, anthropogenic sources usually dominate both N and P in western BOBLME basins. Future changes in nutrient export, as well as the relative contribution of different sources, are projected to be quite variable among rivers. The increases in dissolved N and P export can be large, up to more than a factor of 5 for DIP and more than a doubling for DIN and DON. The increases in dissolved N and P loads are associated primarily with increased N and P in agriculture and with an increasing population and economic development. Particulate N and P export in many basins are projected to decrease and are associated with changes in hydrology and with damming of rivers. Based on nutrient export ratios (N and P relative to DSi) we generally calculate positive ICEP values for BOBLME rivers, indicating a risk for development of non-siliceous algal species which can potentially produce toxins and otherwise disrupt nearshore coastal ecosystems. In the future the risk for coastal eutrophication may increase due to both changing nutrient ratios (ICEP) and increasing nutrient loads. Effective management of coastal eutrophication calls for a basin-specific approach.

List of acronyms

AM	Adapting Mosaic scenario
BOB	Bay of Bengal
BOBLME	Bay of Bengal Large Marine Ecosystem
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DOC	Dissolved Organic Carbon
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DSi	Dissolved Silica
GEF	Global Environment Facility
GDP	Gross Domestic Product
GHAAS	Global Hydrologic Archive and Analysis System
Global NEWS	See NEWS
GO	Global Orchestration scenario
ICEP	Indicator for Coastal Eutrophication Potential
IMAGE	Integrated Model for the Assessment of the Global Environment
LME	Large Marine Ecosystem
MEA	Millennium Ecosystem Assessment
N	Nitrogen
N-ICEP	ICEP defined relative to nitrogen
NEWS	Nutrient Export to WaterSheds model
N-Flx	Fluxes (yields) of total nitrogen delivered at river mouth
OS	Order from Strength scenario
P	Phosphorus
P-ICEP	ICEP defined relative to phosphorus
P-Flx	Fluxes (yields) of total phosphorus delivered at river mouth
PN	Particulate Nitrogen
POC	Particulate Organic Carbon
PP	Particulate Phosphorus
Si	Silica
Si-Flx	Fluxes (yields) of dissolved silica delivered at river mouth
STN-30p	Simulated Topological Network at 0.5-degree x 0.5-degree grid-cell spatial resolution
TG	TechnoGarden scenario
Tg	Teragrams equals10^{12} grams
TSS	Total Suspended Solid
TWAP	Transboundary Water Assessment Project
WBM_{plus}	Water Balance Model plus

Table of Contents

List of Figures

List of Tables

1. Introduction

Land use and human activities in watersheds draining into the Bay of Bengal Large Marine Ecosystem (BOBLME) are affecting nutrients transported by rivers to the BOBLME. River transported nutrients can have positive effects on coastal systems by increasing coastal ecosystem productivity. However, excess nutrients or changes in nutrient ratios can lead to a number of negative changes in coastal ecosystems including algal blooms, alterations in community composition, production of toxic algae, hypoxic or anoxic conditions, and increased turbidity (Glibert et al. 2010).

The major anthropogenic sources of river nutrient loading are primarily associated with the production of food and energy. This includes, for example, runoff from fertilizer use and livestock production, sewage, and atmospheric deposition of nitrogen. Understanding the sources of nutrients in a watershed that are transported by rivers is important in managing current and understanding potential future loadings and effects. Future anthropogenic drivers of nutrient export to coastal waters, for example increases in population and urbanization, may increase pressures on the BOBLME.

There are few measurements available of river nutrient loadings over annual cycles in rivers discharging to the BOBLME. There also are few analyses of what the major nutrient sources are in these watersheds that contribute to the nutrient loading.

In this study we focus on contemporary and future trends in river export of nutrients to the Bay of Bengal. The information on nutrient loadings can be used in designing current and future policy actions for management measures to improve the ecosystem health of the BOBLME.

River delivered inputs of nitrogen (N), phosphorus (P) and silica (Si) to the Bay of Bengal for contemporary conditions, and for one future scenario for the years 2030 and 2050 as calculated by the Global NEWS model are presented (Seitzinger et al., 2010, Mayorga et al., 2010, Beusen et al., 2009). The major N and P sources are identified (e.g., sewage, agriculture from crops and from livestock, atmospheric deposition directly to watershed). We also present the Indicator of Coastal Eutrophication (ICEP) (Garnier et al., 2010) for rivers draining watersheds of the BOBLME. The calculations for future years are based on one scenario developed from the Millennium Ecosystem Assessment (MEA).

Relation to Transboundary Water Assessment Project (TWAP). This study directly builds on the river basin and LME components of the Global Environment Facility (GEF) TWAP. Both the GEF TWAP and this BOBLME project use the Global NEWS model and both address contemporary conditions, and 2030 and 2050 assessments from the MEA Global Orchestration scenario. However, this BOBLME project goes substantially beyond the TWAP in both the level of spatial detail of nutrient input to the LME (individual river basin information) and in providing N and P source information in the river basins draining into the BOBLME. In the TWAP, LME level information – not individual river basin information – is developed, and nutrient source attribution is not included.

2. Method

2.1 Global NEWS model

The Global NEWS model consists of spatially explicit and internally consistent sub-models unified in a single modelling framework quantifying multi-form and multi-element nutrient export loads of >5000 world rivers to coastal waters (Seitzinger et al., 2010, Mayorga et al., 2010, Beusen et al., 2009). It represents river networks and basins using the Simulated Topological Network at 0.5-degree x 0.5-degree grid-cell spatial resolution (STN-30p, version 6.01) (Mayorga et al., 2010, Vörösmarty et al., 2000). The relevant output of Global NEWS with respect to this project consists of basin scale annual export at the river mouth of: dissolved inorganic N and P (DIN and DIP), dissolved organic N and P (DON, DOP), and particulate forms of N and P (PN, PP) and dissolved silica (DSi).

Inputs and drivers for the Global NEWS model consist of a range of natural and anthropogenic N and P sources within watersheds, in-watershed and in-river transformation and removal processes, climatic data, and other information as detailed in the original model description (Seitzinger et al., 2010, Mayorga et al., 2010) (Figure 1). The future scenarios are quantitative interpretations of the Millennium Ecosystem Assessment (MEA) scenarios. To this end, the MEA storylines have been used to develop model input datasets for diffuse sources (Bouwman et al., 2009), point sources (Van Drecht et al., 2009), and hydrology (Fekete et al., 2010).

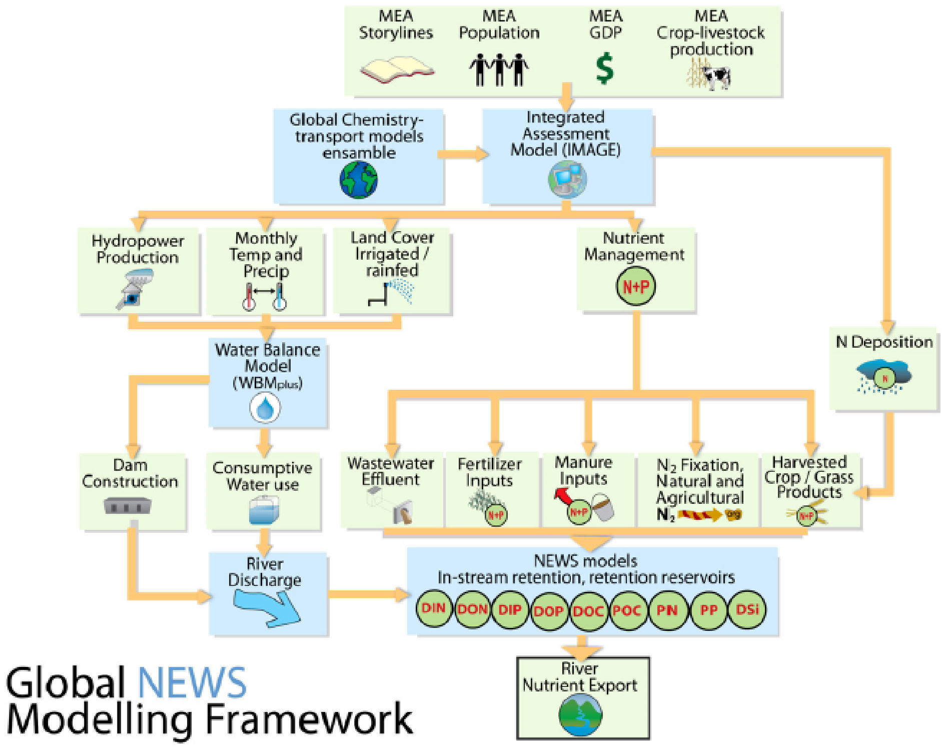


Figure 1: Conceptual diagram of the Global NEWS model construction, submodels and parameters (from Glibert et al. 2010 modified from Seitzinger et al. 2010)

Global NEWS applies both process-based modeling approaches and more statistical methods and calibrated coefficients (Kroeze et al., 2012, Mayorga et al., 2010). The model consists of two sets of sub-models: (1) dissolved sub-models (N, P) based on a mass-balance approach for the riverine system, which allows for source attribution analysis to total export at the river mouth and (2) particulate sub-models and DSi built on lumped, multiple regression approaches unsuitable for source attribution. The source attribution analysis of the N and P dissolved sub-models (DIN, DON, DIP and DOP) are categorized in diffuse sources from natural processes, fertilizer leaching from crop production, livestock production, and atmospheric N deposition, and point sources from urban wastewater (human sewage) treatment.

Global NEWS was developed to estimate nutrient export from watersheds globally, to see overall spatial trends, and to elucidate changes over time under a range of scenarios. It was not developed for accuracy to any one river basin. A major strength of this model is its ability to model river export of multiple nutrients in several forms simultaneously in a comprehensive and spatially explicit manner. Moreover, it is the only globally applicable nutrient export model that can identify the sources of dissolved N and P in rivers. Furthermore, because it includes N, P and Si, Global NEWS can be used to calculate the Index of Coastal Eutrophication (ICEP). It should be recognized that the NEWS model was developed for application to watersheds globally, and was not specifically developed for the Bay of Bengal. The lack of nutrient monitoring data for many rivers throughout the BOBLME hampers the development of a model specifically for the Bay of Bengal, justifying the use of Global NEWS. Furthermore, while the model has been applied with global databases to watersheds globally, it has also been applied with more in-depth analysis to some specific world regions (Yasin et al., 2010, Yan et al., 2010, Van der Struijk and Kroeze, 2010).

2.2 Preparation of Global NEWS model for application to BOBLME watersheds

The BOBLME is bordered by Bangladesh, India, Indonesia, Malaysia, the Maldives, Myanmar, Sri Lanka and Thailand (Figure 2).

For this work we selected Global NEWS basins that drain into the BOBLME using the 2013 revision of the LME polygon boundaries shapefile obtained from http://www.lme.noaa.gov.

An initial selection of Global NEWS basins to the BOBLME was performed via an automated procedure that expanded (buffered) the LME polygon boundary by 0.3 degrees (approximately 33 km at the equator, decreasing with latitude) and selected Global NEWS basin polygons that intersected this expanded boundary. This step was followed by a comprehensive manual assessment and correction. As a result, 133 exorheic Global NEWS basins were assigned to the BOBLME (Figure 1 in Annex and Table 1 in Annex). Many of these basins are small and contain relatively few input grid cells (0.5 x 0.5 degrees for most inputs) per basin. Model output is less reliable for basins consisting of few grid cells. Therefore, basins that cover less than 10 grid cells and are adjacent to each other are aggregated, resulting in nine “combined basin regions”. These are balanced between the eastern and western sides of the BOBLME, depending on the distribution of small basins. All results in this report are for these “combined basin regions” and for the 13 largest individual basins.

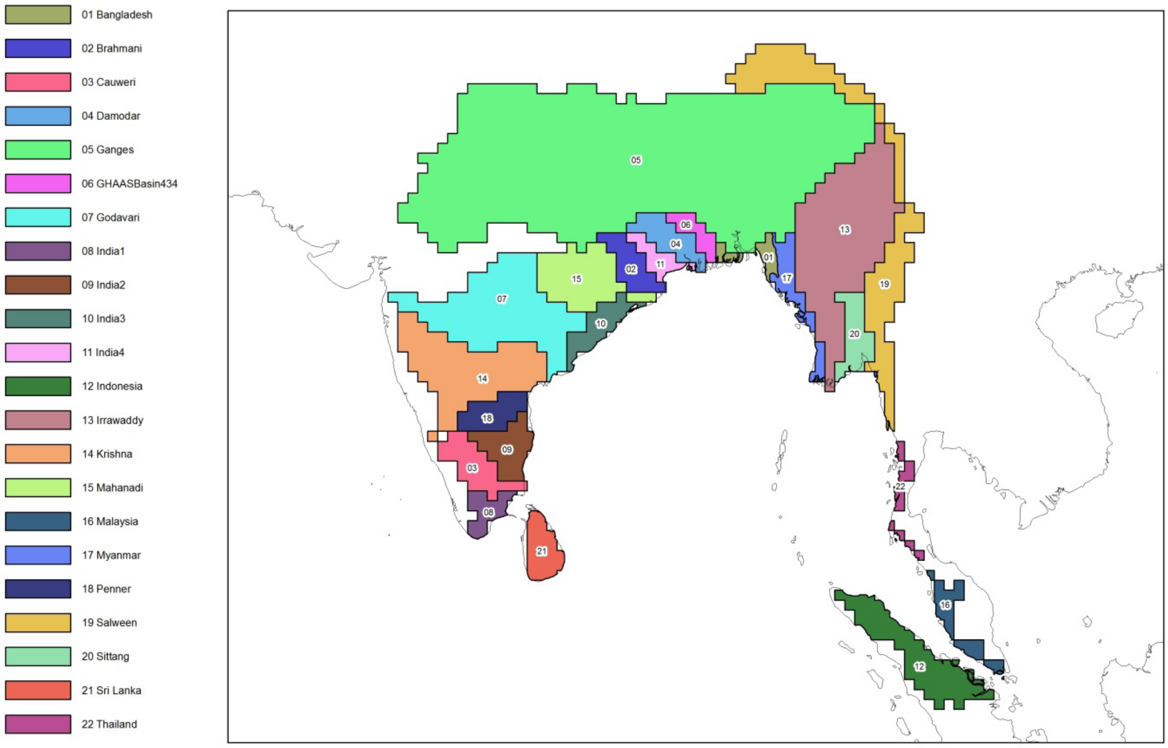


Figure 2: The 22 combined river basins draining into the Bay of Bengal LME as included in this study (>10 grid cells).

The Global NEWS model was then used to analyze the following model output by river basin: annual river export of N by form (dissolved inorganic N, dissolved organic N, particulate N), total N (sum of N forms), P by form (dissolved inorganic P, dissolved organic P, particulate P), total P (sum of P forms), and dissolved Si. River export of nutrients is presented as load (Tg/year) or yield (kg/km^2 basin/year). Moreover, the relative share of sources of nutrients in rivers are identified, including diffuse and point sources. Diffuse sources include natural soils, fertilizer leaching from crop production and animal production, and atmospheric N deposition. Point sources are from urban wastewater (human sewage) exports. Modeled yields for "combined basin regions" have been aggregated by summing the loads of the individual basins and dividing by total basin area as in equation 1:

$$x_{\text{yield}} = \frac{\sum_{i=1}^{n} \left(w_{\text{area basin}} \cdot x_{\text{yield}} \right)}{\sum_{i=1}^{n} w_{\text{area basin}}} \qquad (1)$$

2.3 Future scenario analysis for 2030 and 2050

Results for one future scenario for the years 2030 and 2050 were developed, based on the Global Orchestration MEA scenario. This scenario was chosen in consultation with BOBLME leadership.

Input databases to Global NEWS for future scenario analysis include several anthropogenic drivers derived directly from the MEA storylines (Figure 1). Additional inputs for nutrient management scenarios have been developed and added to these storylines to generate quantitative nutrient management scenarios and the input datasets for the Global NEWS model.

In brief, the MEA scenarios consist of internally consistent, plausible global futures and their implications for ecosystem services which differ in terms of environmental management (proactive and reactive) and in their degree and scale of international integration (globalization or regionalization) growth(Alcamo et al., 2005). These four scenarios are Global Orchestration (GO), Order from Strength (OS), TechnoGarden (TG), and Adapting Mosaic (AM). GO describes a globalized world with a focus on economic development with rapid economic and urbanization growth, and a reactive environmental management. OS describes a regionalized and segregated world with a focus on security and a reactive approach to environmental issues. TG describes a globalized world with a focus on environmentally sound technology and highly managed engineering solutions. AM describes a regionalized world with proactive socio-ecological management at regional and local scales, mostly through simple and economically feasible options.

As increased urbanization, and intensification of agriculture and economic activities are likely major drivers of increased nutrient loads in the Bay of Bengal, future trends for the years 2030 and 2050 are analyzed for the GO scenario. This scenario is also the most straightforward for interpretation against current conditions, and provides a reference point if additional analysis of one or more of the other MEA scenarios is undertaken in a future project. The GO scenario is also used in the river basin and LME components of the TWAP.

2.4 Application of gridded databases to Global NEWS for contemporary conditions and validation

Input datasets used in the Global NEWS model include various components of hydrography (areas and regions), geophysical, climate and hydrology, land use and ecosystems, and point and diffuse sources of nutrients (Table 1). The input datasets for the BOBLME watersheds were extracted from published global spatially gridded (generally 0.5^{o} latitude x 0.5^{o} longitude) data sources and applied to Global NEWS. Compared to earlier publications of the current version of Global NEWS, in this study we use a more realistic simulation for contemporary hydrological conditions (described in Mayorga et al., 2010) using climate observations (New et al., 1999) as drivers for the hydrological model (Water Balance Model Plus, WBM_{plus}), and the discharge-gauge correction (Fekete et al., 2002). As in the global application, contemporary conditions correspond broadly to the year 2000 (Seitzinger et al., 2010, Mayorga et al., 2010).

The Global NEWS model has been validated and calibrated at the global scale, and has been used to analyze global trends in nutrient export by rivers (Seitzinger et al., 2010, Mayorga et al., 2010). It has also been successfully applied in continental scale studies for South America(Van der Struijk and Kroeze, 2010), Africa (Yasin et al., 2010) and China (Qu and Kroeze, 2010, Qu and Kroeze, 2012), and validated for the Bay of Bengal (Sattar et al., 2014).

2.5 Application of gridded databases to Global NEWS for 2030 and 2050 future scenario analysis

Input datasets for the 2030 and 2050 Global Orchestration (GO) scenario analysis were developed for Global NEWS (Seitzinger et al., 2010) and are summarized here. Inputs for population, Gross Domestic Product (GDP) and crop-livestock production were taken from the MEA directly. Additional input data sets were developed by interpreting the original MEA scenario. For example agricultural areas used net surface

N and P balances as input. These surface balances were based on N and P inputs from fertilizer use, animal manure application, N_2-fixation by crops, atmospheric N deposition, and sewage N and P, minus N and P removal from crop harvest and animal grazing (Bouwman et al., 2009). The surface nutrient balances form the basis of the scenario assumptions for nutrient management in agriculture. Quantitative nutrient management scenarios used an updated version (2.4) of the Integrated Model for the Assessment of the Global Environment (IMAGE) (Bouwman et al., 2006). Regional scenarios for N and P fertilizer use were based on efficiency of N and P uptake in crop production (Bouwman et al., 2009). Manure production was computed from livestock production, animal numbers and excretion rates, and distributed over different animal manure managements systems (Bouwman et al., 2009). Livestock production was related to a number of factors including human population and diet. Atmospheric N deposition from natural and anthropogenic sources to all watersheds was from Bouwman et al. (2009). Natural ecosystem inputs include biological N_2-fixation and atmospheric nitrogen deposition.

N and P flows in urban wastewater for 2030 and 2050 were calculated from influents to wastewater treatment systems computed from per capita incomes and stemming from human N and P emissions and P-based detergent use (Van Drecht et al., 2009). Each MEA storyline was interpreted to generate differing degrees of access to improved sanitation, connection to sewage systems, and nutrient removal in wastewater treatment systems (Van Drecht et al., 2009).

For hydropower production, the WBM_{plus} hydrological model was driven with scenario estimates of monthly temperature and precipitation, land use, and irrigated and rainfed crop production areas from the IMAGE model to develop projections for construction of reservoirs (dams) and consumptive water use and irrigation (Fekete et al., 2010).

The published global scenario application of Global NEWS was based on modeled climate drivers ("Modeled Hydrology") for both contemporary (year 2000) and future conditions (Seitzinger et al., 2010). To adjust modeled results for future conditions to the "Realistic Hydrology" baseline for contemporary conditions used here, we scaled published future nutrient exports ("X") as follows:

$$X_{year} = (X_{2000\ Realistic\ Hydrology} / X_{2000\ Modeled\ Hydrology}) * X_{year\ Modeled\ Hydrology} \quad (2)$$

where "year" is the scenario year (2030 or 2050) and ($X_{2000\ Realistic\ Hydrology}$ / $X_{2000\ Modeled\ Hydrology}$) is the scaling factor.

Table 1. Input data sets used in the Global NEWS model for DIN, DON, DIP, DOP, PN and PP. Table adapted from Mayorga et al. (2010).

Dataset	Resolution	Time-varying	DIN	DON	DIP	DOP	PN, PP	Sources
Hydrography, areas and regions								
Basins and river networks	0.5°		X	X	X	X	X	1
Cell and land area	0.5°		X	X	X	X	X	1, 2, 3
Continents, oceans[a]	basin		X	X	X	X	X	1, 4
Latitude bands[a]	basin		X	X	X	X	X	5
Geophysical								
Lithology	1°						X	6, 7
Topography	0.5°						X	6, 8
Climate and Hydrology								
Precipitation	0.5°	X					X	2, 9, 10
Runoff & Discharge	0.5°	X	X	X	X	X	X	9
Consumptive water use	0.5°& basin	X	X	X	X	X		9, 11
Reservoirs	0.5°&dams	X	X		X		X	9, 12
Land Use and Ecosystems								
Agriculture & sub-classes	0.5°	X	X	X	X	X		2
Wetland rice & marginal grassland	0.5°	X					X	2
Wetlands	0.5 minute							13
Humid tropical forests (Koppe Climate Zones)	0.5°		X					14
Point Sources (socioeconomic and sanitation drivers)								
Gross Domestic Product	nation	X	X	X	X	X		
Total and urban population density	0.5°	X	X	X	X	X		15
Sanitation statistics	nation/region	X	X	X	X	X		
Detergent emissions	nation/region	X			X	X		
Diffuse Sources								
Fertilizers, manure, crop harves & animal grazing	0.5°	X	X	X	X	X		2
N fixation, atmospheric N deposition	0.5°	X	X					2

[a]Used for analysis of results.

Data sources: [1](Vörösmarty et al., 2000)[2](Bouwman et al., 2009); [3](Processed as described in Global NEWS model description (Mayorga et al., 2010); [4](Bouwman et al., 2009); [5](Bouwman et al., 2009); [6](Beusen et al., 2009); [7](Bouwman et al., 2009); [8](Bouwman et al., 2009); [9](Fekete et al., 2010); [10](New et al., 1999); [11](Meybeck and Ragu, 1996); [12](Vörösmarty et al., 2003); [13](Lehner and Döll, 2004); [14](Kottek et al., 2006); [15](Van Drecht et al., 2009)

2.6 Indicator for Coastal Eutrophication Potential (ICEP)

In order to estimate the potential for eutrophication in the near shore waters of the Bay of Bengal we calculate, for each river basin, an Indicator for Coastal Eutrophication (ICEP), which is based on the Redfield molar ratio (C:N:P:Si=106:16:1:20) (Garnier et al., 2010). This indicator assumes that N and P levels in excess of Si may favour growth of potentially harmful non-siliceous algae.

According to Garnier et al. (2010), ICEP is calculated for N (when N is limiting) and P (when P is limiting) as follows:

$$\text{N-ICEP} = [\text{NFlx}/14 \cdot 16 - \text{SiFlx}/28 \cdot 20] \cdot 106 \cdot 12 \quad (3)$$

$$\text{P-ICEP} = [\text{PFlx}/31 - \text{SiFlx}/28 \cdot 20] \cdot 106 \cdot 12 \quad (4)$$

Where

PFlx, NFlx and SiFlx are the fluxes (yields) of total N (TN), total P (TP) and dissolved silica (DSi), respectively, delivered at the mouth of river. N, P and silica fluxes are expressed in kg/km^2 basin/day. ICEP is expressed in kg $C/km^2/day$. Total N and P fluxes are calculated as the sum of the three constituent elemental forms as shown in equations (5) and (6), respectively, whereas silica fluxes are derived from Beusen et al. (2009):

$$\text{NFlx} = \text{DINyield} + \text{DONyield} + \text{PNyield} \quad (5)$$

$$\text{PFlx} = \text{DIPyield} + \text{DOPyield} + \text{PPyield} \quad (6)$$

Considering that the N:P ratio is indicative of which nutrient (N or P) is most limiting, we have opted for a combined ICEP (indicated simply as ICEP) for which we use the N or P ICEP with the lowest value (Garnier et al. 2010).

A negative ICEP (ICEP<0) indicates a low potential for coastal eutrophication as a result of non-siliceous algae development. A positive ICEP (ICEP >0) indicates a potential risk of coastal eutrophication.

3. Nutrient exports and eutrophication potential in the Bay of Bengal from 2000 to 2050

3.1 Drivers of N and P export by rivers

Important drivers of changes in N and P export by rivers include trends in population, GDP and the associated N and P inputs to soils and changes in hydrology (Table 2).

According to the GO scenario, GDP increases faster between 2000 and 2050 than the population in the BOBLME. The population density increases by about one-third, and the urban population by about two-thirds. GDP is projected to increase by a factor 7-11.

Total inputs of N and P to rivers from point sources (sewage) are projected to increase by more than a factor of three between 2000 and 2050 based on the GO scenario. This is a result of the population increase and the assumed increase in the percentage of people connected to sewage systems (Van Drecht et al., 2009). In addition, the amount of P in sewage may increase because a more widespread use of P detergents.

Inputs to land from fertilizer and manure are projected to increase by 60-155% between 2000 and 2050. These increases are larger than the population increase. This can be explained by an increase in per capita caloric intake and meat consumption.

As a result of these trends, N and P inputs to terrestrial and aquatic systems may increase.

Table 2: Selected drivers of river export of nutrients to the Bay of Bengal for the years 2000, 2030 and 2050 (percentage change relative to the year 2000) for the Global Orchestration (GO) scenario.

Driver/Source	2000	2030GO		2050GO	
	value	value	% change	value	% change
GDP at market exchange rate (1994US$/inhabitants/year)	1130	5308	370%	13915	1132%
GDP at purchasing power parity (1994US$/inhabitants/year)	2894	9886	242%	24432	744%
Total population (inhabitants/km^2)	227	293	29%	302	33%
Urban population (inhabitants/km^2)	95	138	45%	158	66%
Population connected to sewage (inhabitants/km^2)	33	63	93%	123	275%
Total N input to rivers from sewage (kg/km^2/year)	120	435	261%	538	347%
Total P input to rivers from sewage (kg/km^2/year)	26	92	253%	115	342%
Total N input to land from fertilizer (kg/km^2/year)	2007	2471	23%	3226	61%
Total P input to land from fertilizer (kg/km^2/year)	1352	2265	67%	2742	103%
Total N input to land from manure (kg/km^2/year)	303	639	111%	773	155%
Total P input to land from manure (kg/km^2/year)	279	473	70%	575	106%

3.2 River export of nutrients in the BOBLME (2000-2050)

In 2000, rivers exported 7.1Tg N to the BOBLME (Figure 3). By 2050, this load may amount to 8.6Tgaccording to the GO scenario. This increase is mainly caused by a 45% increase in DIN loads from 4.1Tg in 2000 to 6.0Tg in 2050. The two main sources of DIN in rivers are fertilizers and manure (Figure 4), accounting for 32% and 26% of the total DIN loads for the year 2000, respectively.

Loads of DON (0.9 Tg in 2000) are small compared to DIN (4.1 Tg) and PN (2.1 Tg) (Figure 3). In 2000, about 90% of the DON was from leaching with similar amounts from agricultural and natural areas (42% and 48% respectively) (Figure 4). In 2050, leaching accounts for 73% of the total DON load, and sewage for 18% according to the GO scenario.

Unlike dissolved N and P loads, particulate N and P loads are expected to decrease in the future. This is explained by the increased damming of rivers according to the GO scenario, which results in increased particulate retention. This effect is most visible for PP which decreases by 27%, i.e. from 1.2 Tg in 2000 to 0.9 Tg in 2050 (Figure 3).

Total P exports amounted to 1.5 Tg P in 2000. TP loads do not change a lot over time (Figure 3). This is a net effect of the decreasing trend in PP loads and increases in DIP (92% increase, i.e. from 0.2Tg in 2000 to 0.5Tg in 2050) and DOP (21% increase i.e. from 0.05 Tg in 2000 to 0.06 Tg in 2050).

In 2000, about 69% of DIP export can be attributed to agriculture (fertilizer and manure) (Figure 5). In the future, sewage may become more important. By 2050, point sources (sewage) are calculated to account for 39% of the total DIP load, or 0.2 Tg P/y based on the GO scenario.

The DOP load was 0.05 Tg in 2000. Leaching from natural and agricultural land was the dominant source of DOP in 2000 (accounting for 79% of the load) with fertilizer and manure accounting for the remaining 20% (10% each). According to the GO scenario, by 2050 fertilizer and manure account for 17% and 15% of the total DOP loads, respectively (Figure 5).

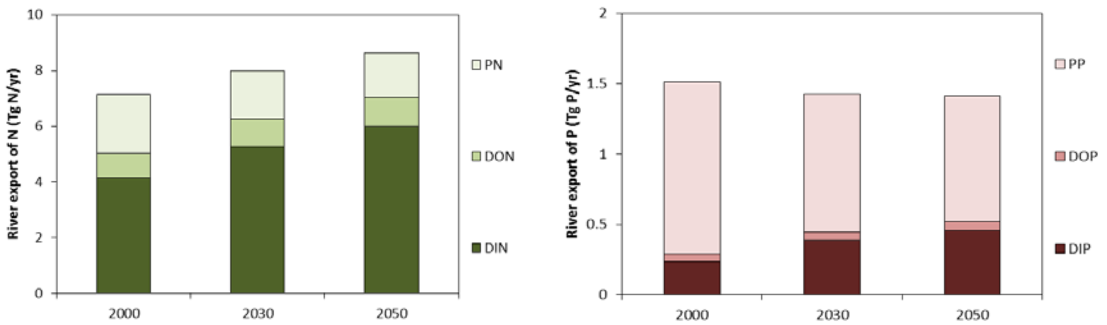


Figure 3: River export of nitrogen and phosphorus to the Bay of Bengal for the years 2000, 2030 and 2050 (Global Orchestration Scenario). The graphs present dissolved inorganic N and P (DIN and DIP), organic N and P (DON and DOP) and particulate N and P (PN and PP).

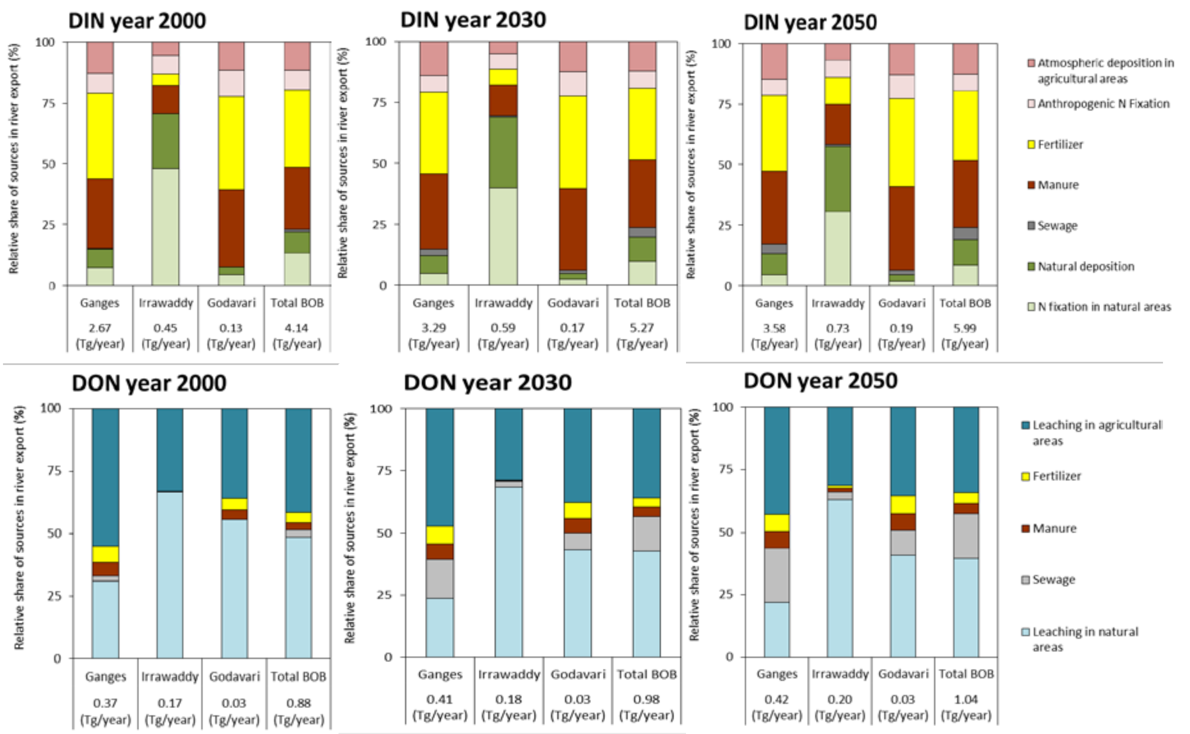


Figure 4: Relative share of sources (%) in river export of nitrogen for the three largest three basins (Ganges, Irrawaddy, Godavari) and the total drainage area of the Bay of Bengal for the years 2000, 2030 and 2050 (future scenarios for Global Orchestration).

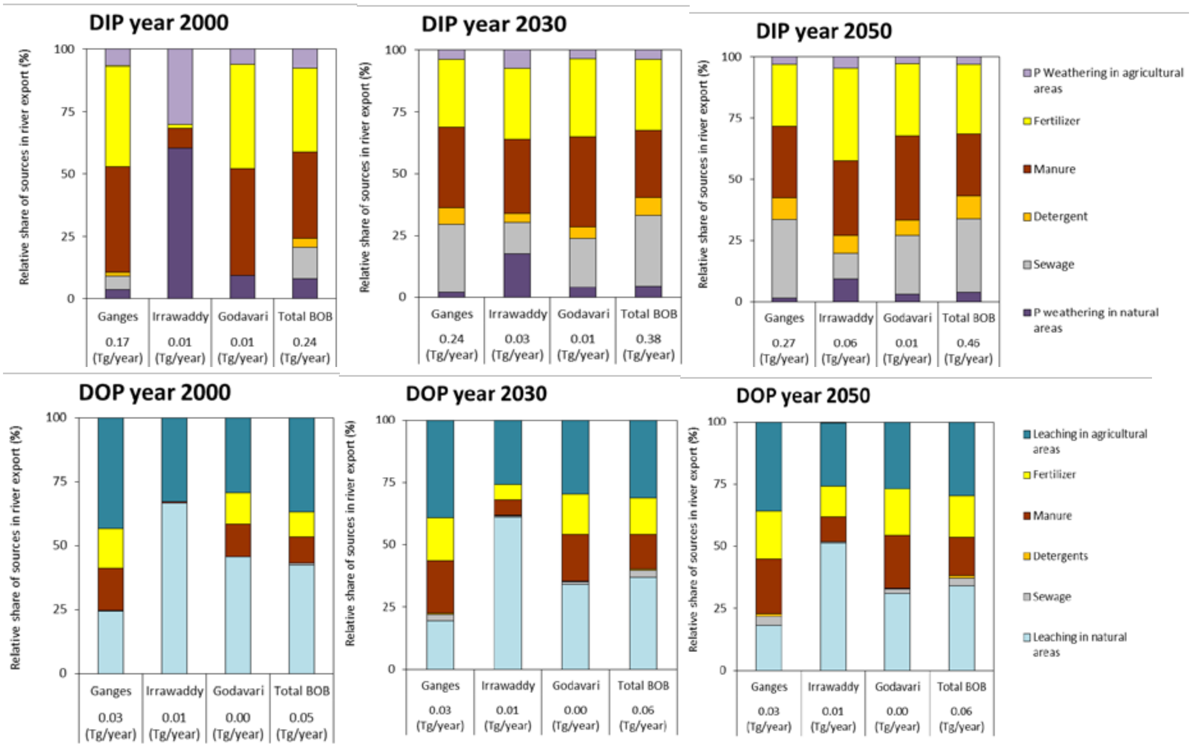


Figure 5: Relative share of sources (%) in river export of phosphorus for the three largest three basins (Ganges, Irrawaddy, Godavari) and the total drainage area of the Bay of Bengal for the years 2000, 2030 and 2050 (future scenarios for Global Orchestration.)

3.3 Patterns in nutrient export and source attribution across BOBLME watersheds (2000-2050)

3.3.1 Nutrient loads and yields

Two units for nutrient export are used in this study, load and yield. Load is expressed as the total amount of an element (e.g., N, P, Si by form) exported from the watersheds to the mouth of the river, in units of Tg per year (Tg = 10^{12} g). Yield is also the amount of an element exported to the mouth of the river but is normalized by basin areas with units of kg per km^2 of watershed per year. Yield can provide insight into the intensity of anthropogenic activity in a watershed. Yield is particularly useful in comparing the intensity of nutrient export across watersheds of widely different sizes. Eutrophication in coastal systems is related more to the amount (load) rather than the yield of nutrients exported. In addition the ratio of nutrients (N, P and Si) is important in determining the response of coastal systems to nutrient export, as discussed later. Algal blooms develop locally and temporally, and depend on nutrient loads, ratios and local conditions. The river nutrient loads and ratios from BOBLME rivers likely most directly affect the near coastal regions (estuaries, bays), as they would be substantially altered through biological processing and dilution both within near coastal regions and in open waters of the BOBLME. Beyond nutrients, the particular morphological, climatic and hydrological conditions, including temporal variations, also are important in determining the response of both near coastal systems and the open waters of the BOBLME to nutrient loads and ratios. Evaluating the exact response of the BOBLME to the river nutrient export would require further modeling and analysis with coastal hydrological-biogeochemical-ecosystem models.

The analysis of the total loads in the Bay of Bengal in the previous section gives insight in the magnitude of the total nutrient inputs to the BOBLME. Three rivers have a relatively large share in the total nutrient export: the Godavari, Ganges and Irrawaddy. In the year 2000, these three basins were responsible for 79% of total DIN river export (load) to the BOBLME, 65% of total DON load, 76% of total DIP load and 68% of total DOP load. The six rivers with the highest DIN loads are the Ganges, Irrawaddy, Godavari, Salween, Indonesia, and Mahanadi[1] which are also 6 of the 7 largest basins of the Bay of Bengal. As noted above, the degree of eutrophication (algal blooms, anoxia, etc.) in response to nutrient loads will be a function of not only the magnitude of the nutrient loading but also will depend on the local morphological and hydrological conditions. Therefore, rivers with smaller nutrient loads can also lead to eutrophication in estuaries and bays. Furthermore, rivers with large discharges might rapidly transport their nutrients and their effects further offshore.

For the year 2000 the six rivers with the highest DIN yields include the Ganges, Bangladesh, Malaysia and Damodar (>1200 kg N/km^2/y) and Irrawaddy, Myanmar, and India4 (>850 kg N/km^2/y) (Figure 6), indicating high intensity of land use (nutrient input to the watersheds). A number of basins in Europe and North America have similarly high DIN yields (Seitzinger et al. 2010).

Dissolved N and P yields and loads are projected to increase between 2000 and 2050 from most basins as a result of increased N and P inputs within the river basins (Figure 4-6; Table 2 Annex). These increases can be large, up to more than a factor of 5 for DIP and more than a doubling for DIN and DON. For a few basins a small decrease is calculated.

[1] For river basin names, please refer to Table A-4 (Annex): List of selected basins of the Bay of Bengal study area

River export of particulate N and P decreases in all large basins and in some smaller basins as well (both yield and loads). This can be explained by changes in hydrology largely associated with damming of rivers and consumptive water use based on GO scenario.

It is interesting to note that for some western BOB basins the DIP yields decrease between 2000 and 2030, and increase between 2030 and 2050. This is caused by assumed damming of rivers between 2000 and 2030, increasing DIP retention in the reservoirs. From 2030 onwards DIP yields increase again as a result of human activities increasing P input to the landscape and rivers.

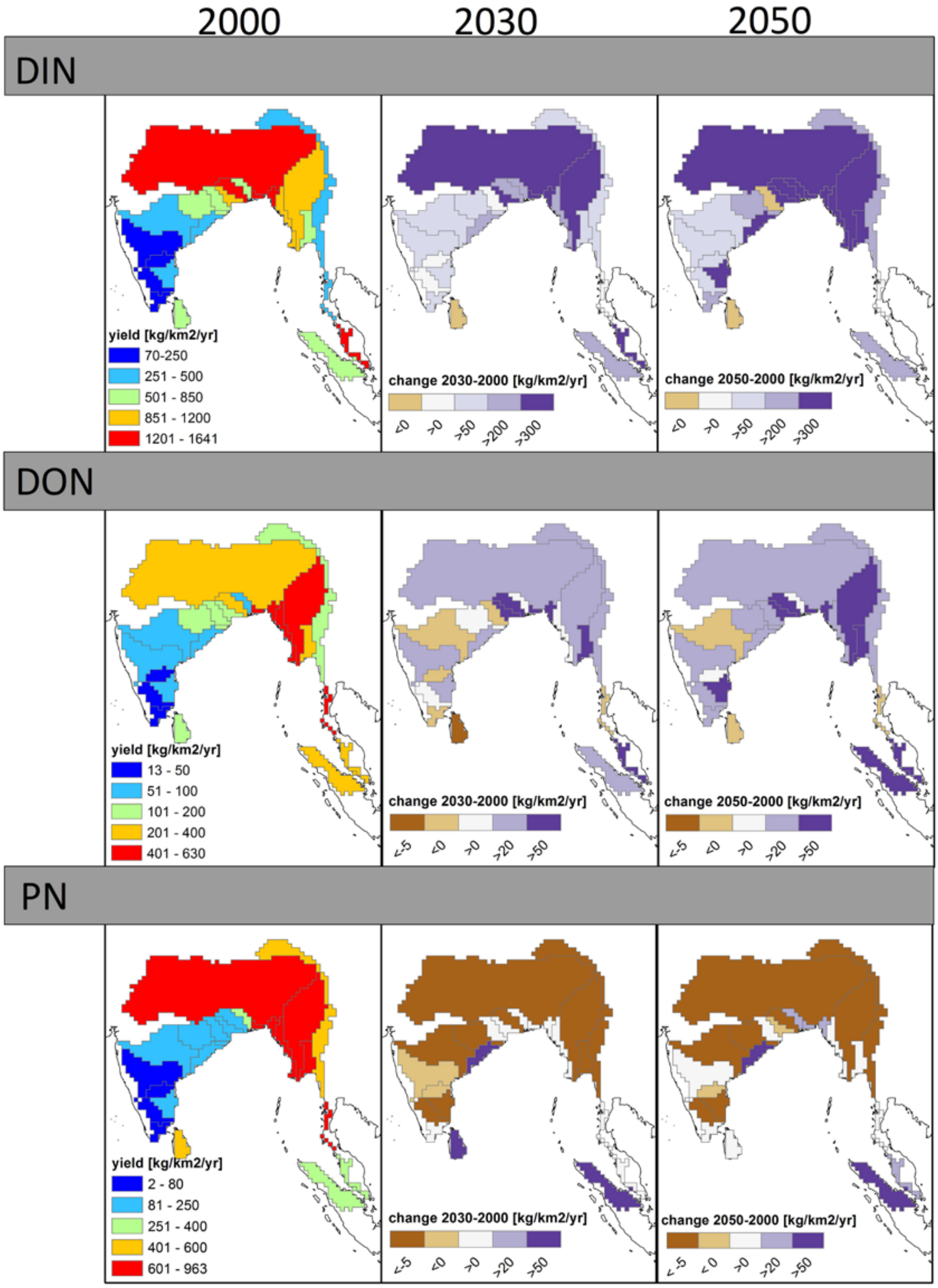


Figure 6: River export of DIN, DON and PN to the Bay of Bengal for the year 2000 (in kg/km2/year) and changes 2000-2030 and 2000-2050 [kg/km2/year] for the Global Orchestration scenario.

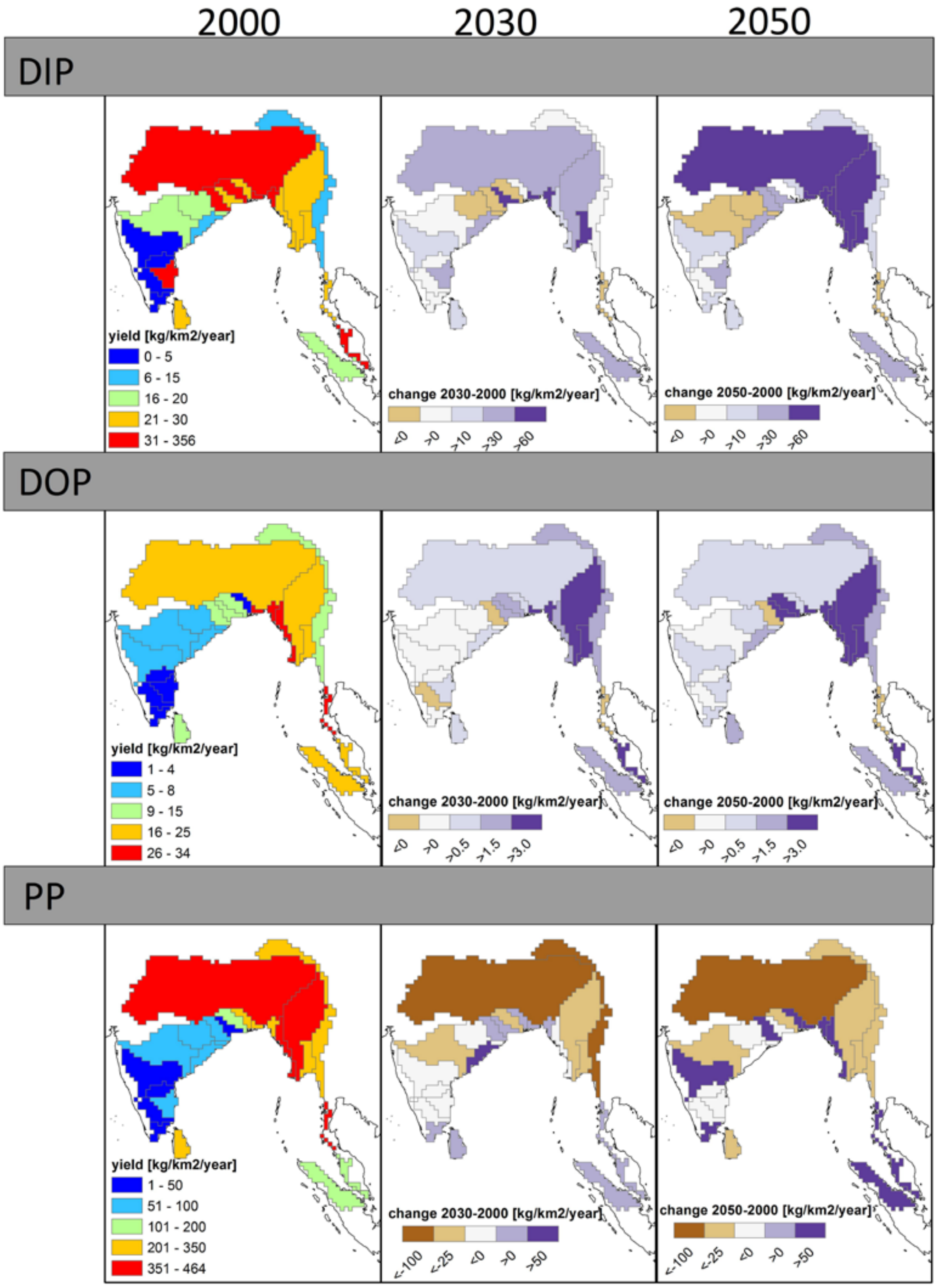


Figure 7: River export of DIP, DOP and PP to the Bay of Bengal for the year 2000 (in kg/km2/year) and changes 2000-2030 and 2000-2050 [kg/km2/year] for the Global Orchestration scenario.

3.3.2 Nutrient sources

Changes in nutrient export by rivers are the net effect of changes in N and P input to watersheds from human activities, and changes in hydrology as a result of damming, consumptive water use and climate change. Here, we focus on anthropogenic sources of dissolved N and P in rivers (Figure 8-11, Table 3).

Fertilizers and manure are the two largest sources for DIN in many rivers throughout the BOBLME (Figures 8 and 9, Table 3). The exceptions are in eastern rivers where N_2 fixation in, and atmospheric N deposition to, natural soils are generally the dominant sources of DIN. In the future according to the GO scenario, the relative share of sources of DIN in eastern BOBLME rivers will not change much. For most other rivers agriculture (fertilizer and increasingly manure) remain the two largest sources of DIN, although their relative contribution changes in some basins. An exception is the Damodar River where sewage inputs are projected to become dominant.

Leaching is the main source of DON in all BOBLME rivers under 2000 conditions, with the exception of a few watersheds where sewage and fertilizer are the 2 largest sources of DON (Figures 8 and 9). In the future this picture is projected to change slightly according to the GO scenario: leaching will remain the main source of DON in most rivers but leaching from agricultural land will replace leaching from natural soils in a number of rivers. Also sewage will become increasingly important in a number of rivers throughout the BOB. This may be related to both an increase in population and an increasing fraction of population connected to sewage in these basins.

Compared to N, there is more variation in dominant DIP sources across basins (Figures 10 and 11 and Table 3). As with DIN, agriculture (manure and fertilizer) is important as a source of DIP throughout much of the BOBLME under 2000 conditions. In some basins sewage is the largest source of DIP. In a number of eastern basins in the BOBLME natural weathering or weathering from agricultural soils are the two largest sources. There are also similarities between DON and DOP: first of all, in many of the basins throughout the BOBLME leaching from natural and agricultural areas are the largest or second largest contributors for DOP. However, fertilizer, manure and sewage are the second largest sources of DOP in a number of basins throughout the BOBLME.

Projected future changes in sources of DIP according to the GO scenario reflect the urbanization trends in the BOBLME basins. By 2050 sewage is projected to be the largest source of DIP in most rivers, with agricultural sources and P in detergents second largest in many rivers (Fig. 10 and 11). As a result of agricultural development, diffuse agricultural sources (fertilizer and manure) will be important sources of DIP in the large eastern basins and in Godavari and Penner in the Indian subcontinent.

While leaching from natural or agricultural areas is projected to remain the largest source of DOP in most rivers by 2050, manure becomes the second largest source in the Ganges, and the cluster of basins in southern India.

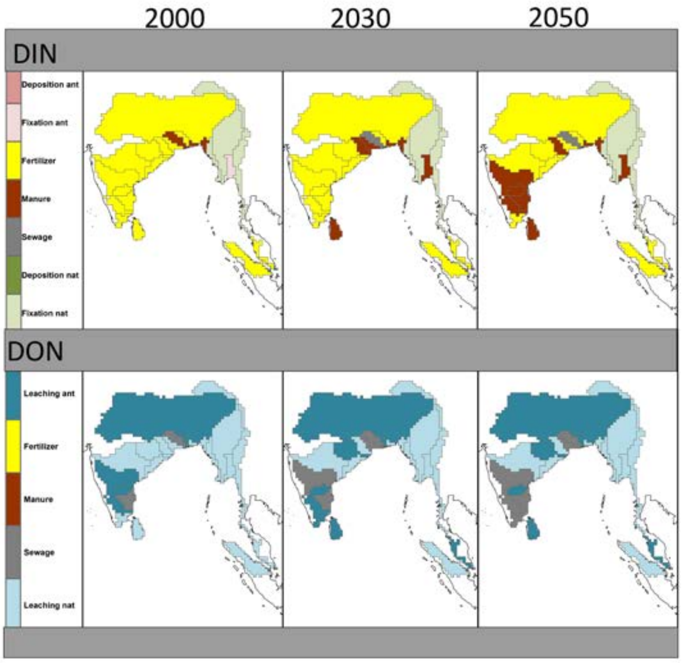


Figure 8: Largest source of DIN and DON yields transported from watersheds to the mouth of the rivers in the Bay of Bengal in the year 2000, and according to the Global Orchestration scenario in 2030 and 2050.

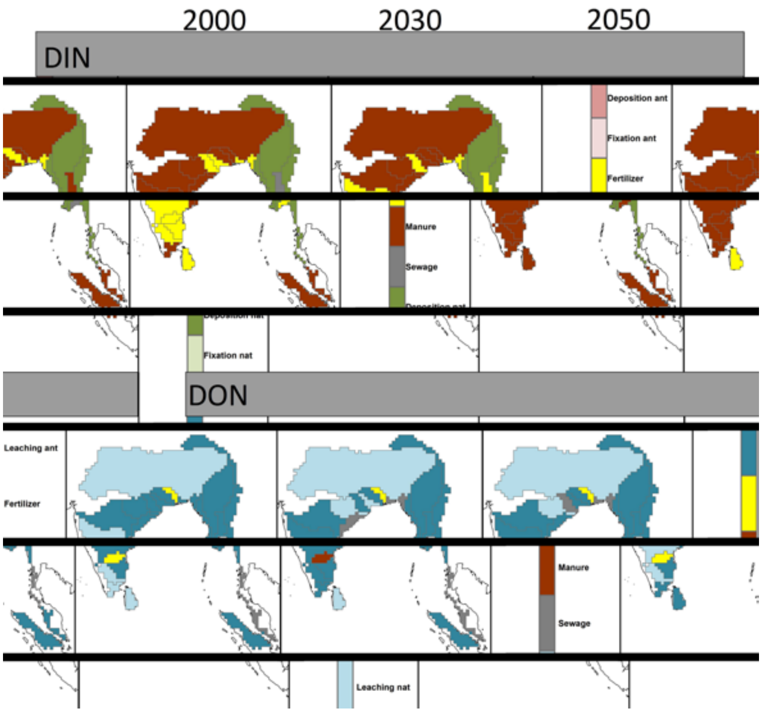


Figure 9: Second largest source of DIN and DON yields transported from watersheds to the mouth of the rivers in the Bay of Bengal in the year 2000, and according to the Global Orchestration scenario in 2030 and 2050.

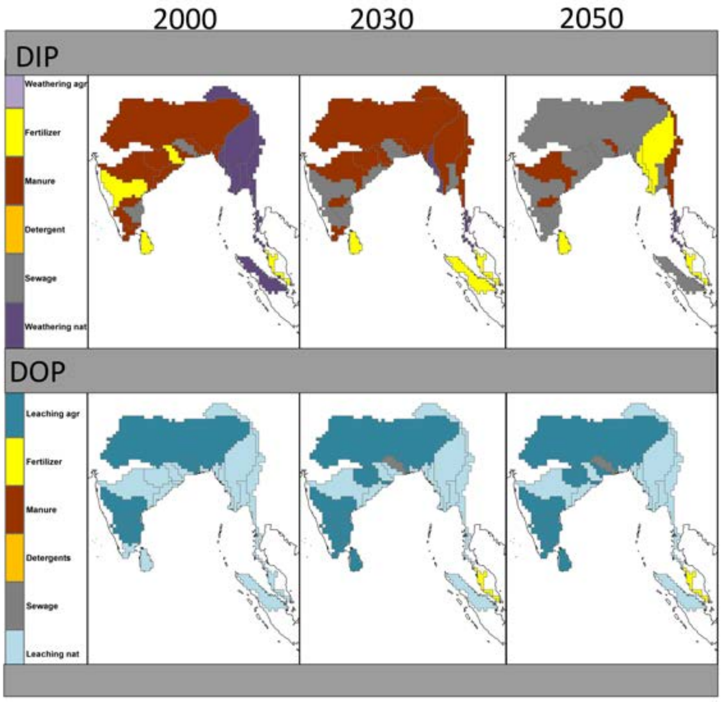


Figure 10: Largest source of DIP and DOP yields transported from watersheds to the mouth of the rivers in the Bay of Bengal in the year 2000, and according to the Global Orchestration scenario in 2030 and 2050.

[redacted]

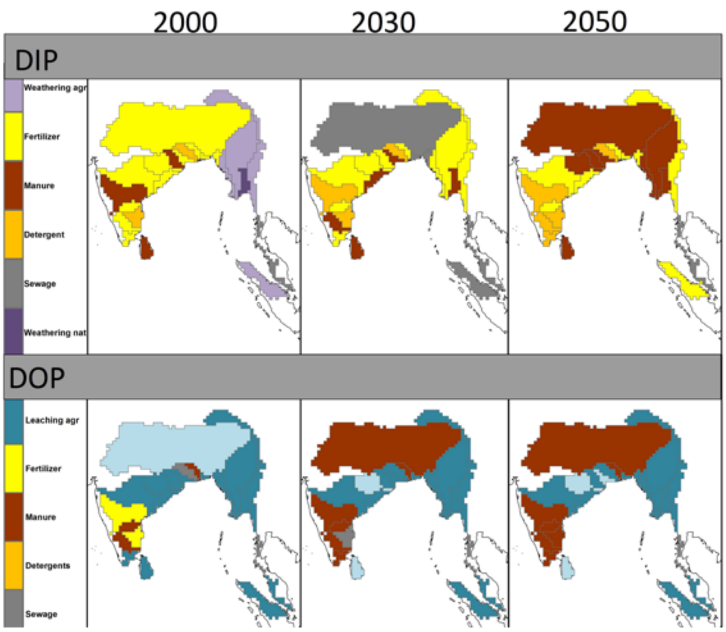


Figure 11: Second largest source of DIP and DOP yields transported from watersheds to the mouth of the rivers in the Bay of Bengal in the year 2000, and according to the Global Orchestration scenario in 2030 and 2050.

Table 3: Relative share (in %) of source attribution for each basin for each nutrient form (DIN, DON, DIP, DOP) for the year 2000.

ID	DIN							DON					DIP						DOP					
	Fix nat	D nat	S	M	F	Fix ant	D ant	L nat	S	M	F	L ant	W nat	S	D	M	F	W ant	L nat	S	D	M	F	L ant
Bangladesh	10	7	0	35	32	9	8	79	0	2	2	17	15	0	0	52	27	6	73	0	0	8	4	15
Brahmani	4	4	0	31	39	7	15	55	0	4	5	36	8	0	0	42	44	5	44	0	0	13	14	29
Cauweri	1	1	0	36	40	11	11	21	0	7	8	64	2	0	0	47	44	7	15	0	0	20	19	46
Damodar	0	0	23	29	27	7	14	4	67	3	3	23	0	66	20	7	6	1	6	22	7	17	14	35
Ganges	7	8	0	29	35	8	13	31	2	5	7	55	4	5	2	42	40	7	24	0	0	16	16	43
GHAASBasin434	0	0	0	34	40	10	15	8	0	9	10	74	1	0	0	53	39	7	6	0	0	23	17	54
Godavari	4	3	0	32	38	11	11	56	0	4	5	36	9	0	0	43	42	6	46	0	0	13	12	29
India1	3	2	0	36	41	10	9	52	0	4	5	38	8	0	0	45	41	6	42	0	0	14	13	30
India2	0	0	16	30	36	9	9	11	51	3	4	31	1	63	19	9	9	1	13	14	4	16	16	37
India3	6	4	0	32	36	10	11	67	0	3	3	27	15	0	0	42	37	6	57	0	0	10	9	23
India4	3	3	0	33	37	9	16	45	0	5	6	44	12	0	0	43	40	6	35	0	0	16	15	34
Indonesia	14	5	3	19	41	10	7	70	5	1	1	23	58	13	4	3	5	18	74	1	0	0	0	24
Irrawaddy	48	22	0	12	5	8	6	67	0	0	0	33	61	0	0	8	2	30	66	0	0	1	0	33
Krishna	1	1	0	34	42	12	11	25	0	6	8	61	10	0	0	42	43	6	18	0	0	19	19	44
Mahanadi	3	2	0	31	38	10	15	46	0	5	6	44	6	0	0	44	43	6	36	0	0	15	15	34
Malaysia	5	1	7	11	64	6	5	43	13	1	4	39	4	36	10	7	39	4	39	3	1	3	19	35
Myanmar	57	27	0	4	3	6	3	89	0	0	0	11	88	0	0	0	0	12	89	0	0	0	0	11
Penner	3	2	0	34	41	10	11	9	0	8	10	73	1	0	0	47	46	6	6	0	0	22	22	49
Salween	42	21	0	12	8	10	8	59	0	0	0	40	43	0	0	19	7	30	59	0	0	1	1	39
Sittang	12	5	1	22	20	25	15	58	1	0	0	40	37	14	5	10	11	23	57	0	0	1	1	40
Sri Lanka	4	1	0	21	56	11	6	51	0	2	5	41	19	0	0	31	34	16	50	0	0	5	5	40
Thailand/ South-Myanmar	77	23	0	0	0	0	0	100	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0

3.3.3 Potential for coastal eutrophication

Eutrophication from excess anthropogenic nutrient inputs to coastal waters is an increasing problem in many areas around the world. Both nutrient loads and nutrient ratios are important determinants of the algal biomass and species composition that develop and consequently the negative effects on coastal systems (e.g., very high algal biomass, decrease in dissolved oxygen, toxin production, changes in ecosystem structure and function). The Index of Coastal Eutrophication (ICEP) is one approach for assessing the potential effect of nutrient ratios (ratio of N and P to Si in river export) on coastal ecosystems(Garnier et al., 2010). In Figure 12 the yields (kg/km^2/y) of silica across the Bay of Bengal`s basins under 2000 conditions and future trends are shown which allow for comparison with mapped yields for N and P forms in Figures 6 and 7.

For the year 2000, lowest yields of DSi are generally distributed across basins in India, whereas relatively higher yields are calculated for the Ganges and eastern BOBLME rivers (>2000 kg/km^2). Future trends in DSiyields are projected to increase in some basins and decrease in others under the GO 2050 scenario (Figure 12). Future changes in water runoff and biological removal in reservoirs are two important factors that control DSi yields(Beusen et al., 2009).

Figure 13 presents ICEP values for BOBLME basins. Positive values (ICEP>0) indicate a risk for non-siliceous algal biomass (e.g., dinoflagellates) many of which produce toxins and otherwise disrupt nearshore coastal ecosystems (Glibert et al., 2010). Negative values (ICEP<0) indicate that on average silica is in excess over N or P for algal growth and as such diatom growth is favored rather than the growth of potentially harmful algal species. However, negative ICEP values do not guarantee that there is no coastal eutrophication, since high biomass algal blooms (e.g. diatoms) may develop due to high nutrient loads. Neither nutrient loads nor ICEP take into account the particular morphological, climatic and hydrological conditions, including temporal variations, which also are important in determining the response of algae in coastal systems. However, as Garnier et al. (2010) have shown, positive ICEP values indicate that the yearly averaged N and P loads favor non-siliceous algal species, and should therefore be considered a strong indication that the coastal waters are at risk. As noted above for nutrient loads (Section 3.3.1), the effects of river delivery of nutrients (loads and ratios) is likely most strongly expressed in near shore receiving waters (estuaries and bays).

For the BOBLME basins, we generally calculate positive ICEP values (Figure 13) indicating a risk for development of non-siliceous algal biomass in the near coastal zone. According to the GO scenario by 2050, the ICEP values for a number of basins become more positive relative to 2000, indicating an increased risk. There are a few exceptions. For Salween and Sittang the present low potential for non-siliceous algal biomass will remain low (for Sittang there will be a decrease after 2030). The decrease in river export of particulate nutrients (especially for Salween) and an increase in DSi (especially for Sittang) compensate for an overall increase in dissolved N and P over time. We calculate a decreasing potential for coastal eutrophication for a number of smaller coastal river basins around the BOBLME. This is mostly associated with increasing DSi yields (e.g., Krishna and Indonesia).

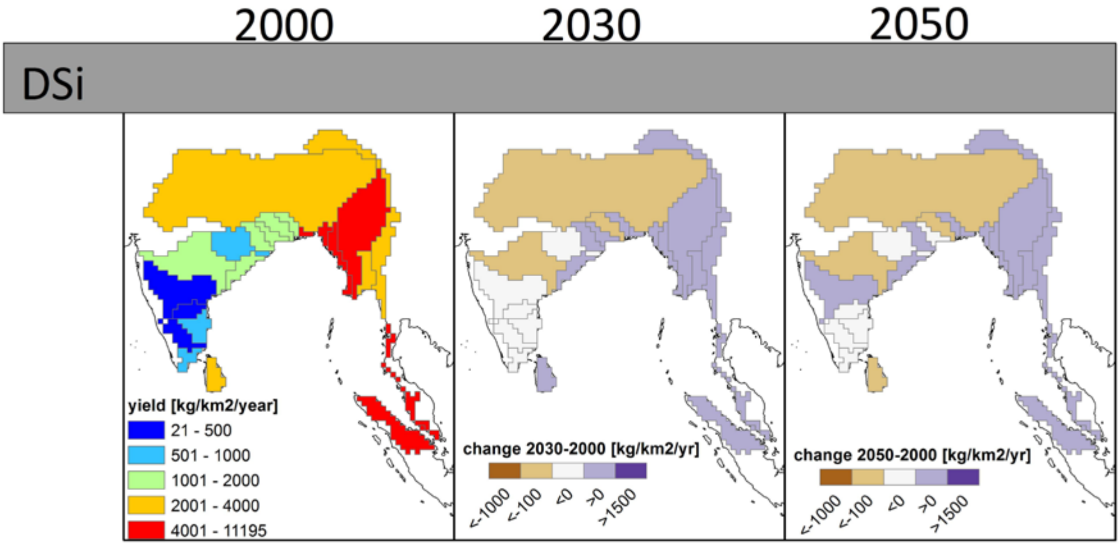


Figure 12: River export of DSi to the Bay of Bengal for the year 2000 (kg/km2/year) and changes 2000-2030 and 2000-2050 for the Global Orchestration scenario.

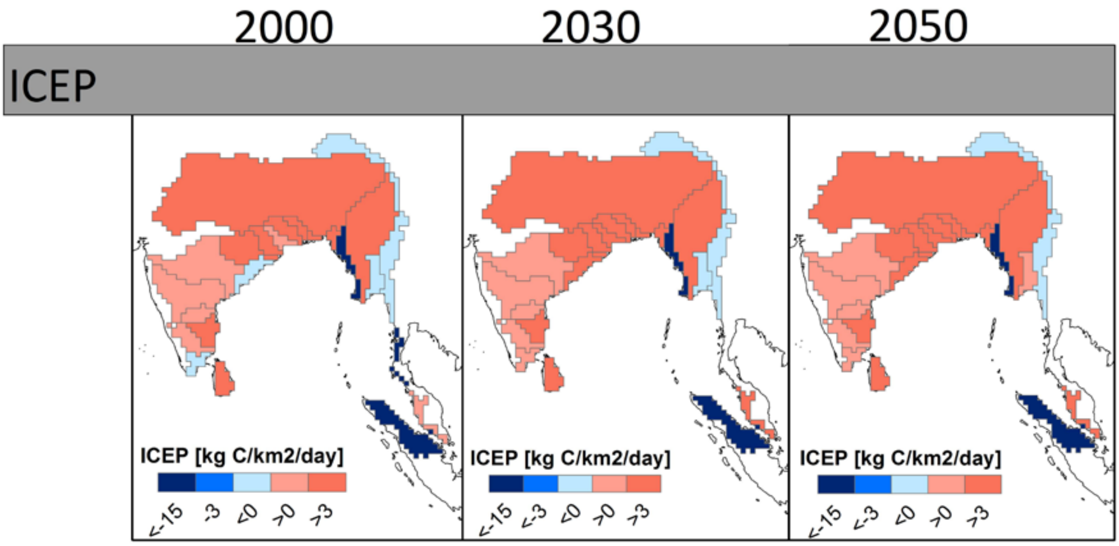


Figure 13: ICEP for rivers draining into the Bay of Bengal for the years 2000, 2030 and 2050. Future changes are calculated according to the Global Orchestration scenario.

4. Discussion, Conclusions and Future Directions

The Global NEWS model has been applied to watersheds throughout the BOBLME for approximate year 2000 conditions and future trends. The future trends that we present here are based on the Global Orchestration scenario, which is one of the Millennium Ecosystem Assessment scenarios. We selected this scenario because it assumes a globalized socio-economic development, and a reactive approach towards ecosystem management. It should be noted however, that other scenarios may be as likely as this scenario. We also would like to stress that the scenario is a "what if" scenario, projecting environmental changes on the basis of assumptions on human activities in the future.

The important conclusions of this study include:

- In 2000, rivers exported 7.1 Tg N and 1.5 Tg P to the BOBLME. By 2050, the N load may amount to 8.6 Tg, while the P load will not change much. This is the net effect of increasing loads for dissolved N and P, and decreasing loads for particulate N and P.
- Future trends in N and P river export differ substantially among basins.
- Dissolved N and P yields are projected to increase between 2000 and 2050 from most basins. These increases can be large, up to more than a factor of 5 for DIP and more than a doubling for DIN and DON.
- The increases in dissolved N and P loads are associated primarily with increased N and P in agriculture and with an increasing population and economic development.
- The decreases in particulate N and P loads are associated with changes in hydrology, and most importantly with damming of rivers, increasing the retention of total suspended solids.
- We generally calculate positive ICEP values for BOBLME rivers, indicating a risk for coastal eutrophication of non-siliceous algal blooms. In the future, based on the Global Orchestration scenario, the ICEP values are generally higher than in 2000, indicating an increased risk.
- The dominant sources of the different forms of N and P differ across basins. Thus effective management of coastal eutrophication calls for a basin-specific approach. In general, we may conclude that agriculture is an important source of dissolved inorganic N in rivers, and sewage of dissolved inorganic P.

Future directions:

Next steps to consider for open waters of the BOBLME. A few large rivers (Ganges, Godavari and Irrawaddy) contribute approximately 75-80% of the N and P loads to the BOBLME overall. It follows that, in order to reduce eutrophication effects in the open waters of the BOBLME, reductions in nutrient loads from those major rivers would be targeted for reduction using the information in this report. Coupled hydrodynamic-biogeochemical-ecosystem models of the BOBLME coupled with river nutrient loads provided in this report would be useful in understanding the effects of current, and potential future, nutrient loading from BOBLME watersheds on the BOBLME ecosystem (e.g., algal blooms, hypoxic conditions, etc.). One such modeling effort is under development by the Sustained Indian Ocean Biogeochemistry and Ecosystem Research activity (SIBER) of IGBP's Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) project (http://www.imber.info/index.php/Science/Regional-Programmes/SIBER).

Next steps to consider for Bay of Bengal near coastal systems (estuaries, bays) would be to identify those near coastal systems with signs of eutrophication (e.g., high phytoplankton biomass, high abundances of harmful non-siliceous phytoplankton species such as dinoflagellates, low oxygen conditions, degradation of seagrass environments). The river basins draining into those coastal systems could then be targeted for nutrient reductions using the information on major nutrient sources provided in this report. Projected future trends in nutrient loadings based on the scenario analyses presented here also could be used to avoid future eutrophication in specific coastal areas.

Improvements in the accuracy of current and future river nutrient export and source identification will be facilitated by monitoring of nutrient export in BOBLME rivers (for comparison with model predictions and refinement of model parameterization), development of higher resolution gridded databases of nutrient use, nutrient management practices, hydrology, etc. for the river basins, and monitoring of environmental conditions in coastal ecosystems.

5. References

ALCAMO, J., VAN VUUREN, D., CRAMER, W., ALDER, J., BENNETT, E., CARPENTER, S., CHRISTENSEN, V., FOLEY, J., MAERKER, M., MASUI, T., MORITA, T., O'NEILL, B., PETERSON, B., RINGLER, C., ROSEGRANT, M., SCHULZE, R., BOUWMAN, L., EICKHOUT, B., FLOERKE, M., LAL, R., K., T., SINH, B. T., HAMMOND, A. & FIELD, C. 2005. Chapter 9. Changes in Ecosystem Services and Their Drivers across the Scenarios. *In:* CARPENTER, S., PINGALI, P., BENNET, E. & ZUREK, M. (eds.) *Millennium Ecosystem Assessment. Volume 2: Scenarios.* Washington: Island Press.

BEUSEN, A. H. W., BOUWMAN, A. F., DÜRR, H. H., DEKKERS, A. L. M. & HARTMANN, J. 2009. Global patterns of dissolved silica export to the coastal zone: Results from a spatially explicit global model. *Global Biogeochem. Cycles,* 23, GB0A02, doi:10.1029/2008GB003281

BOUWMAN, A. F., BEUSEN, A. H. W. & BILLEN, G. 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970-2050. *Global Biogeochemical Cycles,* 23, GB0A04, doi:10.1029/2009GB003576

BOUWMAN, A. F., KRAM, T. & KLEIN GOLDEWIJK, K. (eds.) 2006. *Integrated Modelling of Global Environmental Change. An overview of IMAGE 2.4,* Bilthoven: Netherlands Environmental Assessment Agency (MNP).

FEKETE, B., VÖRÖSMARTY, C. & GRABS, W. 2002. High-resolution fields of global runoff combining observed river discharge and simulated water balances. Global Biogeochemical Cycles 16 *Glob Biogeochem Cycles,* 16**,** 1042, doi:10.1029/1999GB001254.

FEKETE, B. M., WISSER, D., KROEZE, C., MAYORGA, E., BOUWMAN, A. F., WOLLHEIM, W. M. & VÖRÖSMARTY, C. J. 2010. Millennium Ecosystem Assessment Scenario drivers (1970-2050): Climate and hydrological alterations. *Global Biogeochemical Cycles,* doi:10.1029/2009GB003593.

GARNIER, J., BEUSEN, A. H. W., THIEU, V., BILLEN, G. & BOUWMAN, A. F. 2010. N:P:Si nutrient export ratios and ecological consequences in coastal seas evaluated by the ICEP approach *Global Biogeochemical Cycles,* doi:10.1029/2009GB003583.

GLIBERT, P.M., ALLEN, J.I., BOUWMAN, A.F., BROWN, C.W., FLYNN, K.J., LEWITUS, A.J & MADDEN, C.J. 2010. Modeling of HABs and eutrophication: Status, avances, challenges. *Journal of Marine Systems*, 83, 262-275.

KOTTEK, M., GRIESER, J., RGEN, BECK, C., RUDOLF, B. & RUBEL, F. 2006. World Map of the Koppen-Geiger climate classification updated. *Meteorologische Zeitschrift,* 15**,** 259-263.

KROEZE, C., BOUWMAN, L. & SEITZINGER, S. 2012. Modeling global nutrient export from watersheds. *Current Opinion in Environmental Sustainability,* 4**,** 195-202.

LEHNER, B. & DÖLL, P. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. *Journal of Hydrology,* 296**,** 1-22.

MAYORGA, E., SEITZINGER, S. P., HARRISON, J. A., DUMONT, E., BEUSEN, A. H. W., BOUWMAN, A. F., FEKETE, B. M., KROEZE, C. & VAN DRECHT, G. 2010. Global Nutrient Export from WaterSheds 2 (NEWS 2): Model development and implementation. *Environmental Modelling & Software,* 25**,** 837-853.

MEYBECK, M. & RAGU, A. 1996. *River discharges to the oceans: An assessment of suspended solids, major ions, and nutrients,* Paris, U.N. Environment Programme.

NEW, M., HULME, M. & JONES, P. 1999. Representing Twentieth-Century Time Climate Variability. Part I: Development of a Mean Monthly Terrestrial Climatology. *Journal of Climate,* 12**,** 829-856.

QU, H. & KROEZE, C. 2012. Nutrient export by rivers to the coastal waters of China: Management strategies and future trends. *Regional Environmental Change,* 12**,** 153-167.

QU, H. J. & KROEZE, C. 2010. Past and future trends in nutrients export by rivers to the coastal waters of China. *Science of The Total Environment,* 408**,** 2075-2086.

SATTAR, M. A., KROEZE, C. & STROKAL, M. 2014. The increasing impact of food production on nutrient export by rivers to the Bay of Bengal 1970-2050. *Mar. Pollut. Bull.,* 8**,** 168-178.

SEITZINGER, S., EMILIO MAYORGA, E., BOUWMAN, A. F., KROEZE, C., BEUSEN, A. H. W., BILLEN, G., VAN DRECHT, G., DUMONT, E., FEKETE, B. M., GARNIER, J. & HARRISON, J. 2010. Global River Nutrient

Export: A Scenario Analysis of Past and Future Trends. *Global Biogeochemical Cycles,* doi:10.1029/2009GB003587.

VAN DER STRUIJK, F. & KROEZE, C. 2010. Future Trends in Nutrient Export to the Coastal Waters of South America: Implications for Occurrence of Eutrophication. *Global Biogeochemical Cycles,* doi:10.1029/2009GB003572.

VAN DRECHT, G., BOUWMAN, A. F., HARRISON, J. & KNOOP, J. M. 2009. Global nitrogen and phosphate in urban wastewater for the period 1970 to 2050. *Global Biogeochem. Cycles,* 23**,** GB0A03.

VÖRÖSMARTY, C., MEYBECK, M., FEKETE, B., SHARMA, K., GREEN, P. & SYVITSKI, J. P. M. 2003. Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planetary Change,* 39**,** 169-190.

VÖRÖSMARTY, C. J., FEKETE, B. M., MEYBECK, M. & LAMMERS, R. B. 2000. Global system of rivers: Its role in organizing continental land mass and defining land-to-ocean linkages. *Global Biogeochemical Cycles,* 14**,** 599-621.

YAN, W., MAYORGA, E., LI, X., SEITZINGER, S. P. & BOUWMAN, A. F. 2010. Increasing anthropogenic nitrogen inputs and riverine DIN exports from the Changjiang River basin under changing human pressures. *Global Biogeochemical Cycles,* doi:10.1029/2009GB003575.

YASIN, J. A., KROEZE, C. & MAYORGA, E. 2010. Nutrients export by rivers to the coastal waters of Africa: Past and future trends. *Global Biogeochemical Cycles,* 24**,** GB0A07.

ANNEX 1: Original Global NEWS Basins

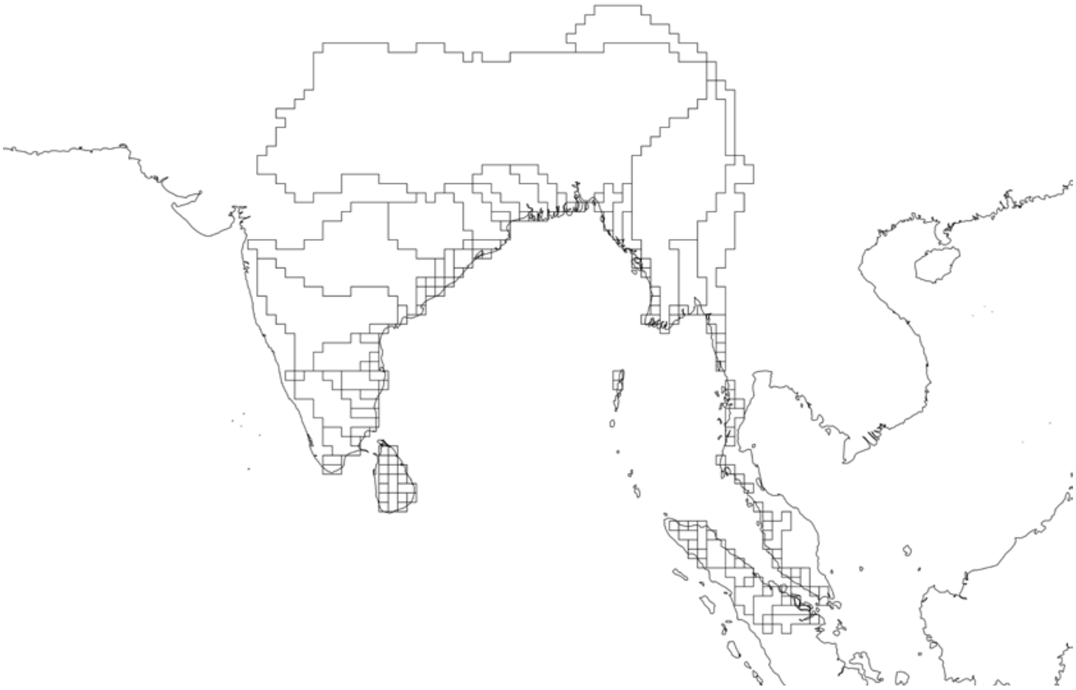


Figure A-1: The 133 original river basins draining into the Bay of Bengal assigned to the BOBLME before aggregation of small basins

Table A-4 List of selected basins of the Bay of Bengal study area

Basin ID in Figure 1	Combined basin name	Original Global NEWS Basin name	Area of original Global NEWS basin (km^2)
01	Bangladesh	GHAASBasin3395	2858
		GHAASBasin3423	2847
		GHAASBasin3403	2858
		GHAASBasin1863	5705
		GHAASBasin1853	5746
		GHAASBasin865	14247
02	Brahmani	Brahmani	57289
03	Cauweri	Cauweri	78587
04	Damodar	Damodar	59591
05	Ganges	Ganges	1626470
06	GHAASBasin434	GHAASBasin434	31150
07	Godavari	Godavari	311206
		GHAASBasin1777	5921
08	India1	GHAASBasin2947	3043
		GHAASBasin1677	6077
		GHAASBasin1660	6103
		GHAASBasin1654	6111
		GHAASBasin549	24348
09	India2	GHAASBasin3100	3012
		GHAASBasin3123	2999
		GHAASBasin1735	5992
		GHAASBasin1723	6011
		GHAASBasin1701	6035
		Vellar	9085
		Palar	21062
		Ponnaiyar	24126
10	India3	GHAASBasin3300	2906
		GHAASBasin3267	2924
		NAGAVALI	2932
		GHAASBasin3196	2957
		GHAASBasin1828	5803
		GHAASBasin1801	5873
		GHAASBasin1800	5873
		GHAASBasin1793	5889
		VAMSADHARA	8745
		GHAASBasin1277	8771
		GHAASBasin1012	11642
11	India4	GHAASBasin3386	2868
		GHAASBasin3385	2868
		GHAASBasin3354	2878
		GHAASBasin1854	5736
		Subamarekha	22810
12	Indonesia	GHAASBasin2537	3088
		GHAASBasin2744	3075
		GHAASBasin2750	3075
		GHAASBasin2749	3075
		GHAASBasin2733	3077
		GHAASBasin2707	3079
		GHAASBasin2690	3081
		GHAASBasin2689	3081
		GHAASBasin2678	3083
		GHAASBasin2672	3083
		GHAASBasin2628	3085
		GHAASBasin2609	3086
		GHAASBasin2599	3087
		GHAASBasin2584	3087
		GHAASBasin1612	6154
		GHAASBasin1594	6164
		GHAASBasin1565	6171
		GHAASBasin1167	9231
		GHAASBasin945	12338
		GHAASBasin794	15437
		GHAASBasin681	18486
		GHAASBasin679	18526
		BARUMUM	21605
		GHAASBasin594	21609
13	Irrawaddy	Irrawaddy	405481

Basin ID in Figure 1	Combined basin name	Original Global NEWS Basin name	Area of original Global NEWS basin (km^2)
14	Krishna	Krishna	251385
		GHAASBasin1761	5943
		GUNDALAKAMMA	5958
		GHAASBasin3108	3005
15	Mahanadi	Mahanadi	141040
16	Malaysia	GHAASBasin1560	6173
		GHAASBasin2780	3069
		GHAASBasin2771	3072
		GHAASBasin2754	3075
		GHAASBasin2735	3077
		GHAASBasin2704	3081
		GHAASBasin2671	3083
		GHAASBasin2641	3084
		GHAASBasin2640	3084
		GHAASBasin2618	3086
		GHAASBasin1573	6169
		Perak	18457
17	Myanmar	GHAASBasin3310	2906
		GHAASBasin3285	2915
		GHAASBasin3284	2915
		GHAASBasin3266	2924
		GHAASBasin3234	2941
		GHAASBasin3219	2949
		GHAASBasin3205	2957
		GHAASBasin1770	5929
		LEMRO	14426
		Kaladan	20033
18	Penner	Penner	53845
19	Salween	Salween	273038
		GHAASBasin3142	2993
		GHAASBasin3150	2986
		GHAASBasin3167	2979
		GHAASBasin3180	2972
		GHAASBasin3122	2999
		GHAASBasin1256	8900
20	Sittang	Sittang	55601
		GHAASBasin3202	2957
		GHAASBasin3195	2957
		GHAASBasin3193	2964
		GHAASBasin3099	3012
21	Sri Lanka	GHAASBasin2942	3048
		GHAASBasin2943	3048
		GHAASBasin2918	3052
		GHAASBasin2893	3052
		GHAASBasin2878	3056
		GHAASBasin2862	3056
		GHAASBasin2848	3059
		GHAASBasin2847	3059
		GHAASBasin2821	3063
		GHAASBasin2808	3066
		GHAASBasin2807	3066
		GHAASBasin2792	3066
		GHAASBasin2788	3069
		GHAASBasin2781	3069
		GHAASBasin1642	6126
		GHAASBasin1633	6136
		GHAASBasin1199	9178
22	Thailand	GHAASBasin3058	3023
		GHAASBasin3098	3012
		GHAASBasin3074	3017
		GHAASBasin2989	3038
		GHAASBasin2968	3043
		GHAASBasin1658	6107
		GHAASBasin1212	9090
		GHAASBasin2840	3059
		GHAASBasin2820	3063
TOTAL	**22 basins**	**133 basins**	**4059950**

Annex 2

Global NEWS 2 River Nutrient Exports

Global NEWS 2 model run: **"realistic hydrology" for the reference year 2000 and Global Orchestration (GO) Scenarios for the years 2030 and 2050**

Dataset version 2 April 2014

This excel file provides the results of calculations of basin-level nutrient export for 22 aggregated basins in the Bay of Bengal.
This excel file is ancillary to the report "Understanding nutrient loading and sources in the Bay of Bengal Large Marine Ecosystem"
The data for this model run are based on Mayorga et al. (2010) and, for silica, on Beusen et al. (2009)
For basins <10 grid cells nutrient exports have been aggregated in 10 "combined basin regions".

For questions and additional information, please contact:
Sybil Seitzinger
International Geosphere-Biosphere Program, Stockholm, Swec
sybil.seitzinger@IGBP.kva.se

Simona Pedde, MSc
Environmental System Analysis,
Wageningen University, the Netherlands
simona.pedde@wur.nl

Variable and parameter descriptions

name	*description*	*unit*
	Units	
Global NEWS ID	STN-30p vers. 6.01 basin identification code (unique integer ID). This ID is not available for newly created "combined basin regions"	-
ID in map	Basin ID corresponding to Figure 1 in the report	-
ID	Name of the basin	-
Yld_<NF>	Modeled nutrient form yield, in element mass units (e.g., kg N/k	kg/km2/yr
Ld_<NF>	Modeled nutrient form load, in element mass units (e.g., Mg N/	Mg/yr
ICEP	ICEP (Indicator Coastal Eutrophication Potential)	kg C/km2/day
Area	Area basin	km2
	yields sheets	
ID	Name of the basin	-
Yld_<NF>	Yields for each nutrient form for the reference year 2000 and GO scenarios 2030 and 2050. For future exports, at the right side of each yield, changes in yields with respect to the reference year 2000 are also calculated [in %]	kg/km2/yr
	loads sheet	
Ld_<NF>	Loads for each nutrient form for the reference year 2000 and GO scenarios 2030 and 2050. For future exports, at the right side of each yield, changes in yields with respect to the reference year 2000 are also calculated [in %]	Mg/yr

<NF>: The nutrient form (not including TSS): DIN, DIP, DON, DOP, DSi, PN, PP,

	DIN					DON					PN					TN				
ID	2000	2030	2030 [chang	2050	2050[chang	2000	2030	2030 [chang	2050	2050[chang	2000	2030	2030 [chang	2050	2050[chang	2000	2030	2030 [chang	2050	2050[change]
Bangladesh	1585	2283	44%	2627	66%	452	560	24%	645	43%	612	631	3%	634	4%	2649	3473	31%	3906	47%
Brahmani	730	771	6%	708	-3%	138	136	-1%	168	22%	179	181	1%	187	5%	1047	1088	4%	1063	2%
Cauweri	223	253	14%	320	43%	36	39	9%	61	68%	30	19	-35%	20	-32%	289	311	8%	400	39%
Damodar	1218	1480	22%	1640	35%	298	466	56%	493	66%	231	74	-68%	68	-70%	1747	2020	16%	2202	26%
Ganges	1641	2024	23%	2198	34%	230	250	9%	260	13%	755	570	-24%	464	-39%	2626	2845	8%	2922	11%
GHAASBasin434	606	812	34%	956	58%	54	56	3%	58	7%	331	340	3%	358	8%	991	1208	22%	1372	38%
Godavari	404	548	36%	599	48%	94	93	0%	93	0%	169	99	-41%	74	-56%	667	741	11%	766	15%
India1	189	339	80%	450	139%	38	37	-1%	61	61%	55	62	14%	64	17%	281	439	56%	575	105%
India2	345	532	54%	665	92%	60	102	69%	111	84%	125	117	-6%	113	-10%	531	751	41%	888	67%
India3	336	560	66%	888	164%	67	90	35%	97	45%	145	256	77%	252	74%	548	907	65%	1237	126%
India4	1149	1680	46%	2049	78%	169	331	96%	361	114%	87	91	4%	85	-2%	1405	2102	50%	2495	78%
Indonesia	588	790	34%	883	50%	298	330	11%	350	17%	397	454	14%	467	18%	1283	1574	23%	1699	32%
Irrawaddy	1119	1461	31%	1805	61%	419	448	7%	484	16%	863	815	-6%	825	-4%	2401	2724	13%	3115	30%
Krishna	206	354	71%	404	96%	60	86	42%	85	41%	22	20	-12%	27	20%	289	459	59%	516	78%
Mahanadi	606	735	21%	891	47%	118	125	6%	142	20%	124	114	-8%	111	-11%	847	974	15%	1144	35%
Malaysia	1211	2135	76%	3483	188%	378	510	35%	593	57%	358	376	5%	394	10%	1947	3022	55%	4470	130%
Myanmar	922	1165	26%	1501	63%	632	642	2%	663	5%	963	969	1%	980	2%	2517	2776	10%	3145	25%
Penner	73	92	25%	140	90%	13	12	-2%	16	25%	2	2	-4%	2	0%	88	106	21%	157	79%
Salween	363	549	51%	644	78%	155	176	13%	196	26%	476	312	-35%	386	-19%	994	1036	4%	1225	23%
Sittang	567	695	23%	1044	84%	310	391	26%	441	42%	577	556	-4%	591	2%	1454	1642	13%	2076	43%
Sri Lanka	828	602	-27%	650	-22%	169	163	-4%	165	-2%	454	510	12%	457	1%	1452	1275	-12%	1272	-12%
Thailand/ South-Mya	274	301	0	318	16%	524	522	0%	520	-1%	822	827	1%	831	1%	1620	1650	2%	1669	3%

	DIP					DOP					PP					TP				
ID	2000	2030	2030 [chang	2050	2050[chang	2000	2030	2030 [chang	2050	2050[chang	2000	2030	2030 [chang	2050	2050[chang	2000	2030	2030 [chang	2050	2050[change]
Bangladesh	61	127	106%	202	229.58%	26	30	13%	31	18%	308	319	4%	321	4%	395	475	20%	554	40%
Brahmani	41	37	-9%	73	77.40%	9	9	-3%	9	-2%	76	78	2%	80	5%	127	124	-2%	162	28%
Cauweri	2	4	49%	9	273.64%	3	3	-1%	3	15%	16	9	-44%	9	-41%	21	15	-28%	21	1%
Damodar	356	190	-47%	87	-75.58%	11	13	21%	14	33%	104	33	-68%	31	-70%	470	236	-50%	132	-72%
Ganges	102	146	44%	164	60.47%	16	16	4%	17	7%	464	353	-24%	289	-38%	581	516	-11%	469	-19%
GHAASBasin434	21	27	33%	33	59.26%	4	5	13%	5	27%	201	207	3%	217	8%	226	239	6%	255	13%
Godavari	19	20	5%	18	-2.47%	6	6	3%	7	7%	84	51	-40%	37	-55%	109	77	-29%	62	-43%
India1	4	6	50%	25	552.49%	3	3	16%	4	42%	23	28	20%	29	23%	30	37	23%	58	94%
India2	56	108	91%	116	106.13%	3	3	27%	4	46%	65	61	-7%	57	-12%	124	172	38%	177	43%
India3	12	47	277%	59	368.82%	4	5	17%	6	41%	70	128	84%	127	82%	86	180	109%	191	122%
India4	25	85	238%	79	213.10%	12	14	24%	17	43%	39	41	5%	38	0%	75	140	86%	134	78%
Indonesia	19	49	160%	67	251.25%	15	17	12%	18	17%	189	226	19%	230	22%	223	292	31%	315	41%
Irrawaddy	22	78	261%	137	535.61%	23	27	19%	32	42%	452	407	-10%	415	-8%	496	512	3%	585	18%
Krishna	3	14	361%	14	360.04%	4	5	5%	5	12%	11	10	-16%	12	6%	19	28	49%	31	64%
Mahanadi	18	10	-43%	15	-16.12%	8	8	4%	9	14%	60	55	-9%	52	-14%	86	73	-15%	76	-12%
Malaysia	157	690	340%	712	353.53%	22	53	135%	54	142%	165	179	8%	189	14%	345	922	167%	955	177%
Myanmar	23	47	107%	86	280.77%	34	36	8%	41	20%	449	447	0%	452	1%	505	531	5%	579	14%
Penner	0	0	13%	0	72.94%	1	1	4%	1	46%	1	1	-4%	1	0%	2	2	2%	3	30%
Salween	8	17	113%	29	252.25%	8	10	20%	11	33%	280	176	-37%	221	-21%	296	204	-31%	261	-12%
Sittang	26	141	447%	241	831.42%	17	21	25%	26	56%	322	267	-17%	281	-13%	364	430	18%	548	50%
Sri Lanka	22	39	77%	42	90.12%	9	10	12%	11	18%	260	266	3%	234	-10%	291	316	8%	287	-1%
Thailand/ South-Mya	23	23	0%	23	-0.64%	28	28	0%	28	-1%	360	363	1%	366	1%	411	414	1%	416	1%

	DSi					ICEP				
ID	2000	2030	2030 [change	2050	2050[change	2000	2030	2030 [change	2050	2050[change]
Bangladesh	4008	4096	2%	4181	4%	16	28	72%	35	18%
Brahmani	1514	1523	1%	1542	2%	5	4	-8%	7	-2%
Cauweri	229	179	-22%	196	-14%	1	1	-37%	1	15%
Damodar	1374	439	-68%	412	-70%	19	24	28%	12	33%
Ganges	2044	1793	-12%	1682	-18%	28	33	18%	35	7%
GHAASBasin434	1181	1186	0%	1204	2%	8	11	42%	14	27%
Godavari	1600	954	-40%	717	-55%	0	3	533%	3	7%
India1	570	565	-1%	570	0%	0	1	-398%	3	42%
India2	720	694	-3%	696	-3%	4	7	95%	9	46%
India3	1391	1395	0%	1399	1%	-0.1	5	-4242%	11	41%
India4	1096	1117	2%	1075	-2%	2	9	433%	8	43%
Indonesia	8733	9154	5%	9539	9%	-34	-32	-6%	-33	17%
Irrawaddy	4340	4466	3%	4592	6%	10	15	41%	20	42%
Krishna	210	205	-2%	264	26%	1	2	131%	2	12%
Mahanadi	513	492	-4%	505	-2%	6	5	-20%	5	14%
Malaysia	4735	5004	6%	5251	11%	1	16	1811%	37	142%
Myanmar	11195	11559	3%	11875	6%	-31	-29	-6%	-25	20%
Penner	21	20	-6%	21	-4%	0	0	13%	0	46%
Salween	2639	2672	1%	3146	19%	-1	-1	-46%	-1	33%
Sittang	4058	4534	12%	4975	23%	-3	-3	2%	1	56%
Sri Lanka	2337	2388	2%	2110	-10%	8	5	-38%	7	18%
Thailand/ South-Mya	10455	10611	1%	10752	3%	-40	-40	1%	-41	-1%

ID in map 1	ID	DIN 2000	DIN 2030	DIN 2030 [change	DIN 2050	DIN 2050[chang	DIP 2000	DIP 2030	DIP 2030 [chan	DIP 2050	DIP 2050[chang	DON 2000	DON 2030	DON 2030 [chan	DON 2050	DON 2050[chang	DOP 2000	DOP 2030	DOP 2030 [chan	DOP 2050	DOP 2050[chang
1	Bangladesh	54315	78202	44%	89994	66%	2102	4335	106%	6928	230%	15493	19191	24%	22091	43%	897	1018	13%	1058	18%
2	Brahmani	41849	44163	6%	40582	-3%	2345	2137	-9%	4161	77%	7893	7803	-1%	9631	22%	526	511	-3%	517	-2%
3	Cauweri	17510	19880	14%	25118	43%	186	278	49%	695	274%	2831	3079	9%	4757	68%	211	208	-1%	242	15%
4	Damodar	72560	88213	22%	97752	35%	21195	11300	-47%	5175	-76%	17757	27754	56%	29406	66%	639	776	21%	851	33%
5	Ganges	2669450	3292775	23%	3575465	34%	165745	237992	44%	265976	60%	374025	407424	9%	422258	13%	25548	26679	4%	27211	7%
6	GHAASBasin434	18865	25306	34%	29775	58%	641	851	33%	1020	59%	1697	1745	3%	1822	7%	124	141	13%	157	27%
7	Godavari	128213	173915	36%	189886	48%	5983	6286	5%	5835	-2%	29736	29600	0%	29627	0%	1945	2013	3%	2076	7%
8	India1	8616	15485	80%	20565	139%	178	267	50%	1165	552%	1722	1713	-1%	2777	61%	115	134	16%	164	42%
9	India2	27060	41663	54%	52057	92%	4401	8427	91%	9071	106%	4724	8003	69%	8687	84%	211	268	27%	308	46%
10	India3	21637	36016	66%	57085	164%	803	3027	277%	3766	369%	4300	5818	35%	6251	45%	269	316	17%	379	41%
11	India4	42698	62421	46%	76143	78%	938	3172	238%	2937	213%	6267	12289	96%	13414	114%	433	536	24%	618	43%
12	Indonesia	105246	141270	34%	157879	50%	3392	8808	160%	11914	251%	53271	59106	11%	62538	17%	2720	3039	12%	3188	17%
13	Irrawaddy	453646	592516	31%	731952	61%	8771	31641	261%	55750	536%	169756	181626	7%	196363	16%	9128	10866	19%	12929	42%
14	Krishna	54988	94212	71%	107616	96%	808	3722	361%	3716	360%	16086	22775	42%	22735	41%	1195	1259	5%	1334	12%
15	Mahanadi	85405	103696	21%	125642	47%	2474	1417	-43%	2075	-16%	16637	17658	6%	20018	20%	1139	1186	4%	1294	14%
16	Malaysia	70865	124936	76%	203814	188%	9190	40399	340%	41680	354%	22097	29853	35%	34712	57%	1315	3084	135%	3176	142%
17	Myanmar	56145	70912	26%	91410	63%	1378	2848	107%	5245	281%	38481	39081	2%	40397	5%	2061	2222	8%	2467	20%
18	Penner	3957	4951	25%	7517	90%	10	11	13%	17	73%	684	668	-2%	858	25%	54	57	4%	79	46%
19	Salween	107651	162889	51%	191089	78%	2420	5146	113%	8523	252%	46113	52103	13%	58055	26%	2502	2998	20%	3335	33%
20	Sittang	38249	46892	23%	70468	84%	1746	9548	447%	16264	831%	20933	26378	26%	29765	42%	1135	1417	25%	1770	56%
21	Sri Lanka	53243	38693	-27%	41782	-22%	1411	2491	77%	2683	90%	10889	10465	-4%	10623	-2%	600	669	12%	709	18%
22	Thailand/ South-Myanmar	8305	9141	10%	9642	16%	696	694	0%	692	-1%	15892	15829	0%	15765	-1%	851	848	0%	845	-1%
	TOTAL BOB (in Tg/year)	**4.1405**	**5.2681**		**5.9932**		**0.2368**	**0.3848**		**0.4553**		**0.8773**	**0.9800**		**1.0425**		**0.0536**	**0.0602**		**0.0647**	

ID in map 1	ID	DSi 2000	DSi 2030	DSi 2030 [chan	DSi 2050	DSi 2050[chang	PN 2000	PN 2030	PN 2030 [chan	PN 2050	PN 2050[chang	PP 2000	PP 2030	PP 2030 [chan	PP 2050	PP 2050[change]
1	Bangladesh	137309	140348	2%	143234	4%	20952	21606	3%	21736	4%	10538	10932	4%	10998	7576
2	Brahmani	86722	87257	1%	88315	2%	10234	10364	1%	10713	5%	4376	4443	2%	4606	5%
3	Cauweri	18012	14054	-22%	15412	-14%	2335	1517	-35%	1592	-32%	1262	712	-44%	744	-41%
4	Damodar	81893	26182	-68%	24537	-70%	13779	4383	-68%	4081	-70%	6175	1973	-68%	1847	-70%
5	Ganges	3325001	2915915	-12%	2735448	-18%	1228122	927728	-24%	754110	-39%	753914	574093	-24%	470364	-38%
6	GHAASBasin434	36794	36948	0%	37518	2%	10302	10585	3%	11143	8%	6269	6445	3%	6773	8%
7	Godavari	507334	302637	-40%	227265	-55%	53644	31452	-41%	23433	-56%	26508	16036	-40%	11812	-55%
8	India1	26051	25820	-1%	26029	0%	2494	2838	14%	2912	17%	1066	1275	20%	1310	23%
9	India2	56352	54381	-3%	54480	-3%	9790	9159	-6%	8815	-10%	5121	4744	-7%	4492	-12%
10	India3	89465	89691	0%	90002	1%	9308	16469	77%	16238	74%	4477	8259	84%	8157	82%
11	India4	40734	41498	2%	39944	-2%	3245	3391	4%	3172	-2%	1432	1509	5%	1430	0%
12	Indonesia	1561958	1637204	5%	1706143	9%	71040	81178	14%	83519	18%	33840	40388	19%	41151	22%
13	Irrawaddy	1759593	1811068	3%	1861948	6%	350072	330333	-6%	334718	-4%	183286	164968	-10%	168366	-8%
14	Krishna	55888	54544	-2%	70252	26%	5947	5231	-12%	7108	20%	3044	2553	-16%	3231	6%
15	Mahanadi	72366	69423	-4%	71198	-2%	17474	16021	-8%	15630	-11%	8513	7711	-9%	7345	-14%
16	Malaysia	277027	292765	6%	307225	11%	20971	22008	5%	23025	10%	9682	10446	8%	11049	14%
17	Myanmar	681675	703876	3%	723128	6%	58647	59023	1%	59685	2%	27341	27246	0%	27515	1%
18	Penner	1146	1081	-6%	1105	-4%	92	88	-4%	92	0%	42	40	-4%	42	0%
19	Salween	783385	793232	1%	933828	19%	141337	92497	-35%	114587	-19%	83038	52325	-37%	65573	-21%
20	Sittang	273880	305983	12%	335789	23%	38972	37530	-4%	39899	2%	21715	18037	-17%	18952	-13%
21	Sri Lanka	150225	153488	2%	135580	-10%	29162	32775	12%	29363	1%	16694	17125	3%	15042	-10%
22	Thailand/ South-Myanmar	317110	321821	1%	326114	3%	24928	25075	1%	25214	1%	10934	11015	1%	11096	1%
	TOTAL BOB (in Tg/year)	**10.3399**	**9.8792**		**9.9545**		**2.1228**	**1.7413**		**1.5908**		**1.2193**	**0.9823**		**0.8919**	

Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand are working together through the Bay of Bengal Large Marine Ecosystem (BOBLME) Project to lay the foundations for a coordinated programme of action designed to better the lives of the coastal populations through improved regional management of the Bay of Bengal environment and its fisheries.

The Food and Agriculture Organization (FAO) is the implementing agency for the BOBLME Project.

The Project is funded principally by the Global Environment Facility (GEF), Norway, the Swedish International Development Cooperation Agency, the FAO, and the National Oceanic and Atmospheric Administration of the USA.

For more information, please visit www.boblme.org