Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the

Global Nutrient Cycle



Eutrophication assessment and nutrient criteria development:

Atlas of global assessments and scenario forecasting on nutrient cycling and environmental impacts

Prepared by: GRID-Arendal

Component C: Doc: B7-1

Partners:

December 2018

About the GEF-Global Nutrient Cycle Project

Project objective: to provide the foundations (including partnerships, information, tools and policy mechanisms) for governments and other stakeholders to initiate comprehensive, effective and sustained programmes addressing nutrient over-enrichment and oxygen depletion from land based pollution of coastal waters in Large Marine Ecosystems.

Core project outcomes and outputs:

- the development and application of quantitative modeling approaches: to estimate and map present day contributions of different watershed based nutrient sources to coastal nutrient loading and their effects; to indicate when nutrient over-enrichment problem areas are likely to occur; and to estimate the magnitude of expected effects of further nutrient loading on coastal systems under a range of scenarios
- the systematic analysis of available scientific, technological and policy options for managing nutrient over-enrichment impacts in the coastal zone from key nutrient source sectors such as agriculture, wastewater and aquaculture, and their bringing together an overall Policy Tool Box
- the application of the modeling analysis to assess the likely impact and overall cost effectiveness of the various policy options etc brought together in the Tool Box, so that resource managers have a means to determine which investments and decisions they can better make in addressing root causes of coastal over-enrichment through nutrient reduction strategies
- the application of this approach in the Manila Bay watershed with a view to helping deliver the key tangible outcome of the project – the development of stakeholder owned, cost-effective and policy relevant nutrient reduction strategies (containing relevant stress reduction and environmental quality indicators), which can be mainstreamed into broader planning
- a fully established global partnership on nutrient management to provide a necessary stimulus and framework for the effective development, replication, up-scaling and sharing of these key outcomes.

Project partners:

- Chilika Development Authority
- Energy Centre of the Netherlands
- Global Environment Technology Foundation
- Government of India - Lake Chilika Development Authority
- Government of the Netherlands
- Government of the Philippines
- Government of the United States
- Intergovernmental Oceanographic Commission of UNESCO
- International Nitrogen Initiative
- Laguna Lake Development Authority
- Partnerships in Environmental Management for the Seas of East Asia
- Scientific Committee on Problems of the Environment
- University of Maryland
- University of the Philippines
- University of Utrecht
- Washington State University
- World Resources Institute

Implementing Agency: United Nations Environment Programme
Executing Agency: UNEP- Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA)

Atlas of global assessments and scenario forecasting on nutrient cycling and environmental impacts

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the

Global Nutrient Cycle

gef UNEP GPA Global Programme of Action for the Protection of the Marine Environment from Land-based Activities GPNM Global Partnership on Nutrient Management

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the

Global Nutrient Cycle

About the GEF-Global Nutrient Cycle Project

Project objective: to provide the foundations (including partnerships, information, tools and policy mechanisms) for governments and other stakeholders to initiate comprehensive, effective and sustained programmes addressing nutrient over-enrichment and oxygen depletion from land based pollution of coastal waters in Large Marine Ecosystems.

Core project outcomes and outputs:

- the development and application of quantitative modeling approaches: to estimate and map present day contributions of different watershed based nutrient sources to coastal nutrient loading and their effects; to indicate when nutrient over-enrichment problem areas are likely to occur; and to estimate the magnitude of expected effects of further nutrient loading on coastal systems under a range of scenarios

- the systematic analysis of available scientific, technological and policy options for managing nutrient over-enrichment impacts in the coastal zone from key nutrient source sectors such as agriculture, wastewater and aquaculture, and their bringing together an overall Policy Tool Box

- the application of the modeling analysis to assess the likely impact and overall cost effectiveness of the various policy options etc brought together in the Tool Box, so that resource managers have a means to determine which investments and decisions they can better make in addressing root causes of coastal over-enrichment through nutrient reduction strategies

- the application of this approach in the Manila Bay watershed with a view to helping deliver the key tangible outcome of the project – the development of stakeholder owned, cost-effective and policy relevant nutrient reduction strategies (containing relevant stress reduction and environmental quality indicators), which can be mainstreamed into broader planning

- a fully established global partnership on nutrient management to provide a necessary stimulus and framework for the effective development, replication, up-scaling and sharing of these key outcomes.

Project partners:
- Chilika Development Authority
- Energy Centre of the Netherlands
- Global Environment Technology Foundation
- Government of India - Lake Chilika Development Authority
- Government of the Netherlands
- Government of the Philippines
- Government of the United States
- Intergovernmental Oceanographic Commission of UNESCO
- International Nitrogen Initiative
- Laguna Lake Development Authority
- Partnerships in Environmental Management for the Seas of East Asia
- Scientific Committee on Problems of the Environment
- University of Maryland
- University of the Philippines
- University of Utrecht
- Washington State University
- World Resources Institute

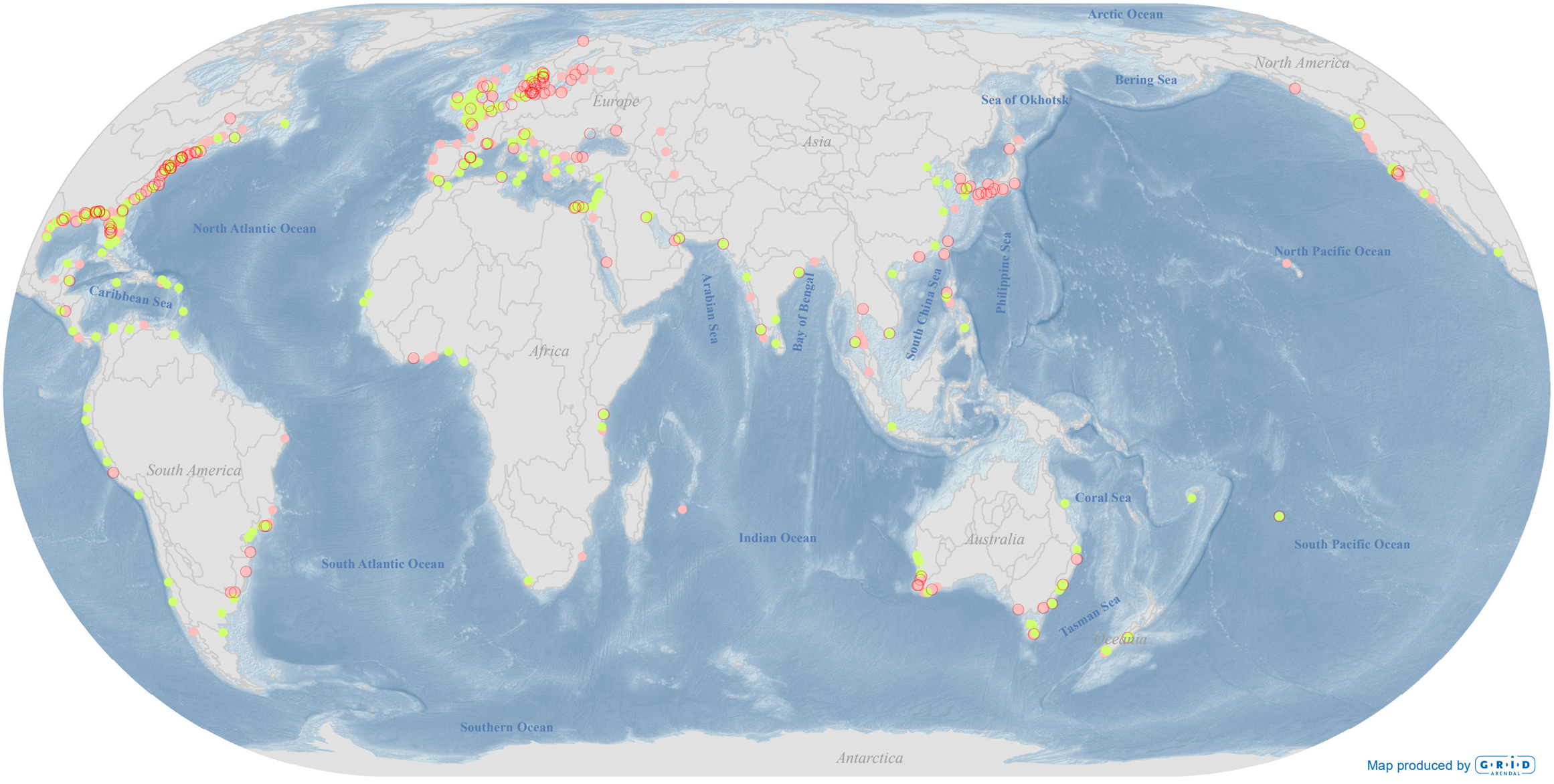
Implementing Agency: United Nations Environment Programme

Executing Agency: UNEP- Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA)

Foreword

(to come)

Global oceanic eutrophication and hypoxia hotspots and reported fish decline



Map produced by GRID-Arendal

Human activities such as agriculture, domestic and industrial wastewater as well as natural processes may cause excessive nutrient loads, known as eutrophication. Increased nutrient loads can lead to many adverse effects including harmful algal blooms, and in extreme cases hypoxia. Hypoxia, or oxygen depletion, is an environmental phenomenon where the concentration of dissolved oxygen in the water column decreases to a level that can no longer support living aquatic organisms. Mitigation of the negative effects of eutrophication requires reduction of nutrient inputs and an ecosystem-based management strategy.

The map shows the location of water bodies impacted by eutrophication and reported hypoxia and impacts (fish reduction) between 1985 and 2000. The data is sourced from the World Resource Institute (https://www.wri.org/resource/interactive-map-eutrophication-hypoxia). The pattern of eutrophic sites reflects the availability of data, with more research available in places like the US and Europe than many other parts of the world.

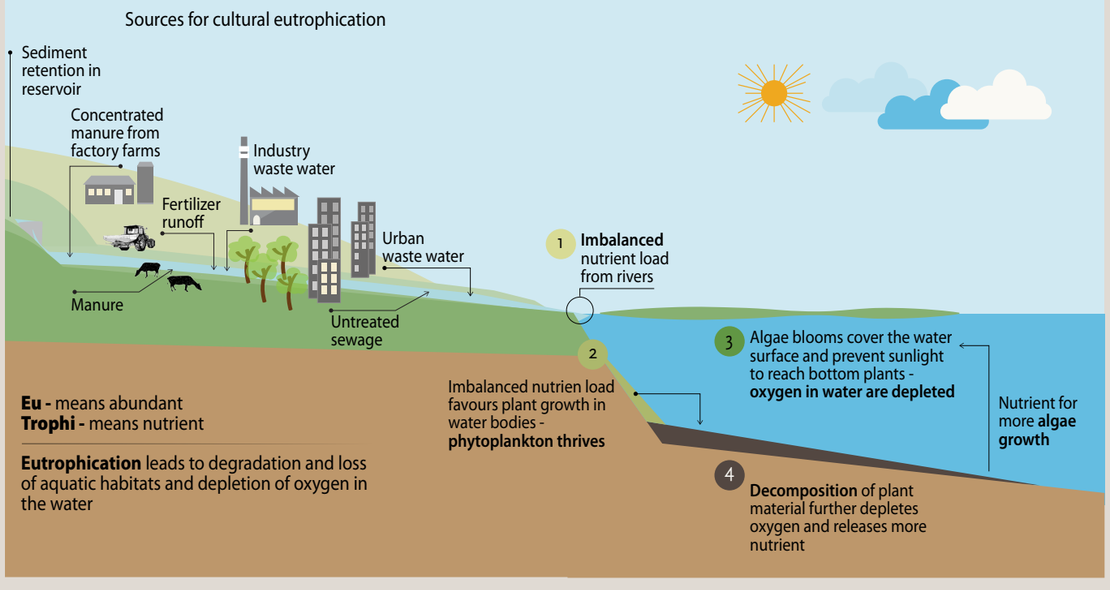
- reported fish decline (1985-2000)
- eutrophic (1985-2000)
- hypoxic (1985-2000)
- large river basins

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the **Global Nutrient Cycle**

gef UN environment

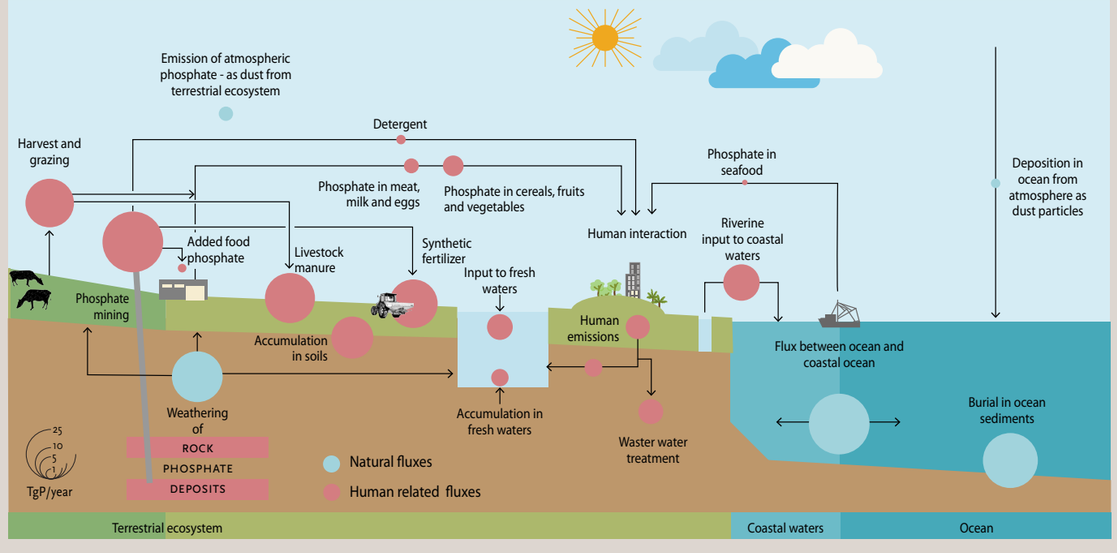
GPA GPNM

The Eutrophication Process



The Phosphorus Cascade

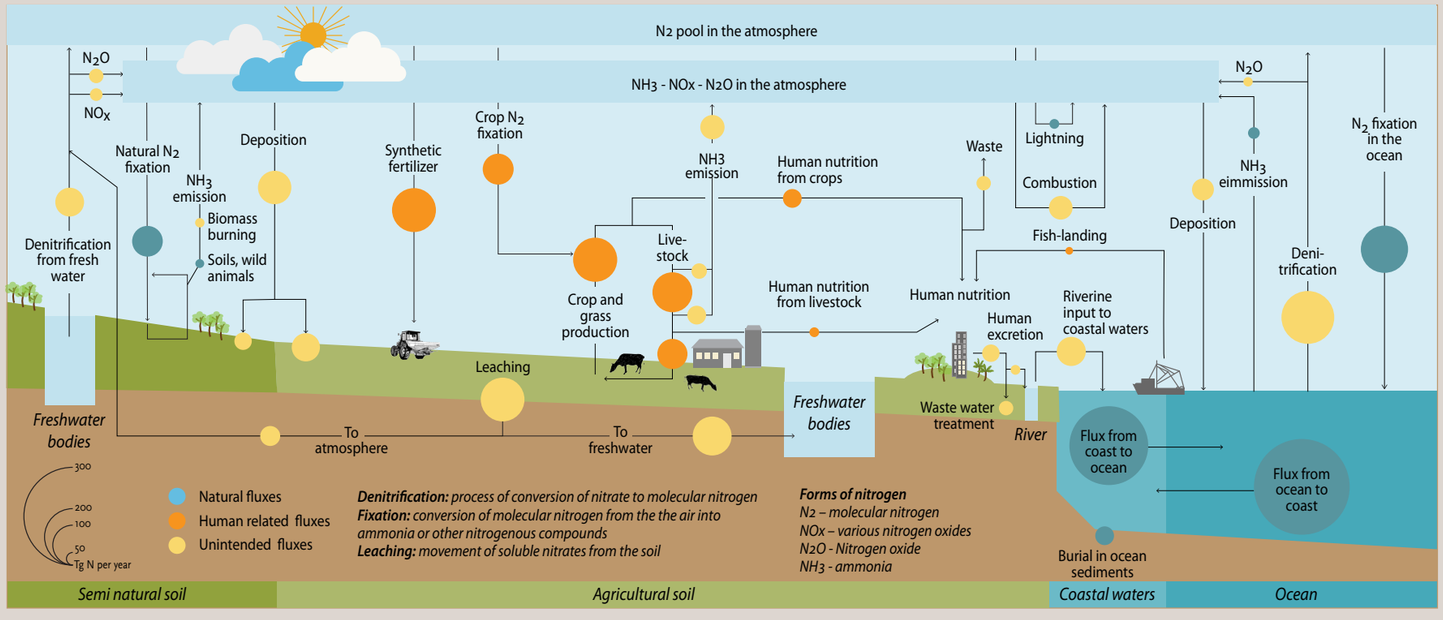
Estimated Phosphorus fluxes
Years 2000 to 2010



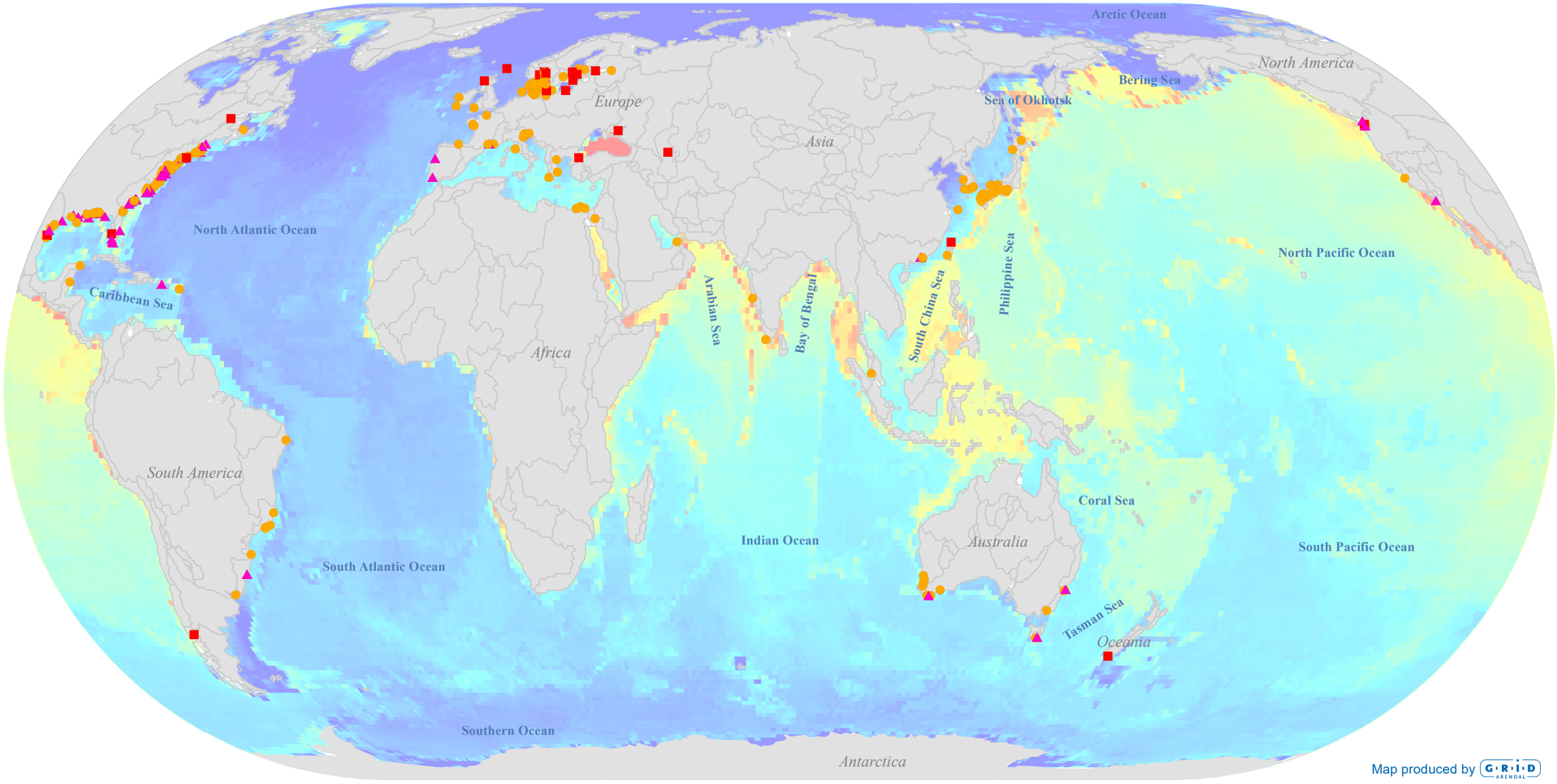


The Nutrient Cascade

Estimated Nitrogen fluxes
Years 2000 to 2010



Global bottom water oxygen concentrations and locations of observed hypoxia



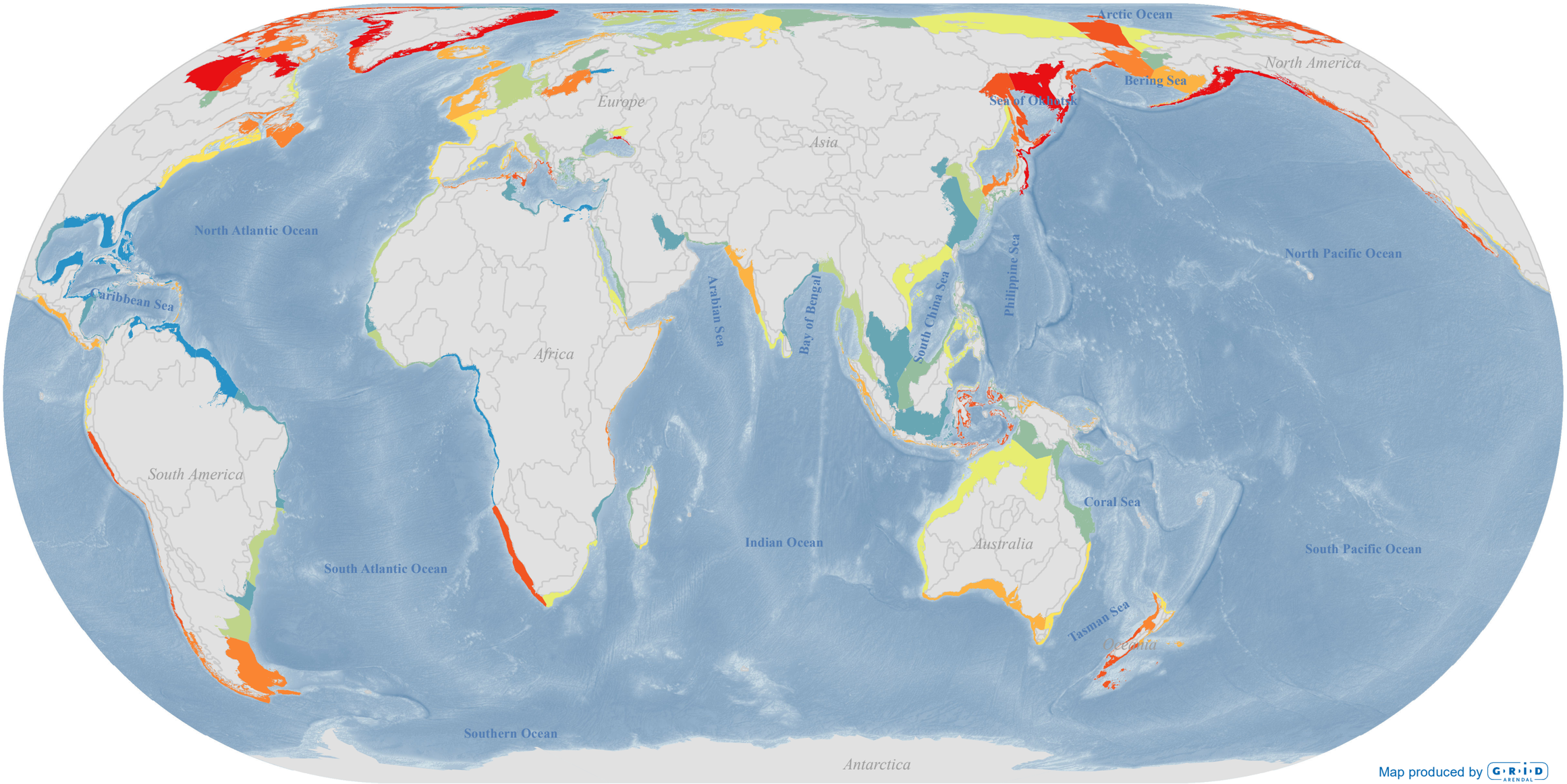
Hypoxic events in coastal regions have been increasing over the last several decades across the globe. These events have been documented along the east and gulf coasts of the United States, in the Baltic region, and off the coast of Japan. The low occurrence of these events in the tropics is likely due to lack of consistent monitoring results in these regions. Hypoxic events have been classified as either persistent (occurring all year round), periodic (occurring at different times) or seasonal (occurring at a certain time of year).

The pattern of dissolved oxygen in bottom water shows many areas with low oxygen concentrations, particularly in Southern and Eastern Asia, the Pacific coast of Central America, the red sea and the Baltic Sea. There is no clear correlation between the location of observed hypoxic events and global bottom water oxygen concentration, reflecting a difference in spatial and temporal scale between the two data sources.

The location of hypoxic events are from the World Resource Institute (http://www.wri.org/resources/data-sets/eutrophication-hypoxia-map-data-set). The global bottom water oxygen concentration data are from the NOAA World Ocean Atlas 2013 version 2 (https://www.nodc.noaa.gov/OC5/woa13/).

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the **Global Nutrient Cycle**

Nutrient loading according to COOLBEANS model



Map produced by GRID ARENDAL

In the above map Sensitivity of COSCATs to changes in nutrient loading according to COOLBEANS model. Red denotes high sensitivity, whereas blue represents low sensitivity. The primary purpose of the COOLBEANS model is to quantitatively link changes in bottom water oxygen concentrations to shifts in terrestrial nutrient loading and vertical exchange. COOLBEANS suggests that O2 conditions in these regions are likely to be sensitive to additional N inputs. In particular, the west coast of Central America and northern South America, the east coast of the South eastern Asian peninsula and the east coast of India are indicated as moderately to strongly sensitive to increasing nutrient inputs.

Large river basins

Sensitivity to nutrient inputs

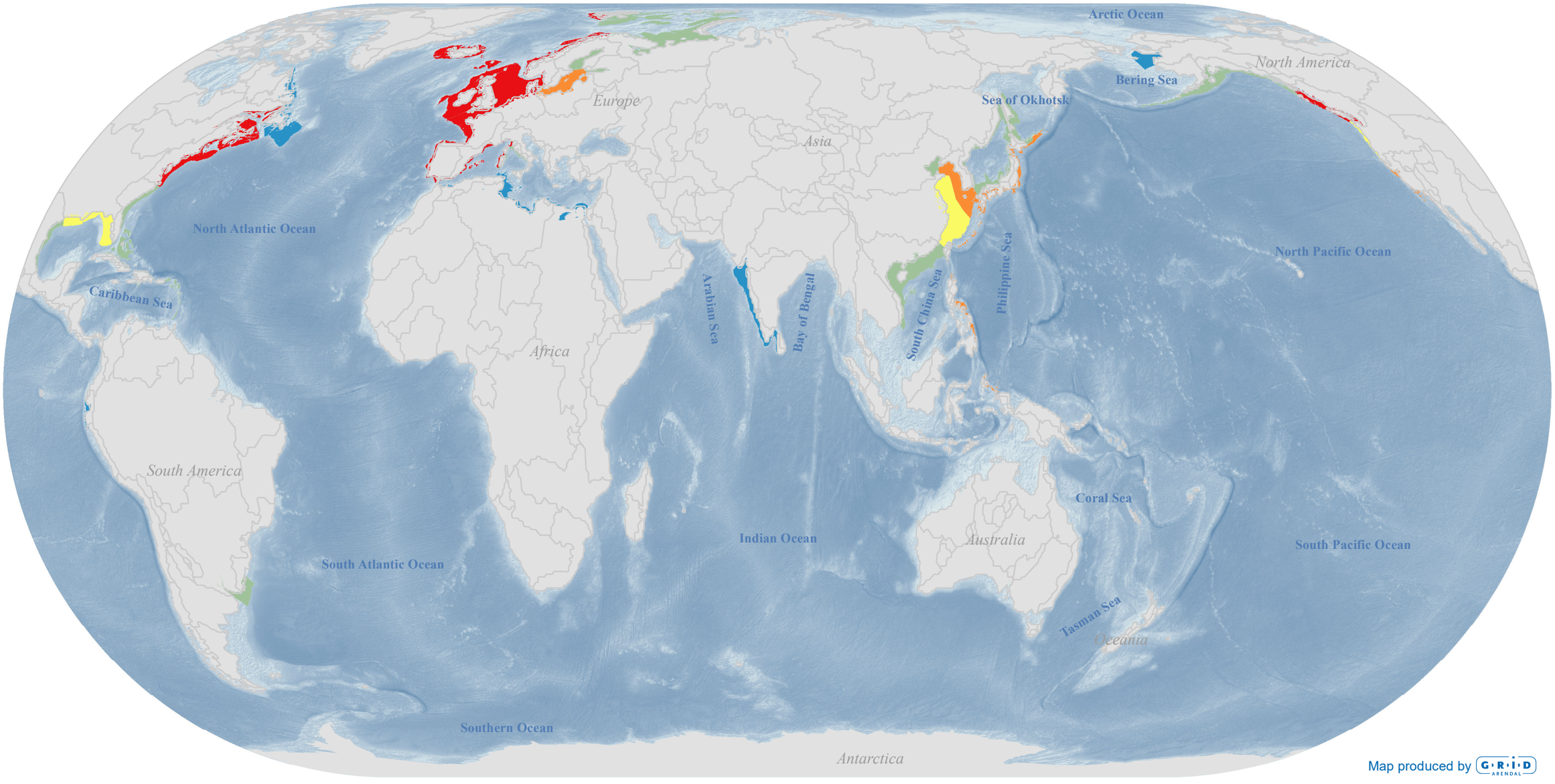
Low — High

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the **Global Nutrient Cycle**

gef UN environment

GPA GPNM

Global reported harmful algal blooms between 1980 and 2015



Map produced by GRID-Arendal

Harmful algal blooms can have direct impacts on aquatic life, for example fish kills, and on human health, for example paralytic shellfish poisoning. Harmful algal blooms are often a result of excessive nutrient loads in a water body allowing certain species of algae to increase rapidly in number. Therefore efforts to reduce nutrient loads in waterways can have direct impacts on improved human health.

The map shows the number of reported harmful algae blooms for the period 1980 to 2015. The data are based on the harmful algae event database (HAEDAT, http://haedat.iode.org) and are displayed by Coastal Segmentation and related CATchments (COSCAT).

Large river basins

Number of reported harmful algal blooms

- 1 - 10
- 10 - 50
- 50 - 100
- 100 - 200
- 200 - 691

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the **Global Nutrient Cycle**

gef UN environment

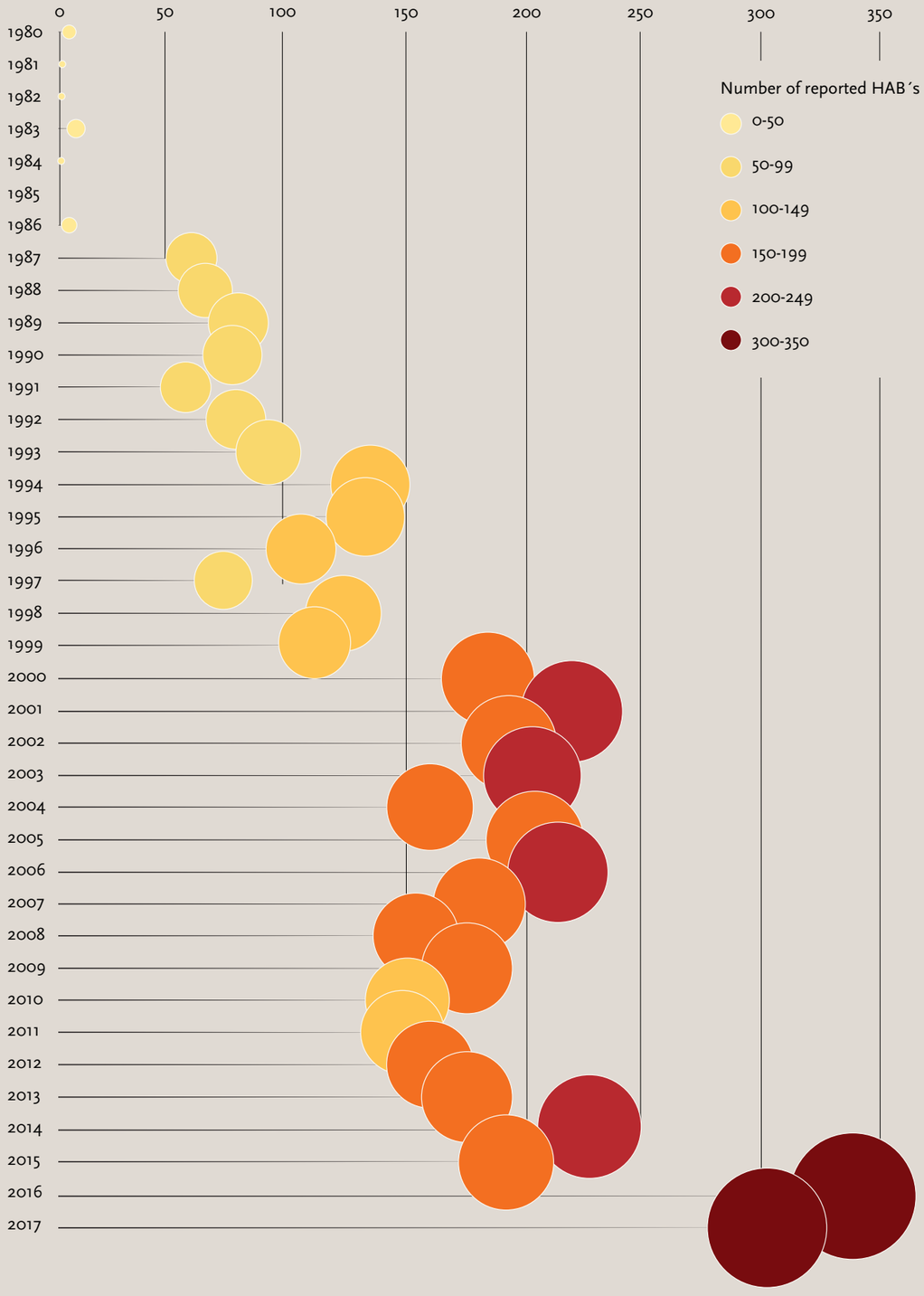
GPA GPNM





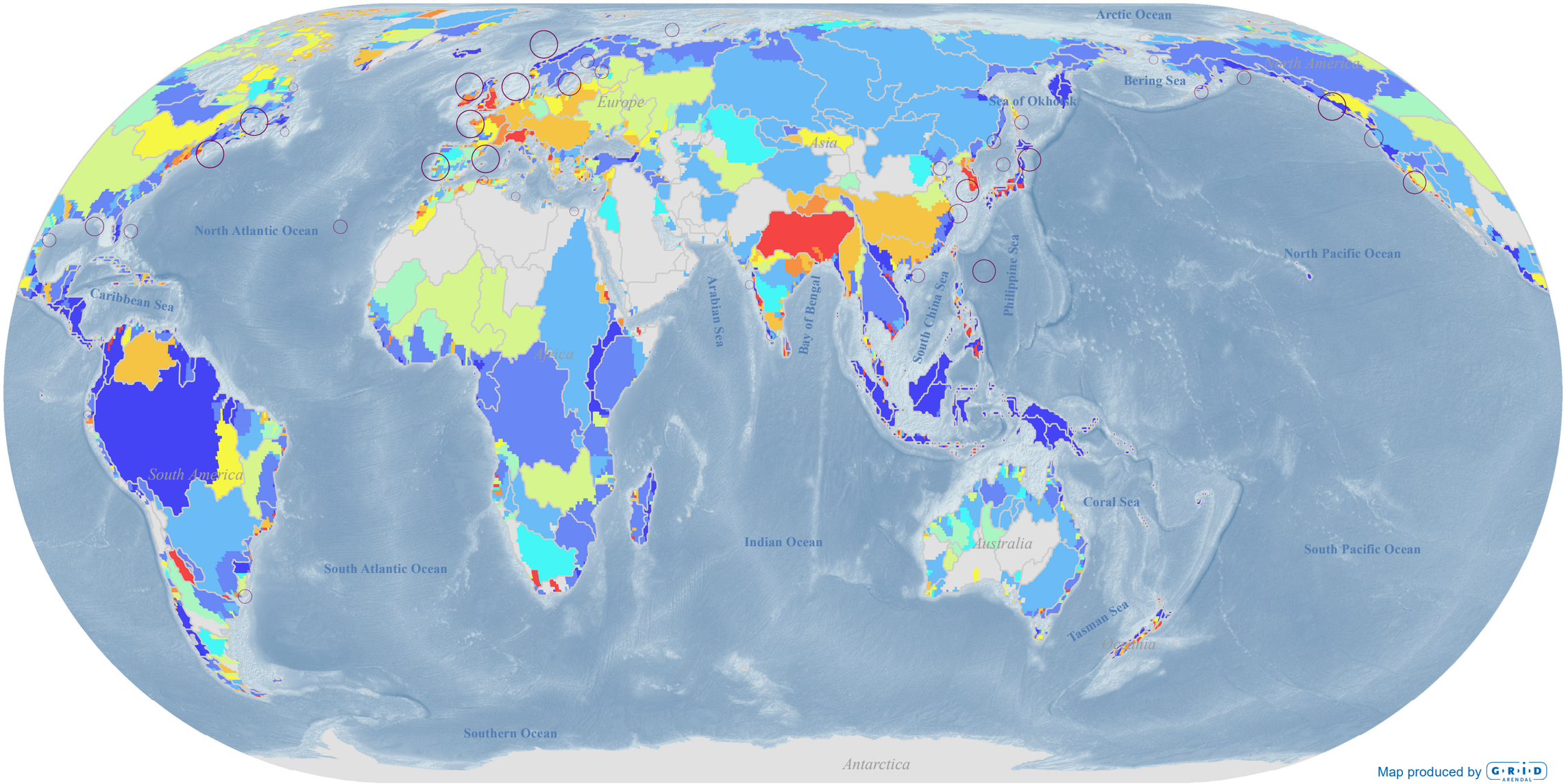
Globally reported Harmful Algal Blooms (HABs)

Number reported between 1980 and 2017



Source: HAEDAT database, 2018

Index for coastal eutrophication of river basins, and number of harmful algal blooms



Map produced by GRID-Arendal

The Index for Coastal Eutrophication Potential (ICEP) is an indicator for the potential of riverine nutrient export to sustain new production of non-diatoms phytoplankton biomass; it is calculated by comparing the N, P and Si loading to the Redfield ratios expressing the requirements of marine diatoms growth.

A negative value of the ICEP indicates that Si is present in excess over the other nutrients and would thus indicate a low likelihood of harmful algal bloom development. Positive values of ICEP indicate an excess of N or P over Si, which may lead to blooms of non-diatom, possibly harmful algae species. The ICEP represents the potential impact of the riverine delivery to the coastal zone.

ICEP of water draining into coastal seas presented on the scale of river basins, and observed algal blooms collected from HAEDAT.

Large river basins

Index for coastal eutrophication

Low — High

Number of reported harmful algal blooms

1 - 10 | 10 - 50 | 50 - 100 | 100 - 200 | 200 - 691

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the Global Nutrient Cycle

gef UN environment

GPA GPNM







An Indicator of Coastal Eutrophication Potential

ICEP is an indicator for the potential of riverine nutrient export to sustain new production of non-siliceous phytoplankton biomass; it is calculated by comparing the Nitrogen (N), Phosphorus (P) and Silicon (Si) loading to the Redfield ratios expressing the requirements of marine diatoms growth.

How to calculate the ICEP:

The ICEP number can be calculated by the following relationships (based on the Redfield molar C:N:P:Si ratios 106:16:1:20):

ICEP = [N River / (14*16) – Si River / (28*20)] * 106 * 12/365
if N/P < 16 (N limiting)

ICEP = [P River / 31 – Si River / (28*20)] * 106 * 12/365
if N/P > 16 (P limiting)

N=nitrogen (14 molar mass) P=phosphorus (31 molar mass) Si=silicon (28 molar mass)

Unit: concentration (mean annual concentration g m-3) or total loads (kg yr-1)

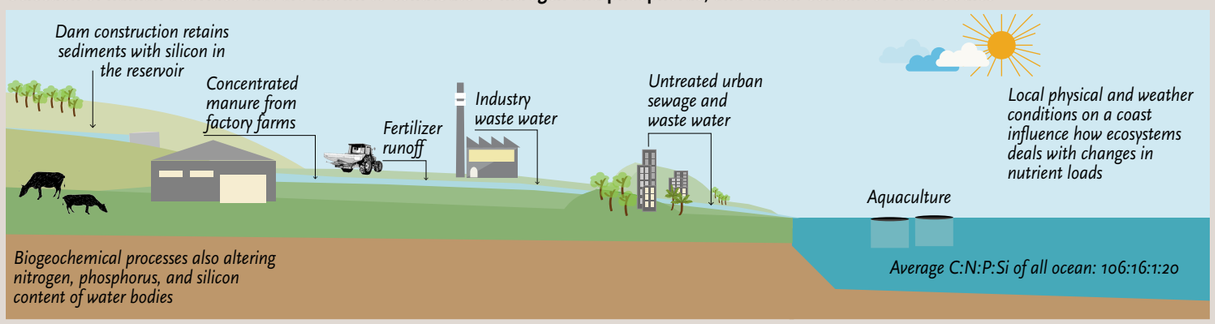
Positive ICEP

Positive values of ICEP indicate an excess of nitrogen or phosphorus over silicon, which may lead to blooms of non-diatom, possibly harmful algae species.

Negative ICEP

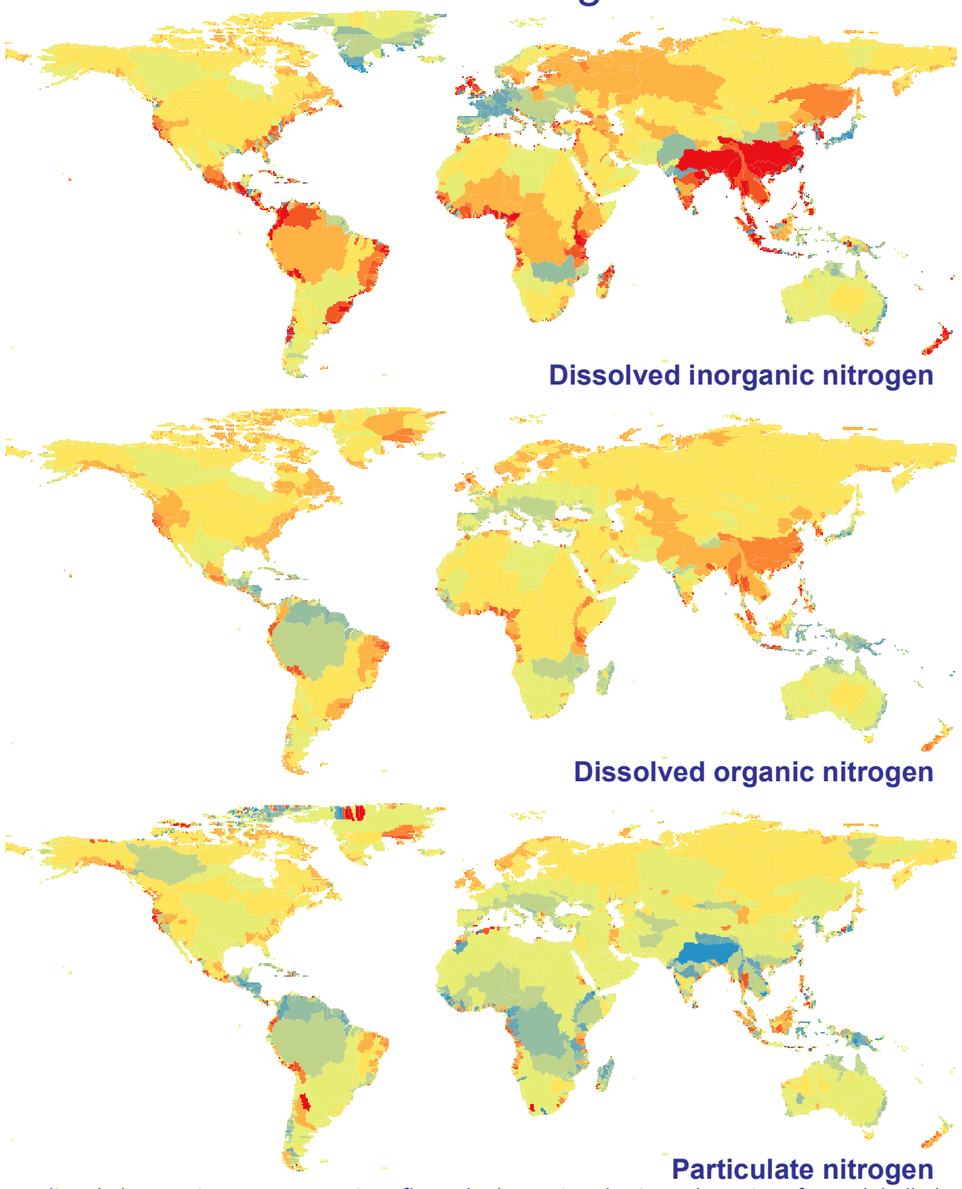
A negative value of the ICEP indicates that silicon is present in excess over the other nutrients and would thus indicate a low likelihood of Harmful Algal Blooms development.

Selection of human activities that are known to contribute to nitrogen and phosphorus, and silicon content of water bodies



Predicted changes in per-area nutrient fluxes and nutrient form (2000 - 2050)

Nitrogen

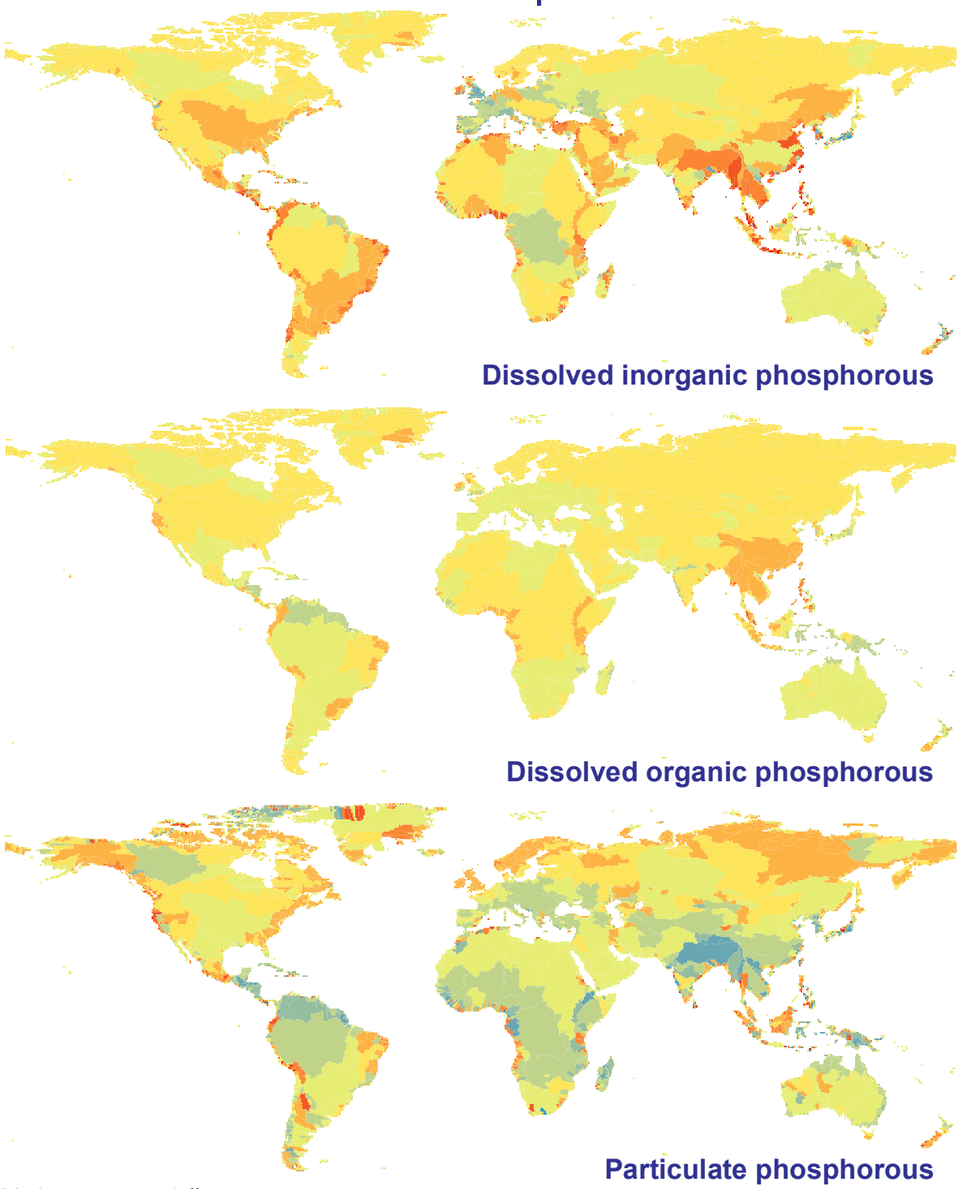


Dissolved inorganic nitrogen

Dissolved organic nitrogen

Particulate nitrogen

Phosphorous



Dissolved inorganic phosphorous

Dissolved organic phosphorous

Particulate phosphorous

Predicted changes in per-area nutrient fluxes by large river basin and nutrient form globally between years 2000 and 2050. Note especially large anticipated changes in DIN and DIP loading in South Asia and parts of Central and South America.
There are substantial differences in the relative contributions of various nutrient sources and human drivers causing the scenario trends between developing countries and industrialized countries.
Global NEWS scenarios for 2030 and 2050 indicate that substantial changes in coastal nutrient loading may occur due to changing nutrient management in agriculture

DIN: Dissolved Inorganic Nutrients
DON: Dissolved Organic Nutrients
PN: Particulate Nitrogen

DIP: Dissolved Inorganic Phosphorus
PP: Particulate Phosphorus
DOP: Dissolved Organic Phosphorus

Map produced by GRID ARENDAL

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the Global Nutrient Cycle

gef UN environment GPA GPNM



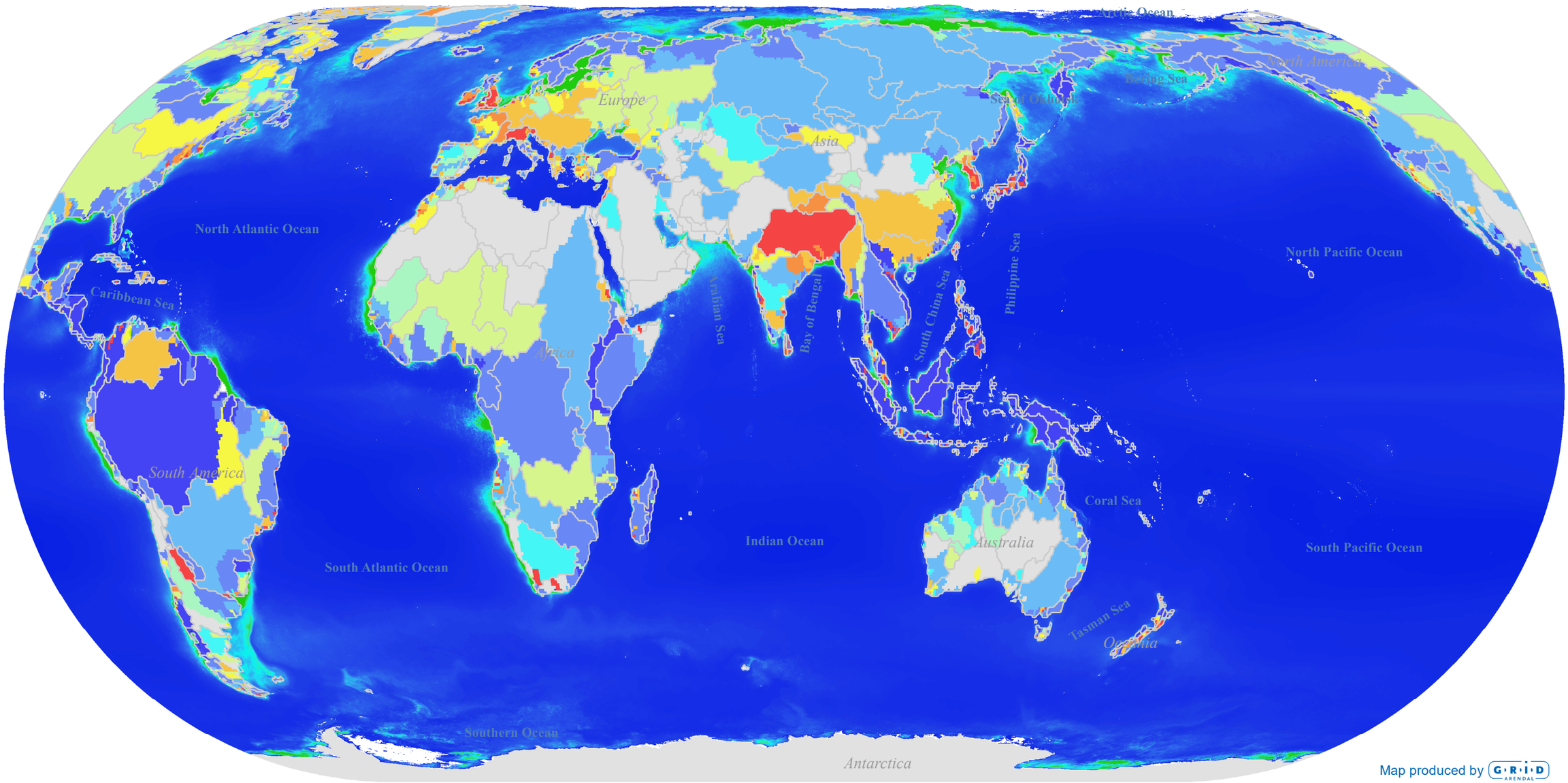
Main drivers of ecosystem change for Millennium Ecosystem Assessment (MEA) scenarios

Urban wastewater drivers

Drivers	Global Orchestration	Order from Strength	Technogarden	Adapting Mosaic
Urbanization *Downscaling to country scale is from Grübler et al. (2006)*	*B1* *Low urbanization rate*	*A2r* *Rapid urbanization*	*B1* *Low urbanization rate*	*B2* *Medium rate*
Fraction of population with access to improved sanitation *Starting point in 2000: Gap between population with and without improved sanitation*	*Increase* *Gap in 2000* *Reduces gap by 2030* *50%* *Reduces gap by 2050* *50%*	*Constant 2000 level*	*Increase* *Gap in 2000* *Reduces gap by 2030* *50%* *Reduces gap by 2050* *50%*	*Constant 2000 level*
Fraction of population connected to public sewerage *Starting point in 2000: Gap between population with and without sewage connection*	*Increase* *Gap in 2000* *Reduces gap by 2030* *50%* *Constant toward 2050*	*Constant 2000 level*	*Increase* *Gap in 2000* *Reduces gap by 2030* *50%* *Constant towards 2050*	*Constant 2000 level*
Detergent use *Phosphorus (P) free detergent connected to GDP*	*Laundry detergent use, fraction of P-free laundry detergents, automatic dishwasher detergent use and fraction P-free dishwasher detergents are entirely based on GDP*	*Laundry detergent use, fraction of P-free laundry detergents, automatic dishwasher detergent use and fraction P-free dishwasher detergents are entirely based on GDP*	*Laundry detergent use, fraction of P-free laundry detergents, automatic dishwasher detergent use and fraction P-free dishwasher detergents are entirely based on GDP*	*Laundry detergent use, fraction of P-free laundry detergents, automatic dishwasher detergent use and fraction P-free dishwasher detergents are entirely based on GDP*
Removal of N and P through wastewater treatment plants: *Four treatment classes:* *1. No treatment* *0% N 0% P* *2. Primary or mechanical treatment* *10% N 10% P* *3. Secondary or biological treatment* *35% N 45% P* *4. Advanced treatment* *80% N 90% P*	*50% of each treatment class shifts toward the next in line in the period 2000–2030 and another 50% in 2030–2050*	*25% of each treatment class shifts toward the next in line in the period 2000–2030 and another 25% in 2030–2050*	*50% of each treatment class shifts toward the next in line in the period 2000–2030 and another 50% in 2030–2050*	*25% of each treatment class shifts toward the next in line in the period 2000–2030 and another 25% in 2030–2050*

Source: modified from Alcamo et al. (2006)

MODIS satellite derived global chlorophyll-a and Index for Coastal Eutrophication



Map produced by GRID ARENDAL

The Index for Coastal Eutrophication Potential (ICEP) is an indicator for the potential of riverine nutrient export to sustain new production of non-diatoms phytoplankton biomass; it is calculated by comparing the N, P and Si loading to the Redfield ratios expressing the requirements of marine diatoms growth.

A negative value of the ICEP indicates that Si is present in excess over the other nutrients and would thus indicate a low likelihood of HAB development. Positive values of ICEP indicate an excess of N or P over Si, which may lead to blooms of non-diatom, possibly harmful algae species. The ICEP represents the potential impact of the riverine delivery to the coastal zone.

Here the ICEP value is presented with the MODIS satellite derived chlorophyll-a measurements. Areas with high chlorophyll-a measurements often correspond to high ICEP values, including the Bay of Bengal, parts of south-east Asia and the Baltic Sea.

Large river basins

Index for coastal eutrophication

Low — High

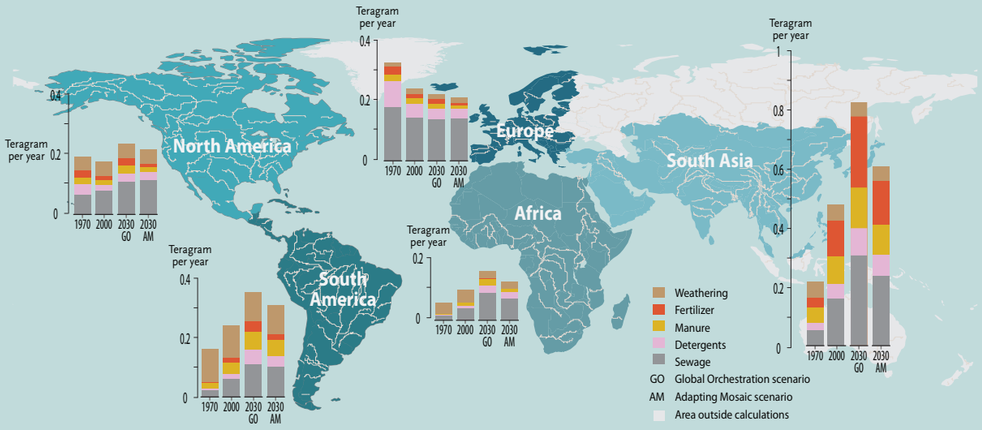
Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the **Global Nutrient Cycle**

gef UN environment

GPA GPNM

Estimated annual volume of Dissolved Inorganic Phosphorus contributed to rivers by Source

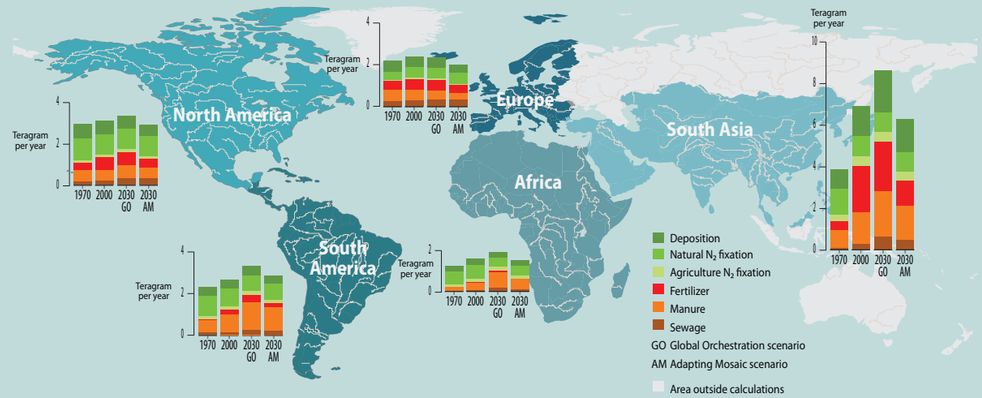
Values calculated using the Global Nutrient Export from WatershedS (NEWS) Model for years 1970 and 2000 and projected to year 2030 based on global development scenarios.



Source: Modifed from Seitzinger et al. (2010)

Estimated annual volume of Dissolved Inorganic Nitrogen contributed to rivers by Source

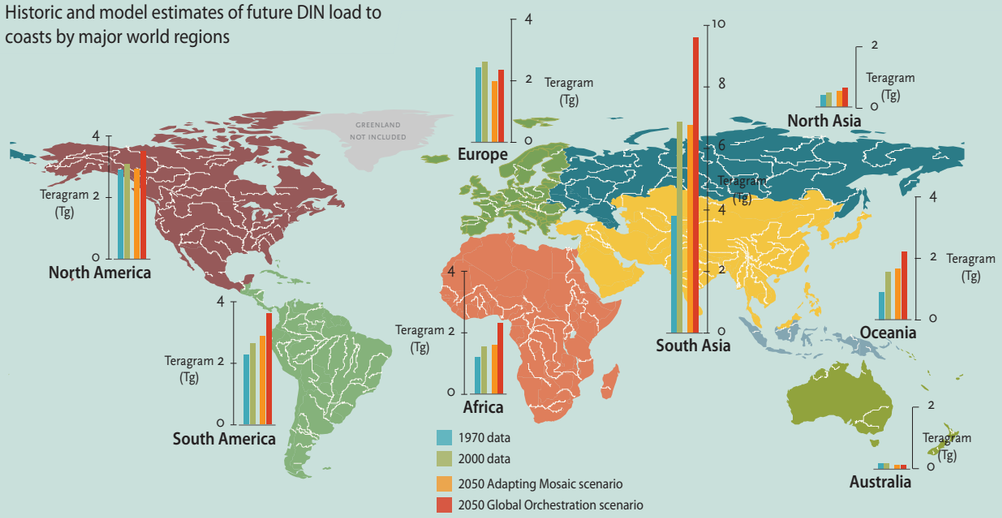
Values calculated using the Global Nutrient Export from WatershedS (NEWS) Model for years 1970 and 2000 and projected to year 2030 based on Millennium Assessment scenarios.



Source: Modifed from Seitzinger et al. (2010)

Estimated annual volume of Dissolved Inorganic Nitrogen load to coasts by major world region

Historic and model estimates of future DIN load to coasts by major world regions



Source: modified from Seitzinger et al. (2010), Van Drecht et al. (2009).

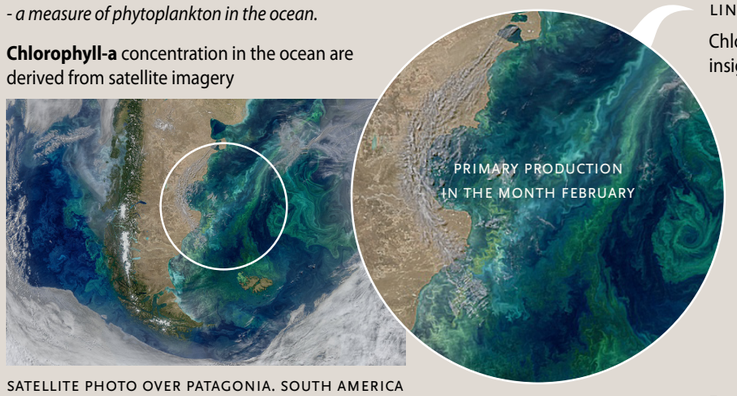
CHLOROPHYLL-A, THE INDEX FOR COASTAL EUTROPHICATION POTENTIAL & HARMFUL ALGAL BLOOMS´S

Assessment of Chlorophyll-a and it´s link to the ICEP and HABs mapping

CHLOROPHYLL-A

- a measure of phytoplankton in the ocean.

Chlorophyll-a concentration in the ocean are derived from satellite imagery



SATELLITE PHOTO OVER PATAGONIA. SOUTH AMERICA

Chlorophyll-a is typically **measured** in milligrams of chlorophyll per cubic meter of seawater in a time period.

LINK TO HARMFUL ALGAL BLOOMS & DEAD ZONES

Chlorophyll measurements give scientists valuable insights into the health of the ocean's environment.

Most phytoplankton blooms are a sign of good health, such as the large blooms occurring every spring in the North Atlantic Ocean.

Other blooms can point to problems developing in the ocean - such as **harmful algal blooms (HABs)**.

Even if the blooming plant itself is not harmful, as billions of phytoplankton die and decay over a span of days, they can rob the water of oxygen, creating "**dead zones**" where fish and other marine organisms cannot survive.

From chlorophyll-a knowledge, Net Primary Production maps can be calculated. These are used to estimate a coastal systems sensitivity to changes in nutrient load.

THE INDEX FOR COASTAL EUTROPHICATION POTENTIAL (ICEP)

- the possibility of a coastal environment becoming eutrophic based on the balance between nutrient loads in coastal waters

ICEP reflects the rivers ratio between nitrogen, phosphorus and silicon.



SATELLITE PHOTO OF THE BLACK SEA, COAST OF TURKEY.

ICEP can be **applied** using total loads (kilograms per year) or concentrations (mean annual concentration (gram per cubic metre).



ESTIMATING THE LAND SOURCES AND POTENTIAL FOR EUTROPHICATION

Nutrient sources are both natural processes, for example weathering of rocks for **silicon** and human activity like fertilizer use in agriculture and urban sewage water providing **nitrogen** and **phosphorus**.

There is an agreement between rivers with positive ICEP values and observed harmful algal blooms.

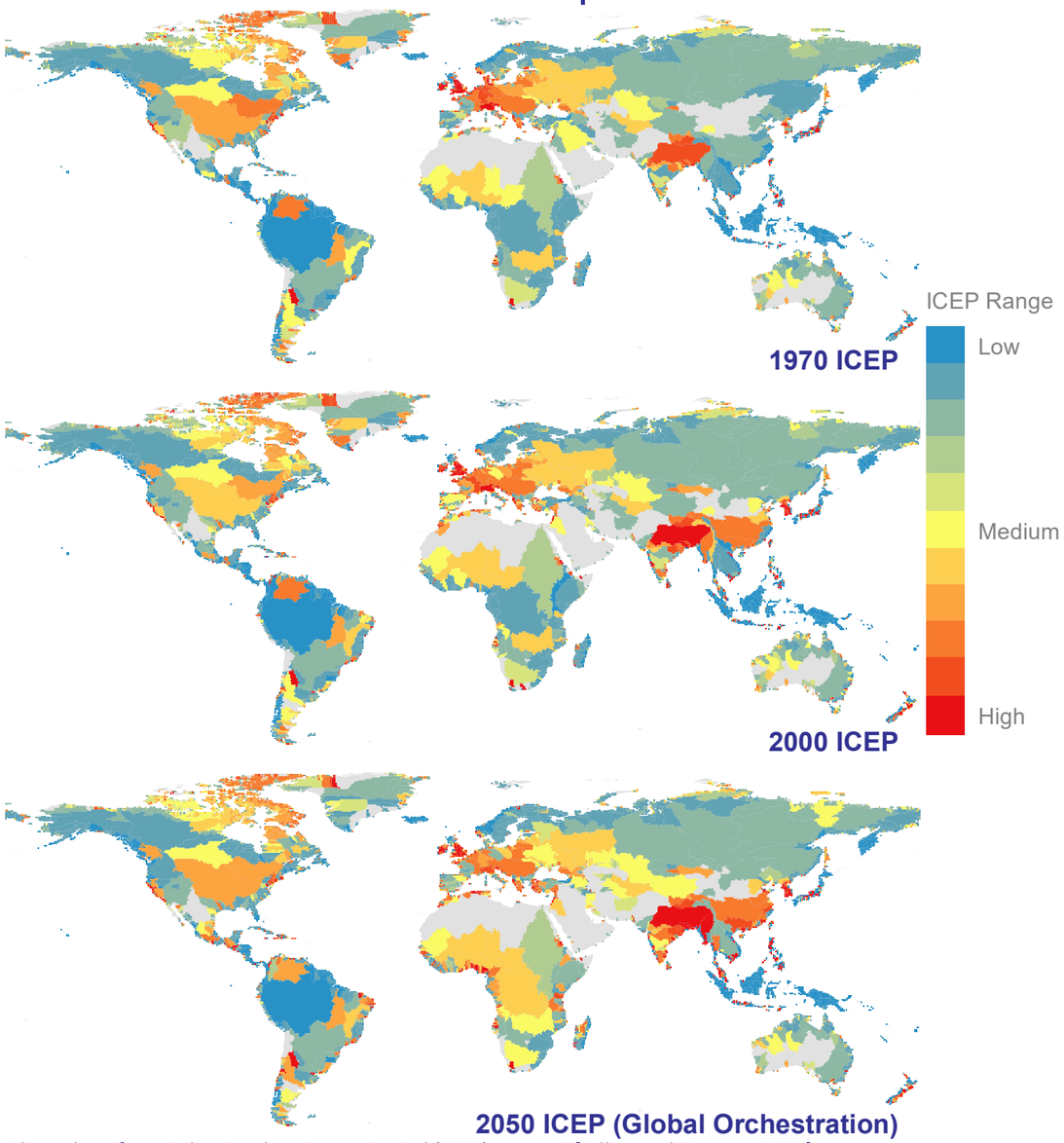
Local physical and environmental conditions will determine the tendency of a coastal marine ecosystem for developing high biomass algal blooms, harmful algal blooms or hypoxia.

RISK OF FUTURE HARMFUL ALGAL BLOOMS

With higher projected estimates of nitrogen and phosphorus (over silica) lost from watersheds, the potential for eutrophication and resultant harmful algal blooms will increase. This is reflected by higher positive ICEP values.

Historic and predicted index of coastal eutrophication (ICEP) at basin level

Historic and predicted

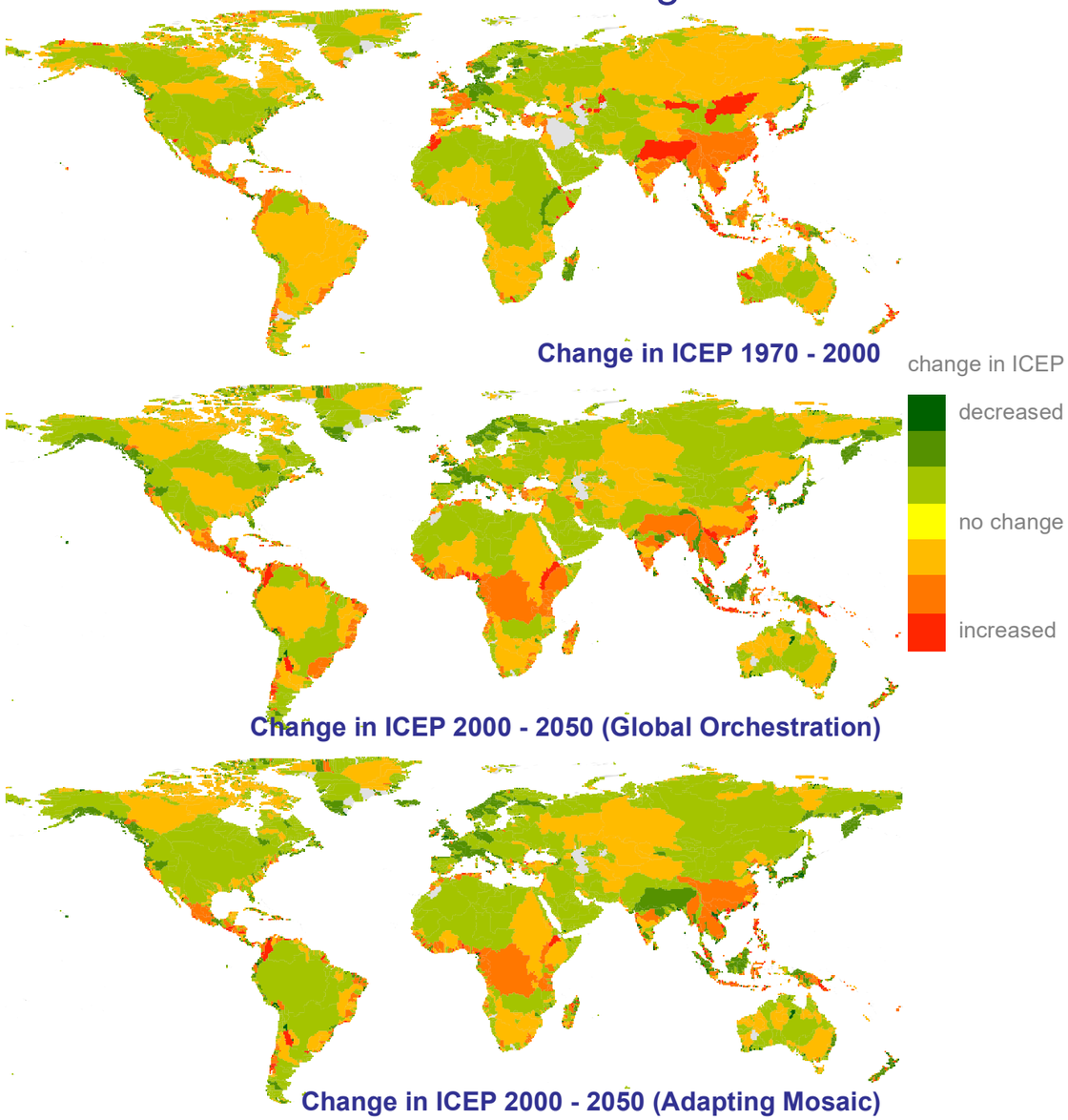


1970 ICEP

2000 ICEP

2050 ICEP (Global Orchestration)

Modelled change



Change in ICEP 1970 - 2000

Change in ICEP 2000 - 2050 (Global Orchestration)

Change in ICEP 2000 - 2050 (Adapting Mosaic)

The index of coastal eutrophication potential (ICEP) concept [Billen and Garnier, 2007],
we can now use the scenarios for river nutrient export to assess the potential risk that non-diatom algal growth may lead to harmful algal blooms in coastal marine ecosystems. ICEP is an indicator for the potential of riverine nutrients to sustain new production of non-diatom phytoplankton biomass; it is calculated by comparing the N, P and Si loading to the Redfield ratios expressing the requirements of marine diatom growth. Positive values of ICEP indicate an excess of N or P over Si, which may lead to blooms of non-diatom, possibly harmful species

The historical data suggest that harmful algal blooms risk increased considerably between 1970 and 2000. Scenario results for 2050 indicate that this risk will further spread (South America, Africa) and increase in areas with current high risk (Eastern Asia) (Figure 7.10). There are also large parts of the world where HAB risk is expected to decrease as a result of higher efficiency of nutrient use in agriculture and improved wastewater treatment. This is particularly so in the Adapting Mosaic scenario, which is a scenario with an orientation towards environmental issues and local simple

Map produced by GRID Arendal

Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the Global Nutrient Cycle

gef UN environment GPA GPNM









Ten Key Action Areas to Address the Nutrient Challenge

1 Implement a 'five-element strategy'
- a. nutrient management;
- b. selecting appropriate crop cultivars;
- c. precision irrigation whenever needed;
- d. integrated weed, pest and disease management;
- e. site-specific mitigation measures.

2 Improve:
- a. animal breeding;
- b. animal housing;
- c. animal health;
- d. dietary management to avoid over-feeding of nutrients;
- e. nutrient management planning.

3 Improving fertilizer value by:
- a. manure processing

Reducing losses from
- b. animal housing;
- c. manure storage and handling;
- d. manure treatment;
- e. land application of manure.

4 Improve techniques to
- a. reduce NOx and other Nr emissions in combustion
- b. improve fuel efficiency in combustion process
- c. reduce energy requirement for fuel use (e.g., improved insulation)
- d. greater use of renewable energy sources (wind, solar, wave, tidal, geothermal)

5 Innovation capture with utilization:
- a. technology for extracting N from waste streams.

6 Reduce and improve:
- a. reducing waste from phosphorous mining and processing;
- b. improving food supply efficiency and reducing food waste.

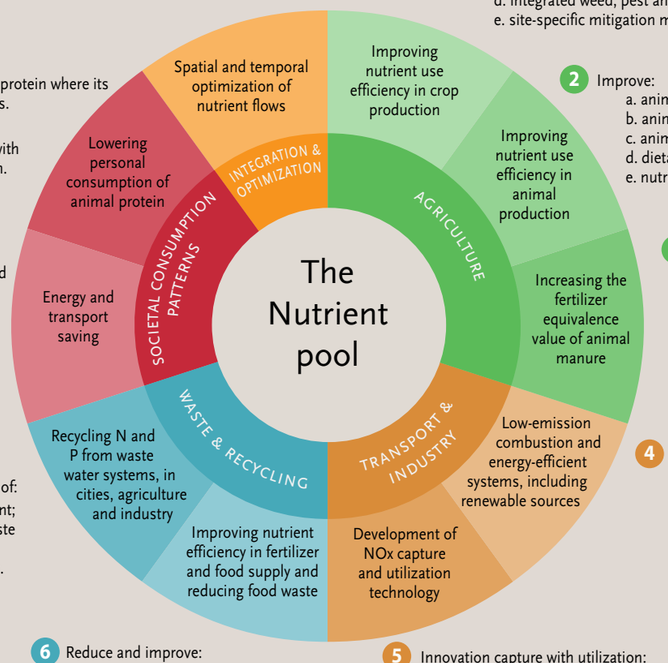
7 Implement and improve treatment of:
- a. sewage system and treatment;
- b. agriculture point source waste treatment;
- c. industrial effluent treatment.

8 Improve:
- a. transport activities by advanced telematics;
- b. transport planning;
- c. mass public transportation;
- d. development of highly fuel-efficient cars.

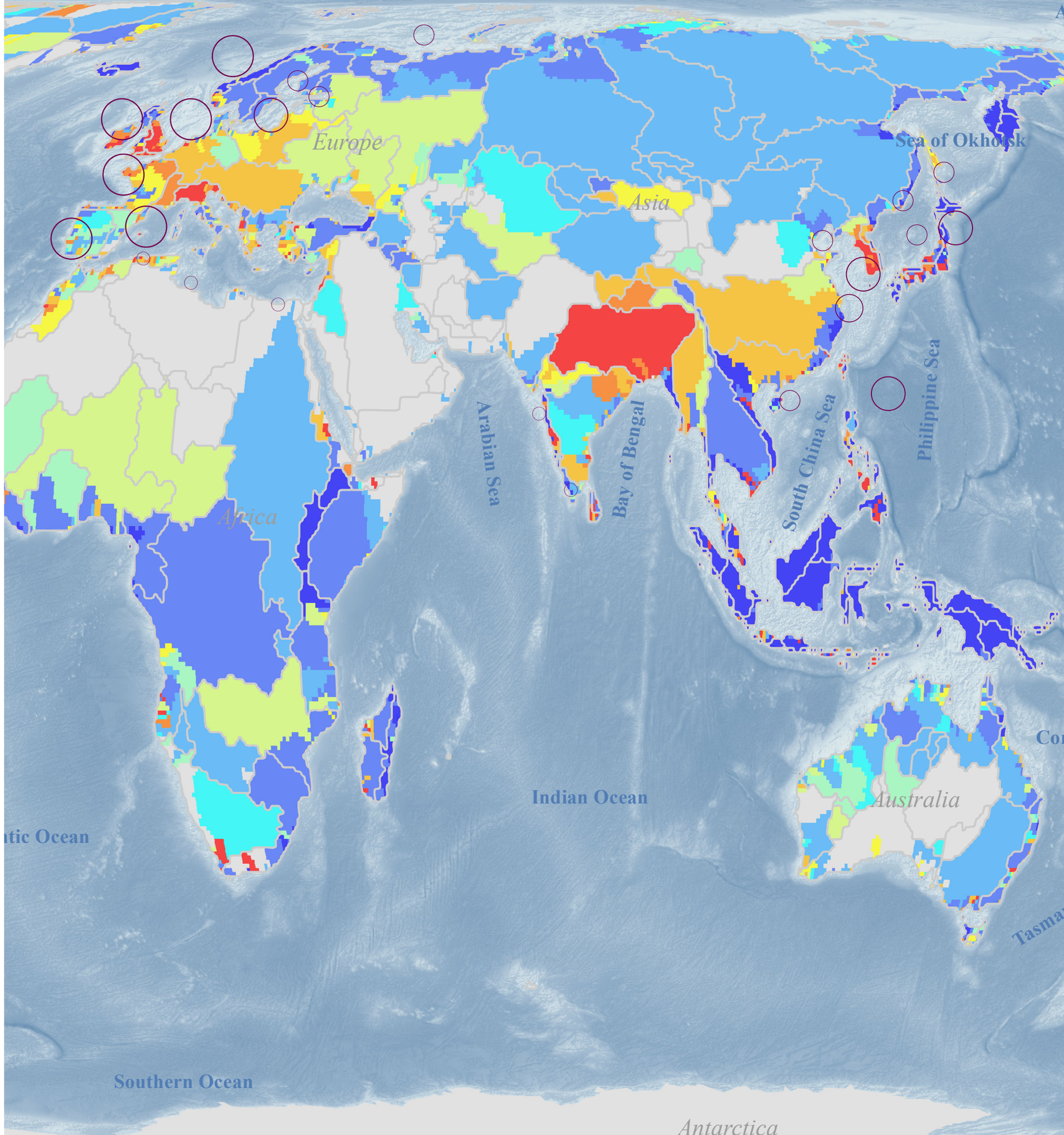
9 Reduce:
- a. intake of animal protein where its above dietary needs.

Replace:
- b. animal protein with plant-based protein.

10 Optimization of:
- a. nutrient pollution sources placing them farther away from sensitive receptors (spatial planning, buffer zones, etc.);
- b. integration of different nutrient flows to foster more effective use;
- c. nutrient production to being closer to consumers



(blurb from foreword?)



Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of the

Global Nutrient Cycle

gef UNEP GPA Global Programme of Action for the Protection of the Marine Environment from Land-based Activities GPNM Global Partnership on Nutrient Management