



for a living planet®

Breathless Coastal Seas

WWF Briefing Paper: Dead Ocean Zones
- a global Problem of the 21. century



Contents

Introduction	3
Eutrophication - the process leading to dead zones	4
Why is eutrophication a problem?	4
Harmful algal Blooms and Hypoxia	6
What are the sources of nutrients?	7
Where are the global eutrophic and hypoxic areas?	9
The situation is alarming - but a complete picture may be even worse	10
The knowledge must improve	11
What WWF asks for	11
Sources	12
Dead Zones of the World - by Region	13
Acknowledgements	19

Impressum

Publisher: WWF Deutschland, Frankfurt/ Main

Editor: Jochen Lamp (WWF) based on the reports from Mindy Selman et al. (WRI), Sybil Seitzinger et al. (State University of New Jersey), Sehstedt, Hansen et al.: BALANCE interim report 17, DHI, Copenhagen)
June 2008

Design: Anja Bruckbauer (WWF)

© 2008 WWF– Germany

Cover photo: Baltic Sea algae bloom from a satellite image, July, 11. 2005 © NASA/ SMHI

2 WWF Germany

Introduction

For a number of years, the United Nations Environmental Programme (UNEP) has observed the problem of oxygen depletion in marine and coastal areas with growing concern. Oxygen depleted zones – or dead zones, are phenomena that occur in some ocean areas as a natural process. However, during the last years the reports of dead zones that are the result of anthropogenic activities have increased:

In 1995 Diaz and Rosenberg identified 44 dead zones globally. In March 2004 in its first Global Environment Outlook Year Book, UNEP reported for the first time, that there are some 150 recurring and permanent dead zones in seas worldwide. Only 4 years later, a research group under the leadership of the World Resource Institute (WRI) did the first systematic comprehensive assessment of the phenomenon.¹ The scientists around Mindy Selman, Suzie Greenhalgh, Robert Diaz and Zachary Sugg identified 415 areas worldwide that are experiencing some form of eutrophication – 169 of them classified as hypoxic. These areas may cover only small bays and inlets of limited area size, they can also cover areas up to some ten thousands of square kilometres.

This paper will give an overview of the problem and of the most concerned areas world wide as well as highlight the most concerned global marine areas. It is mainly based on the WRI findings, but also taking account of information from other sources.

Robert Diaz, the author of the complete list, estimates that the area of documented Dead Zones accounts for 150.000 to 200.000 km² but also states, that only 30% of the cases are systematically monitored and documented.

Seven of the Top ten largest areas are according to Diaz located in the Baltic Sea, covering according to the assessments of the Helsinki Commission (HELCOM) an area of 42.000 km² of permanent anoxic zones but can easily reach up to 90.000

km² of the sea at short periods.

In the Black Sea, once known as the world's largest dead zone, signs of recovery can be observed for some areas outside the stagnant lifeless deepwater areas.

On the other hand, the Baltic Sea is an example for joint action of states: after a HELCOM² decision to eliminate Eutrophication hot spots from point sources in 1989, app. 38% of the Nitrate input from point sources was reduced since, for phosphates the result is even better: the 50% goal was reached by improved wastewater treatment in communities and industrial plants. The Baltic Sea Action Plan also much focuses on eutrophication and has set the goal of further reduction of yearly input of 135.00 tons of Nitrogen and 15.000 tons of Phosphorus by 2021 to reach a reduction of algae blooms, dead zones and to have clear water in the sea.

Eutrophication – the process leading to dead zones

Eutrophication—the overenrichment of waters by nutrients—threatens and degrades many coastal ecosystems around the world. The two most acute symptoms of eutrophication are hypoxia (or oxygen depletion) and harmful algal blooms, which among other things can destroy aquatic life in affected areas. Eutrophication sometimes occurs as a natural process, however in this paper the focus is only on effects of eutrophication caused by anthropogenic influences.

Of the 415 areas around the world identified as experiencing some form of eutrophication, 169 are hypoxic and only 13 systems are classified as “systems in recovery.”

Mapping and research into the extent of eutrophication and its threats to human health and ecosystem services are improving, but there is still insufficient information in many regions of the world to establish the actual extent of eutrophication or identify the sources of nutrients. To develop effective policies to mitigate eutrophication, more information is required on the

extent of eutrophication, the sources of nutrients, and the impact of eutrophication on ecosystems.

Within the past 50 years, eutrophication has emerged as one of the leading causes of water quality impairment. The WRI research identifies over 415 areas worldwide that are experiencing symptoms of eutrophication, highlighting the global scale of the problem

Recent coastal surveys of the United States and Europe found that a staggering 78 percent of the assessed continental U.S. coastal area and approximately 65 percent of Europe’s Atlantic coast³ exhibit symptoms of eutrophication. One of the most concerned seas is the Baltic Sea.

In other regions, the lack of reliable data hinders the assessment of coastal eutrophication. Nevertheless, trends in agricultural practices, energy use, and population growth indicate that coastal eutrophication will be an ever-growing problem.

Why is eutrophication a problem?

The rise in eutrophic and hypoxic events has been primarily attributed to the rapid increase in intensive agricultural practices, industrial activities, and population growth, which together have increased nitrogen and phosphorus flows in the environment. Human activities have resulted in the near doubling of nitrogen and tripling of phosphorus flows to the environment when compared to natural values.⁴ By comparison, human activities have increased

atmospheric concentrations of carbon dioxide, the gas primarily responsible for global warming, by approximately 32 percent since the onset of the industrial age.

Before nutrients—nitrogen in particular—are delivered to coastal ecosystems, they pass through a variety of terrestrial and freshwater ecosystems, causing other environmental problems and a loss of biodiversity.⁶ Once nutrients reach coastal systems, they can trigger a number of responses within the ecosystem. The initial impacts of nutrient increases are the excessive growth of phytoplankton, microalgae (e.g., epiphytes and microphytes), and microalgae (i.e., seaweed).

These, in turn, can lead to other impacts such as:



Photo 1: Filamentous algae overgrow the brown algae and sea grass beds that dominate the habitats in a healthy ecosystem © WWF Askö, Sweden

Loss of subaquatic vegetation as excessive phytoplankton, microalgae, and macroalgae growth reduce light penetration.

Change in species composition and biomass of the benthic (bottom-dwelling) aquatic community, eventually leading to reduced species diversity and the dominance of gelatinous organisms such as jellyfish.

Coral reef damage as increased nutrient levels favour algae growth over coral larvae. Coral growth is inhibited because the algae outcompetes coral larvae for available surfaces to grow.

A shift in phytoplankton species composition, creating favourable conditions for the development of nuisance, toxic, or otherwise harmful algal blooms.

Low dissolved oxygen and formation of hypoxic or “dead” zones (oxygen-depleted waters), which in turn can lead to ecosystem collapse.⁷

The scientific community is increasing its knowledge of how eutrophication affects coastal ecosystems, yet the long-term implications of increased nutrient fluxes in our coastal waters are currently not entirely known or understood. We do know that eutrophication di-

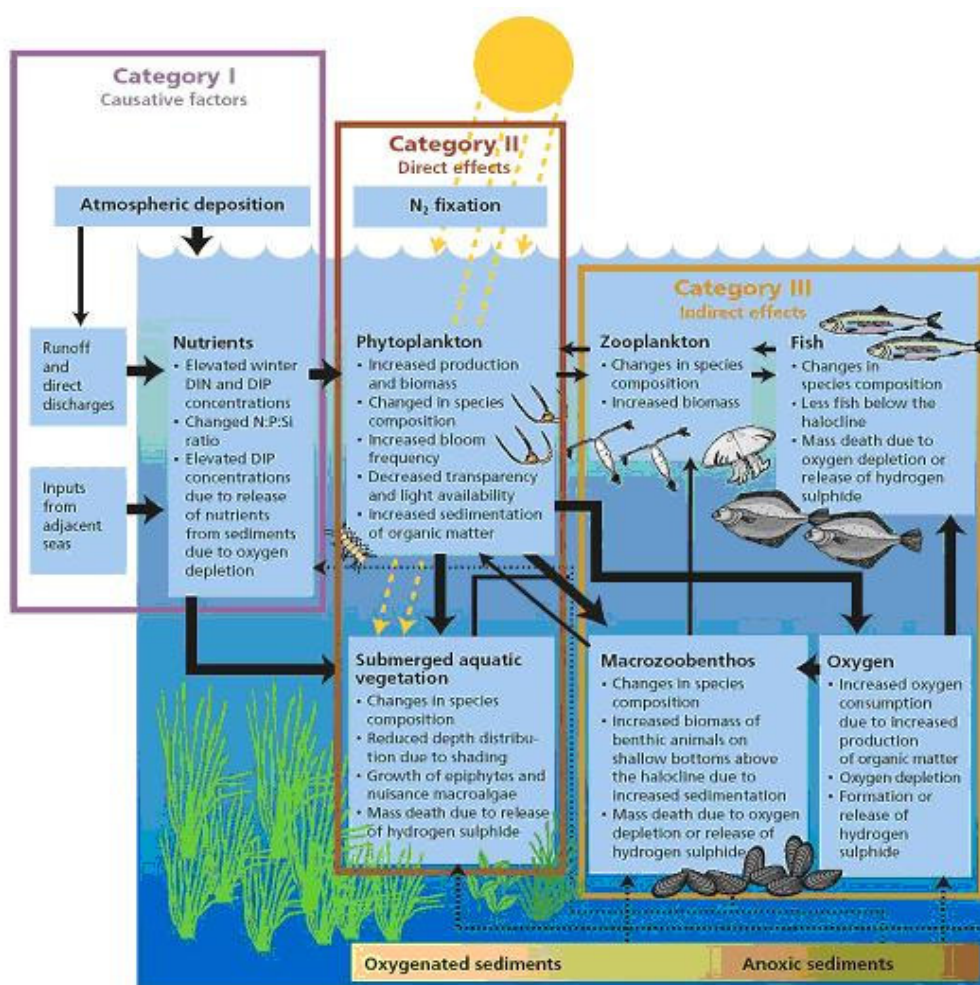


Figure 1: Conceptual model of eutrophication. The arrows indicate the interactions between different ecological compartments. Nutrient enrichment results in changes in the structure and function of marine ecosystems, as indicated with bold lines. Dashed lines indicate the release of hydrogen sulphide (H₂S) and phosphorus, which is positively related to oxygen depletion. © BALANCE Interim report No. 17

minishes the ability of coastal ecosystems to provide valuable ecosystem services such as tourism, recreation, the provision of fish and shellfish for local communities, sport fishing, and commercial fisheries. In addition, eutrophication can lead to reductions in local and regional biodiversity.

Today nearly half of the world's population lives within 60 kilometres of the coast, with

many communities relying directly on coastal ecosystems for their livelihoods.⁸

This means that a significant portion of the world's population is vulnerable to the effects of eutrophication in their local coastal ecosystems.

In the light of reduced availability of e.g. Phosphorus it would be a waste of resources to discharge this fertilizer into the coastal waters instead of using it cautiously for human food supply.

Harmful Algal Blooms and Hypoxia

Two of the most acute and commonly recognized symptoms of eutrophication are harmful algal blooms and hypoxia.

Harmful algal blooms can cause fish kills, human illness through shellfish poisoning, and death of marine mammals and shore birds.⁹

Harmful algal blooms are often referred to as "red tides" or "brown tides" because of the appearance of the water when these blooms occur. One red tide event, which occurred near Hong Kong in 1998, wiped out 90 percent of the entire stock of Hong Kong's fish farms and resulted in an estimated economic loss of \$40 million USD.^{10/11}

In the North Sea, blooms of the Algae *Phaeocystes* beaten by the winds generate large amounts of algae foam on the beaches in some years.

On the Swedish coast in 2005 large areas



Photo 2: Red Tide in the New Zealand coastal waters © Miriam Godney, NMA Science

w h e r e closed for bathing due to blooms of toxic cyanobacteria blooming during that summer in most parts of the Central Baltic Sea.

Hypoxia, considered to be the most severe symptom of eutrophication, has escalated dramatically over the past 50 years, increasing from about 10 documented cases in 1960 to at least 169 in 2007.^{12/13}

Hypoxia occurs when algae and other organisms die, sink to the bottom, and are decomposed by bacteria, using the available dissolved oxygen. Salinity and temperature differ-

ences between surface and subsurface waters lead to stratification, limiting oxygen replenishment from surface waters and creating conditions that can lead to the formation of a hypoxic or "dead" zone.¹⁴

Three of the most well-known hypoxic areas are the Gulf of Mexico and the Black Sea and the Baltic Sea. The Gulf of Mexico has a seasonal hypoxic zone that forms every year in late summer. Its size varies; in 2000, it was less than 5,000 km², while in 2002 it was approximately 22,000 km². While the economic consequences of the Gulf of Mexico dead zone are still unclear, concern over its increasing size led to the formation of the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force in 1997 to develop a strategy to reduce the five-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 km².

The Black Sea, which was once the largest dead zone in the world, had 26 commercially viable fish species in the 1960s but only five species by the 1980s.¹⁵ The growth of the Black Sea hypoxic zone was attributed to the intensification of agriculture in the former Soviet Union. It was stated in 1990 that due to natural conditions and to the anthropogenic inputs "the water is saturated with hydrogen sulphide at depth below 150 m and there is a lack of oxygen "...as a result of all these factors some 87% of the sea is either hypoxic or poisonous to life"¹⁶ It has been "in recovery" since the economic collapse of Eastern Europe in the 1990s, which resulted in significant reductions in fertilizer use. In recent years (year 2000) it is reported that nutrient contents in the marine waters have reached – at least for Phosphorus- the levels of the 60ies, and that many hypoxic zones have been eliminated according to scientific research cruises during 2003, 2004 and 2006.

The Baltic Sea system Diaz contains 7 of the largest dead zones, worldwide – summing up to an area of more than 42.000 km² of sea bottom permanently hypoxic and about 100.000km²

periodically or irregularly. Diaz estimates that the total area of anthropogenic induced dead zones globally ranges between 150.000 km² and 200.000 km².¹⁷



Photo 3: In coastal waters as this example from Danish waters in 2002 shows fish kills can be caused by oxygen depletion and forming SO₂. © BALANCE report No. 17

What are the sources of nutrients?

Agriculture, human sewage, urban runoff, industrial effluent, and fossil fuel combustion are the most common sources of nutrients delivered to coastal systems.¹⁸ Between regions, there are significant variations in the relative importance of each nutrient source. For example, in the United States and the European Union, agricultural sources (particularly animal manure and commercial fertilizers) are generally the primary contributors to eutrophication, while sewage and industrial discharges, which usually receive some treatment prior to discharge, are a secondary source. However, in Latin America, Asia, and Africa, wastewater from sewage and industry are often untreated and may often be the primary contributors to eutrophication. It is currently estimated that only 35 percent of wastewater in Asia is

treated, 14 percent in Latin America and the Caribbean, and less than 1 percent in Africa.¹⁹

Atmospheric sources of nitrogen are also recognized as a significant contributor²⁰ of nutrient in coastal areas. Nitrogen from fossil fuel combustion and volatilization from fertilizers and manure is released into the atmosphere and redeposited on land and in water by wind, snow, and rain. In the Chesapeake Bay in the mid-Atlantic region of the eastern United States, atmospheric sources of nitrogen account for a third of all controllable nitrogen that enters the Bay; similarly, in the Baltic Sea in Europe, atmospheric nitrogen accounts for a fourth of all controllable nitrogen.

Current estimates identifying the sources of nutrients that reach coastal waters were conducted by Sybil Seitzinger for the Intergovernmental Oceanographic Commission during the recent years. According to the models of Seitzinger et al. the amount of the airborne nutrients will increase substantially during the coming decades (for China and India doubling from about 200 to more than 500 kgN /km²/yr.²¹ According to the findings of Seitzinger et al.¹⁸

the global patterns of nutrient sources differ substantially in the watersheds of the different river systems. Patterns vary depending on the nutrients (nitrogen, phosphorus or carbon), its forms (organic or inorganic, diffuse or point sources) and climate and landscape types. Especially, there is a considerable spatial variation in the relative contribution of anthropogenic versus natural sources of nutrients exported to the sea areas. While globally natu-

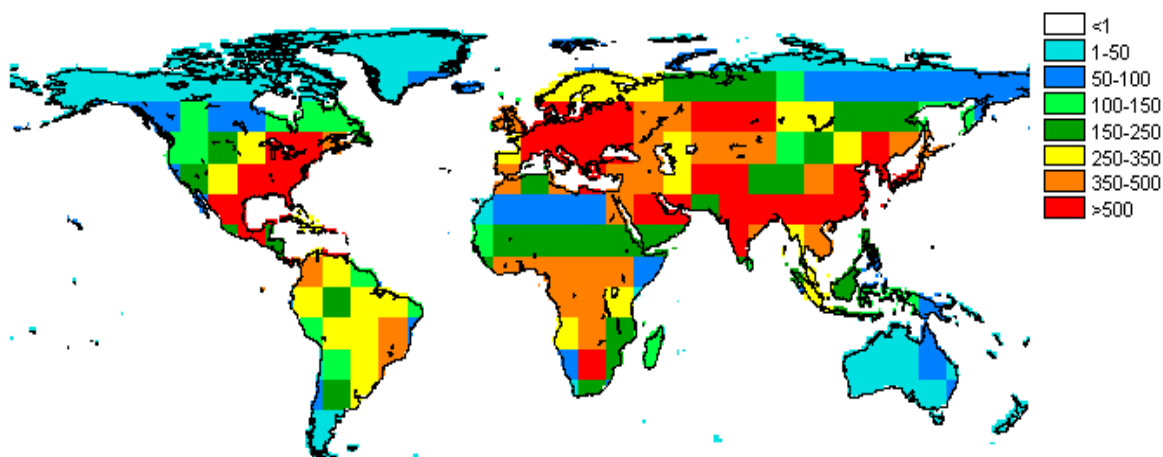


Figure 2: Atmospheric Deposition, predicted for 2050 (kg N/ km² /year) © Seitzinger, 2006

GB4S01

SEITZINGER ET AL.: GLOBAL EXPORT OF C, N, AND P TO COASTAL SYSTEMS

GB4S01

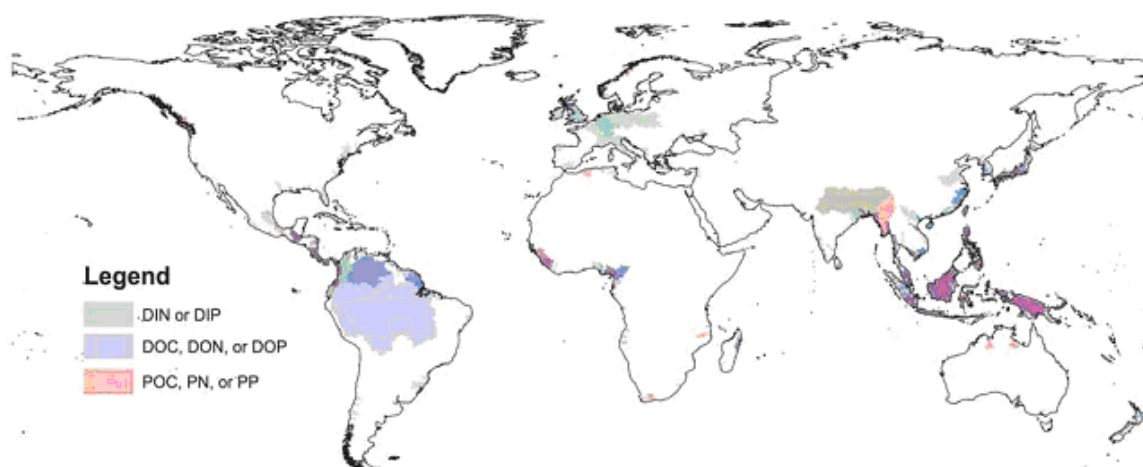


Figure 3: Hot spots for river nutrient yield (kg C,N or P km²/yr). River basins with the highest predicted inorganic P and N yields (DIP,DIN) (top 10% globally) are shaded green. River basins with the highest predicted organic C,P and P (DOC,DOP,DON) yields (top 10% globally) are shaded blue, and river basins with the highest predicted point source organic C, N and P (POC, PON, PON) yields (top 10% globally) are shaded pink. Basins with brownish or purple cast (e.g. basins in Central America and Indonesia are basins where multiple nutrient forms are predicted to fall within the top 10% globally. © Seitzinger, 2006

ral N and P in organic form from diffuse sources account for approximately 75 percent, there are some areas, (e.g. in southern Asia) where more than 50 percent of these nutrients originate from human sources, in western Europe and parts of the United States about 50 percent of organic nitrate and more than 25 percent of organic diffuse phosphorus are pre-

dicted to originate from anthropogenic sources.

Nevertheless, there are some river basin hot spots indicated in the figure 3 that show that all forms of nutrients enter very limited sea areas like from the coasts of Southern Asia, Indonesia and Japan as well as parts of Central America. Here the threats of forming dead

zones are very high. In Japanese basins the anthropogenic input is very high.

For parts of Europe and the northeast United States organic nitrate and phosphorus are also assumed to be of anthropogenic sources.

Where are the global eutrophic and hypoxic areas?

WRI research identified 415 eutrophic and hypoxic coastal systems worldwide (Figure 4).²²

Of these, 169 are documented hypoxic areas, 233 are areas of concern, and 13 are systems in recovery.

The coastal areas reported as experiencing eutrophication are steadily growing. This is because of the increasing prevalence of eutrophication and advances in identifying and reporting eutrophic conditions.

The first comprehensive list of hypoxic zones was compiled by Diaz and Rosenberg in 1995 and identified 44 documented hypoxic areas.²³ Twelve years later, there are 169 documented hypoxic areas, a nearly four-fold increase. The list of hypoxic areas assembled by Diaz was compiled from scientific literature and identified the majority of documented hypoxic areas.

However, the list did not include areas with suspected—but not documented—hypoxic events or systems that suffer from other impacts of eutrophication such as nuisance or harmful algal blooms, loss of subaquatic vegetation, and changes in the structure of the benthic aquatic community (for example, decline in biomass, changes in species composition, and loss of diversity). To supplement this list of hypoxic zones, the authors undertook an extensive literature review to catalogue systems experiencing any symptoms of eutrophication, including—but not limited to—hypoxia.²⁴

The eutrophic areas identified were categorized as:

Documented hypoxic areas: Areas with scientific evidence that hypoxia was caused, at least in part, by nutrient overenrichment. This category includes the most recent list of hypoxic areas compiled by Diaz (excluding hypoxia caused by natural upwelling of nutrients), as well as some 20 additional systems identified by the WRI research.

Areas of concern: Systems that exhibit effects of eutrophication, such as elevated nutrient levels, elevated chlorophyll a levels, harmful algal blooms, changes in the benthic community, damage to coral reefs, and fish kills. These systems are impaired by nutrients and are possibly at risk of developing

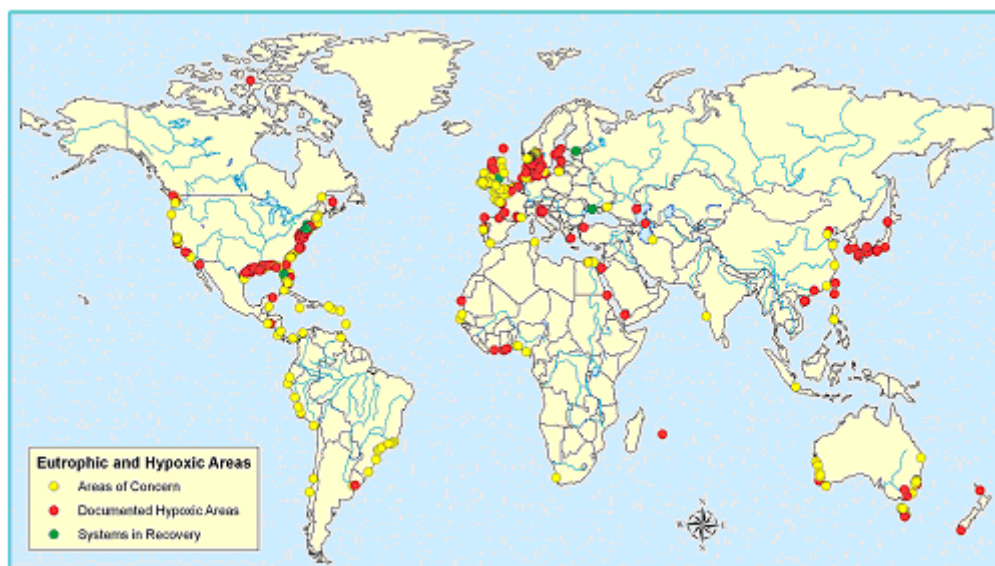


Figure 4: Coastal eutrophic and hypoxic areas of the World © WRI 2008

hypoxia. Some of the systems classified as areas of concern may already be experiencing hypoxia, but lack conclusive scientific evidence of the condition.

Systems in recovery: Areas that once exhibited low dissolved oxygen levels and hypoxia, but are now improving. For example, the Black Sea once experienced annual hypoxic events, but is now in a state of recovery. Others, like Boston Harbor in the United States and the Mersey Estuary in the United Kingdom, also have improved water quality resulting from better industrial and waste-water controls.

The situation is alarming - but a complete picture may be even worse

The actual extent and prevalence of eutrophication in many regions is only beginning to be studied. As a consequence, data do not exist or are not publicly available for many areas that may be suffering from the effects of eutrophication. In addition, the data that do exist are often inconsistent in terms of parameters measured, indicators used, and the scale at which data are reported.

Given the state of global data, the number of eutrophic and hypoxic areas around the world is expected to be greater than the 415 listed here.

The most underrepresented region is Asia. Asia has relatively few documented eutrophic and hypoxic areas despite large increases in intensive farming methods, industrial development, and population growth over the past 20 years. Africa, Latin America, and the Caribbean also have few reliable sources of coastal water quality data, making it difficult to assess the true level of eutrophication.

The scale at which data for eutrophic areas are reported varies greatly. For example, red tides and other eutrophic events are frequently recorded in the South China Sea, Yellow Sea, and Bohai Sea. However, the actual extent of eutrophication or hypoxia in specific bays and estuaries within these systems is unknown. Therefore, these areas are coarsely recorded in Figure 4 and most likely represent several affected bays and estuaries along the Chinese coast. Conversely, within the well-studied Chesapeake Bay system, there are 12 distinct and documented eutrophic and hypoxic zones.

The United States, European Union, and Australia—all of which have each undertaken comprehensive coastal surveys in the past five years—have the most comprehensive coastal data on eutrophication. However, even within the United States and Europe, the quality, consistency, and availability of water quality data varies. For example, in Europe, the coastal survey coordinated through the Commission

for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) highlighted the variability in quality and availability of monitoring data among the various European countries.²⁵

Several coastal areas lacked dissolved oxygen measures and many of the secondary effects of eutrophication, such as fish kills and changes in the benthic community, were not extensively monitored. The U.S. National Oceanic and Atmospheric Agency's (NOAA) National Estuarine Eutrophication Assessment program, which conducted national eutrophication surveys in 1999 and 2007, experienced data issues similar to those encountered in the OSPAR survey. Of the 141 U.S. estuaries evaluated in 2007, 30 percent lacked adequate data for assessing their eutrophication status.

Most systems identified as hypoxic or eutrophic also lack detailed data on the sources of nutrient impairments and the relative contribution of each source. Some systems that have developed detailed nutrient budgets include the Chesapeake Bay, Baltic Sea, Black Sea, Gulf of Mexico (Mississippi-Atchafalaya plume), and Tampa Bay. The absence of detailed nutrient budgets for the majority of eutrophic and hypoxic systems around the world highlights the lack of concerted research efforts in these areas, compromising the ability to effectively address and manage nutrient overenrichment.



Photo 4: Blooming blue-green algae in the Baltic Sea © Anders Møddig

The knowledge must improve

Improving our knowledge of where eutrophication is occurring, the sources contributing to the problem, and the effects of eutrophication on marine ecosystems and human communities ultimately influences the ability of policy-makers to decide where and how resources can be used most effectively to address eutrophication.

Without better data and information, communities cannot effectively manage coastal ecosystems and address land-based sources of pollution. Specifically, time series monitoring data—on nutrient levels, chlorophyll a (as an indicator of the presence of phytoplankton), and dissolved oxygen—as well as eutrophication response parameters—such as loss of sub-aquatic vegetation, fish kills, and algal blooms—are needed to evaluate the extent and degree of eutrophication.

Moreover, comparable and joint standards to classify and define eutrophic waters are needed to increase the transparency, consistency, and comparability of water quality information. For example, currently no common definition of “hypoxia” exists and the interpretation of what is hypoxic can vary widely from place to place.

In countries or regions where robust and systematic monitoring programs are unlikely to be implemented due to limited resources, it would be beneficial to develop credible and consistent simple proxies for water quality (such as turbidity or sulphide smell) that could be used

to identify likely eutrophic areas.

Finally, it is not enough to fill the scientific knowledge gaps. Researchers and policy-makers need tools and information to base decisions on. Such tools include:

- Watershed models to assess nutrient delivery and ecosystem impacts;
 - Nutrient balance assessments to determine the sources of nutrients and relative contribution of each source;
 - Regional and international online information portals for compiling and sharing water quality information and research;
 - Nutrient loss estimation tools; and
 - Tools to help assess the effectiveness of alternative scenarios for reducing nutrient inputs.
- Implementation of these tools is especially needed to estimate coastal impacts and target appropriate policy responses in countries and regions where actual monitoring data are scarce.

Eutrophication is an issue that requires greater attention by governments and society in general. Left untouched, it may have dire consequences for many ecosystems, the food webs that they support, and the livelihoods of the populations that depend on them. To get a better grasp on the immediate and long-term consequences of eutrophication, we need more resources and better information. Improving our knowledge and information on eutrophication is the first step in developing robust policy measures to begin reversing or halting its impacts.

What WWF wants:

Good knowledge for better decisions:

- The state of eutrophication in coastal waters must be regularly monitored and methods and definition internationally agreed.

In Asia, Africa, and Latin America:

- An initial assessment of eutrophication in coastal areas is necessary. Simple indicators for the assessment of Eutrophication and impacts on ecosystem health need to be developed and monitoring on a regular base has to be established and exchanged globally and regionally.

In the United States, Europe, and Australia:

- coastal zone assessments have to continue and methods be internationally agreed and applied for all seas.

Information about the consequences of eutrophication must be disseminated and enlarged.

Worldwide: Actions to reduce eutrophication are urgently needed regardless of complete knowledge:

- Consequent sewage treatment with reduction of nutrients in all urban areas and river catchments,
- Reconstruction of natural wetlands as nutrient traps,
- Fundamental changes in the agricultural practice to strictly avoid nutrient runoff from fertilizers,
- Ban of Washing detergents that use phosphorus
- Reduction of airborne nutrients (low emission standards for cars, ships and households, speed limits)

In the EU context:

- Change of the Common Agricultural Policy to low nutrient production
- Introduction of a Phosphate Directive for affected sea catchments

Sources

1. Selman, Mindy, Suzie Greenhalgh, Robert Diaz and Zachry Sugg: Eutrophication and Hypoxia in Coastal Areas – A global assessment of the state of knowledge, World Resource Institute WRI, , Washington DC, USA March 2008
2. HELCOM Secretariat: Towards a Baltic Sea unaffected by Eutrophication, HELCOM overview 2007, HELCOM Ministerial Meeting, Krakow, Poland 15.November 2007, pp.16-18
3. Bricker, S. B., Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner. 2007. Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. Silver Spring, MD: National Centers for Coastal Ocean Science. Online at: <http://ccma.nos.noaa.gov/publications/eutroupdate/>
4. Howarth, R. and K. Ramakrishna. 2005. "Nutrient Management." In K. Chopra, R. Leemans, P. Kumar, and H. Simons, eds. Ecosystems and Human Wellbeing: Policy Responses. Volume 3 of the Millennium Ecosystem Assessment (MA). Washington, DC: Island Press.
5. National Oceanic and Atmospheric Administration (NOAA). "Global Warming: Frequently asked questions." Available at: <http://lwf.ncdc.noaa.gov/oa/climate/globalwarming.html>. (accessed January 15, 2008)
6. Galloway, J.N, J.D. Aber,, J.W. Erisman, S.P. Seitzinger, R.W. Howarth, E.B. Cowling, and B.J. Cosby. 2003. "The Nitrogen Cascade." *Bioscience* 53(4): 341–356
7. For a discussion on the impacts of eutrophication on coastal ecosystems, see Mee, L. 2006. "Reviving Dead Zones." *Scientific American* 295 (5): 79–85.
8. UN Chronicle Online Edition. "Risks, Untreated Sewage Threatens Seas, Coastal Population." <http://www.un.org/Pubs/chronicle/2003/issue1/0103p39.html>. (accessed January 15, 2008)
9. Anderson, D. M., P. M. Gilbert, and J. M. Burkholder. 2002. "Harmful Algal Blooms and Eutrophication: Nutrient Sources, Composition, and Consequences." *Estuaries* 25 (4b): 704–726.
10. Terra Daily Online Edition. "Hong Kong red tide spreads," (June 10, 2007). http://www.terradaily.com/reports/Hong_Kong_Red_Tide_Spreads_999.html (accessed February 8, 2008).
11. Lu, S., and I. J. Hodgkiss. 2004. "Harmful algal bloom causative collected from Hong Kong waters." *Hydrobiologia* 512(1-3): 231-238
12. Hypoxia is generally defined as having a dissolved oxygen concentration of 2.0 milligrams per liter or less.
13. Diaz, R. J., J. Nestlerode, and M. L. Diaz. 2004. "A global perspective on the effects of eutrophication and hypoxia on aquatic biota." In G. L. Rupp and M. D. White, eds. *Proceedings of the 7th International Symposium on Fish Physiology, Toxicology, and Water Quality*, Tallinn, Estonia, May 12-15, 2003. Athens, Georgia: U.S. Environmental Protection Agency, Ecosystems Research Division (EPA 600/R-04/049).
14. Rabalais, N. N., and R. E. Turner. 2001. Coastal hypoxia consequences for living resources and ecosystems. Washington, DC: American Geophysical Union.
15. Europe Now/Next. "Is the Black Sea recovering?" <http://www.europe.culturebase.net/contribution.php?media=307> (accessed December 30, 2007)
16. Viktor Karamushka : Is the Black Sea recovering? In Europe now,
17. Personal note to the editor. May 2008
18. Seitzinger, S.P., J.A. Harrison, E. Dumont, A.H.W. Beusen, and A.F. Bouwman (2005) Sources and delivery of carbon,, nitrogen, and phosphorus to the coastal zone: An overview of Global Nutrient Export from Watershed (News) models and their application , *Global Biogeochemn. Cycles*, 19, , Rutgers/NOAA, State University of New Jersey, New Brunswick, NJ,USA p.7-11
19. Howarth, R. and K. Ramakrishna. 2005. "Nutrient Management." In K. Chopra, R. Leemans, P. Kumar, and H. Simons, eds. *Ecosystems and Human Wellbeing: Policy Responses*. Volume 3 of the Millennium Ecosystem Assessment (MA). Washington, DC: Island Press
20. Spokes, L. J., and T. D. Jickells. 2005. "Is the atmosphere really an important source of reactive nitrogen to coastal waters?" *Continental Shelf Research* 25: 2022–2035.
21. Sybil P. Seitzinger; Presentation for the Intergovernmental Oceanographic Commission IOC/UNEP GPA/UNEP MEDPOL Working Group: Global Patterns of human Activities on Land and Nutrient enrichment of Coastal Marine Ecosystems – Current conditions and future projections , slide 21.
22. Region-specific maps as well as the data used to create these maps is made available on WRI's website, www.wri.org/project/water-quality
23. Diaz, R. and R. Rosenberg. 1995. "Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macro fauna." *Oceanography and Marine Biology: an Annual Review* 33: 245–303.
24. The primary data sources include: Diaz, R. J., J. Nestlerode, and M. L. Diaz. 2004. "A global perspective on the effects of eutrophication and hypoxia on aquatic biota." In G. L. Rupp and M. D. White, eds. *Proceedings of the 7th International Symposium on Fish Physiology, Toxicology, and Water Quality*, Tallinn, Estonia, May 12-15, 2003. Athens, Georgia: U.S. Environmental Protection Agency, Ecosystems Research Division (EPA 600/R-04/049).
25. OSPAR called for the uniform assessment of coastal waters by signatory countries. Signatory countries to the 1992 Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) include Belgium, Denmark, France, Germany, Ireland, The Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom.
26. Sehested Hansen, Ian, Nina Keul ,Jacob Tornfeldt Sørensen , Anders Erichsen and Jesper H. Andersen :Baltic Sea Oxygen Maps 2000 2006 BALANCE Interim Report No. 17, November 2007, DHI Water – Environment – Health, Copenhagen
27. Xianshi, Jin, Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Qingdao, China, in: *Estuarine, coastal and shelf science*, vol.59, no° 1, pp.163-171, 2004

Dead Zones of the World – by Region

EUROPE

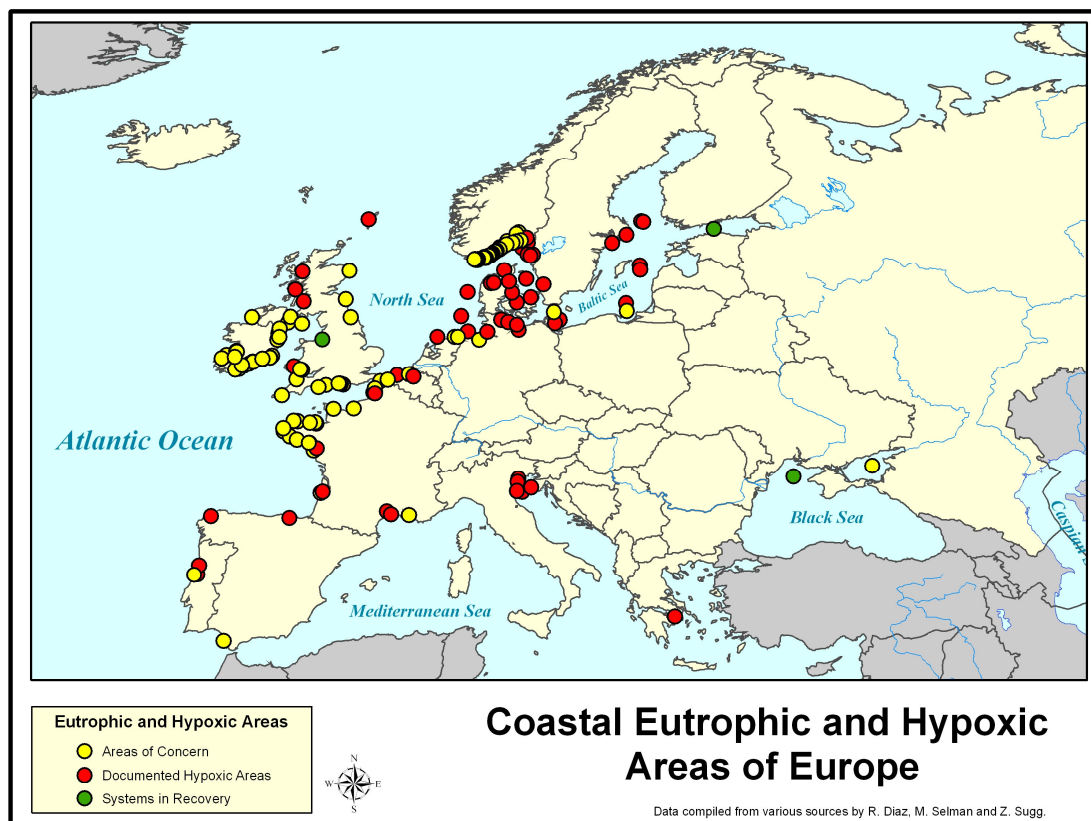


Figure 5: Coastal eutrophic and hypoxic areas of Europe © WRI 2008

This map identifies 168 eutrophic and hypoxic coastal areas in Europe. Fifty-nine of these are documented hypoxic areas, 106 are areas of concern, and 3 are improved systems that are in recovery. Although relatively comprehensive geographically thanks to multinational surveys such as those carried out by the Commission for the Protection of the Marine Environment of

the North-East Atlantic (OSPAR), coordinated eutrophication assessment is still hampered by inconsistent reporting methods between countries and sometimes inconclusive data for determining eutrophic status. It is worth noting the substantial ecological improvements made in the Black Sea, which was formerly one of the most notorious hypoxic areas but is now in recovery. Seven of the world's largest known hypoxic areas are located in the Baltic Sea. This is the reason why the Baltic Sea is treated here with an additional description.



Photo 5: Mats of blue-green algae covered large parts of the Baltic Sea © Anders Modig

Excuse: Baltic Sea

The oxygen situation in the Baltic Sea was documented and modeled for 2000 to 2006 in a recent report published in 2007 in the framework of the EU Project BALANCE. The results in this paper originate mainly from the BALANCE Report No. 17.²⁶ The results from the individual years document the extent and variability of the oxygen depletion.

Due to its hydrology (enclosed sea with limited water exchange with the Atlantic Ocean) the Baltic Sea is very sensitive to oxygen depletion. In the brackish water of the sea, regularly haloclines form that separate the different water layers from each other and prevent the mixing of oxygen richer water with low oxygen water. The Helsinki Convention (HELCOM) the oldest global Regional Seas Convention, has estimated an area of oxygen-depleted bottom

areas can be concerned. This happened in 2002 when mass mortality of benthos dwelling animals and fishes occurred in large parts of the western Baltic Sea and in 2005 when a large algae blooms of blue-green algae covered large areas along the Swedish East coast in the Central Baltic Sea.

Globally, the Baltic accounts for the largest hypoxic areas documented world wide. According to the assessments of the Helsinki Commission in 2006, about 42.000km² of the sea bottom are permanently affected by oxygen depletion, in some years this can sum up 100.000 km². In the Baltic Sea action Plan, the Baltic Sea countries have committed to reduce the input of P by 15.000 t and N by 135.000 t annually from 2016 on. The long-term objective of the Baltic Sea Action Plan is to reduce the dead zones of the Baltic to an area of app. 30.000 km² which is regarded as the historical natural size under Baltic Sea conditions.

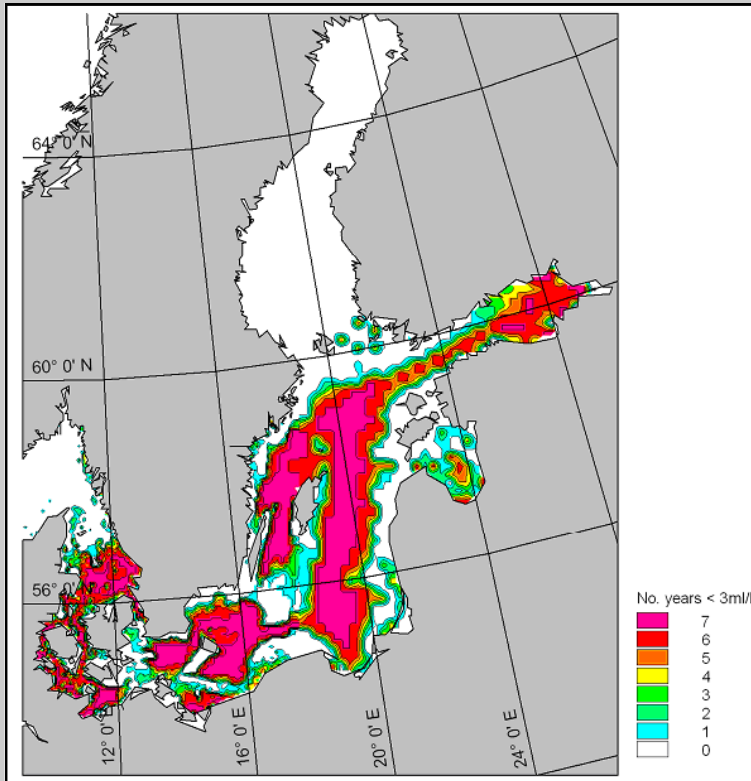


Figure 6: Modelled distribution of frequency for extent of minimum oxygen condition, showing the number of years within seven years 2000—2006 where minimum bottom oxygen becomes below 3 ml O₂/l © BALANCE Interim report No. 17

zones of the sea for the early 20th century of about 10.000 km². Since the seventies of the last century the HELCOM states monitor the oxygen content in the water. In 2006 an area of app. 42.000km² was reported that can be regarded as a permanently oxygen free Dead Zone. Periodically – dependent on stagnation phases and seasonal events – by far larger

From the BALANCE report for the various areas the following conclusions can be drawn:

Skagerrak

The proper of Skagerrak is not suffering from low oxygen conditions in any of the assessment years. Along the Swedish coast of Skagerrak local signs of reduced oxygen are seen in several years and near the Danish coast local signs are seen in 2001.

Kattegat

The assessment shows that most parts of Kattegat have suffered from oxygen depletion once or more times during the assessment period. Only the central part of the northern Kattegat seems not to be affected. The impact includes down to less than 1.5 ml/l in the southernmost part of Kattegat and some way up along the Swedish coast and a large part of this area is subjected to oxygen depletion every year.

Western Gotland Basin

The basin west of Gotland is also subjected to very critical oxygen conditions every year with the years 2000, 2003 and 2004 being the most critical years.

Gulf of Riga

Only the central part of the Gulf of Riga seems to be subjected to depletion every year,

whereas most of the offshore area is subjected to depletion at least once in the seven year period. Year 2001 seems to have been the less critical year and year 2002 among the most critical years. Some critical concentrations are also seen close to the coast.

Gulf of Finland

In the Gulf of Finland the inner-most part and the deeper part all the way out are suffering from depletion every year. The variability from year to year is not large, but the years 2001, 2002 and 2003 seem to have had the most critical conditions.

Åland Sea

The archipelago sea around the Åland islands is probably not sufficiently well resolved in the applied model to assess the bottom oxygen conditions, as the model applied a 9 nm horizontal resolution here. The result showing no significant critical oxygen parts may thus be a too optimistic assessment.

Gulf of Bothnia

The Bothnian Sea does not seem to have suffered from oxygen depletion in the assessment

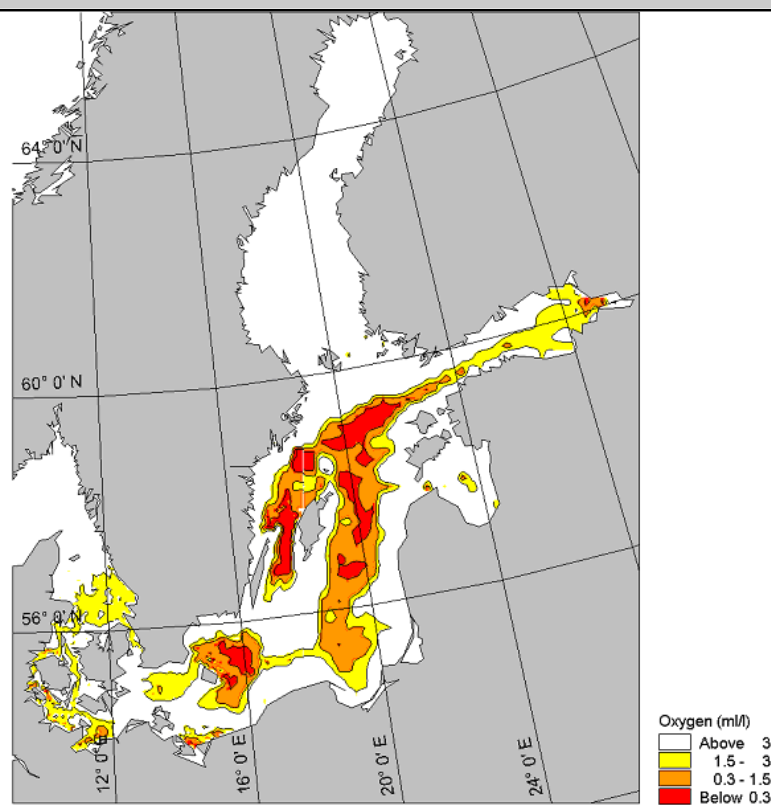


Figure 7: Modelled distribution of every year bottom oxygen depletion area for the entire period 2000—2006, showing where oxygen is low each year in the analysis period © BALANCE report No. 17

period, not even in the deepest parts in the northern end.

The Black Sea

The Black Sea was in the 1970ties and 80ies known to be the most eutrophicated Sea in the world, within 5 years an area of the size of Belgium changed into a dead zone, fed by intensive agricultural nutrients. After the political changes in Eastern Europe, the agriculture collapsed and fertilizer use dropped down. This was the reason for a recovery of the oxygenated water body of the Black Sea. Nevertheless today the Fertilizer Industry estimates an increase of fertilizer market in Eastern Europe by 30% in the years to come. If not precautions of sound nutrient management schemes will be introduced, this means the threat of new dead zones in the Black Sea and in the Baltic Sea as well.

Adriatic Sea /Mediterranean

The northern most part of the Adriatic Sea with the lagoon of Venice and the Po river discharging into it has faced hypoxia several times. About 4300 kg Nitrate per km² of the water-

shed are carried by the Po River into the Adriatic Sea, annually.

North Sea

The North Sea many rivers discharge their loads. Especially the Rhine and the highly intensive agricultural areas for the Netherlands, Belgium, France, the UK and Germany are discharging into this sea area. Due to airborne sources and high population densities anthropogenic input of nutrients is high.

The German Bight recorded hypoxia of 15.000km² in 1982, which accounts for one of the largest areas in the world

Seas around Ireland

In the Celtic Sea, the Irish Sea and in many Irish waters many **areas of concern** according to the Diaz list were recorded during the last 20 years.

NORTH AMERICA AND CARIBBEAN

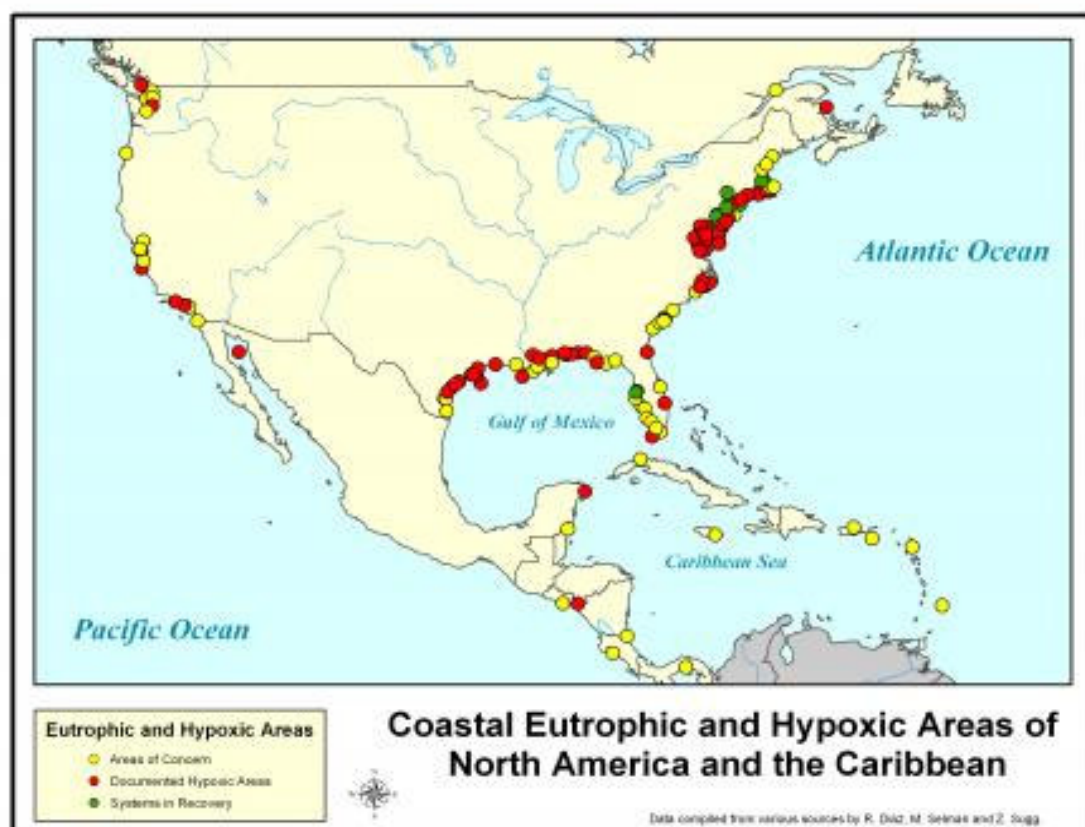


Figure 8: Coastal eutrophic and hypoxic Areas of North America and the Caribbean © WRI 2008

This map identifies 131 eutrophic and hypoxic coast zones in North America and the Caribbean. Sixty-two have documented hypoxia, 59 are areas of concern, and 10 are systems in recovery. Despite having many well-studied systems such as the Chesapeake Bay, which has 12 distinct eutrophic and hypoxic zones, water quality data in the U.S. still have room for improvement. In 2007 the U.S. National Oceanic and Atmospheric Agency's (NOAA) National Estuarine Eutrophication Assessment program evaluated the eutrophic status of 141 estuaries, yet 30 percent lacked adequate data to make a definitive assessment. As with many less-developed regions of the world, data on eutrophication for the Caribbean is generally sparse, making this map likely an underrepresentation of the actual number of eutrophic and hypoxic areas.

Chesapeake Bay

The Chesapeake Bay in the mid-Atlantic region of the eastern United States is one of the best studied sea areas suffering from hypoxia and eutrophication. Here atmospheric sources of nitrogen account for a third of all controllable nitrogen that enters the Bay. Even though some

subsystems are classified as recovering, still 12 areas are regarded as hypoxic or documented eutrophic zones.

The Gulf of Mexico (US part)

The Gulf of Mexico is known as the second largest of the top 10 global Dead Zones: in the worst years the hypoxic zone was 22,000 km² large. To reduce the area to 5,000 km², what is the governments goal, a reduction of Nitrogen fertilization of about 45% would be needed in the river catchment of the Mississippi.

In the Gulf area, several hypoxic events have been recorded since. This led among others to losses for the shrimp fisheries as shrimps flee from the oxygen depleted areas or have to exist at their ecological capacity limits.

Caribbean Sea Areas

The river basins that discharge nutrients from the Central American watershed account among the top ten areas with the highest nutrient loads world wide. Even though not proven by detailed measurements and monitoring data, there is reason for concern that in the Caribbean coastal areas more eutrophicated zones are to be found.

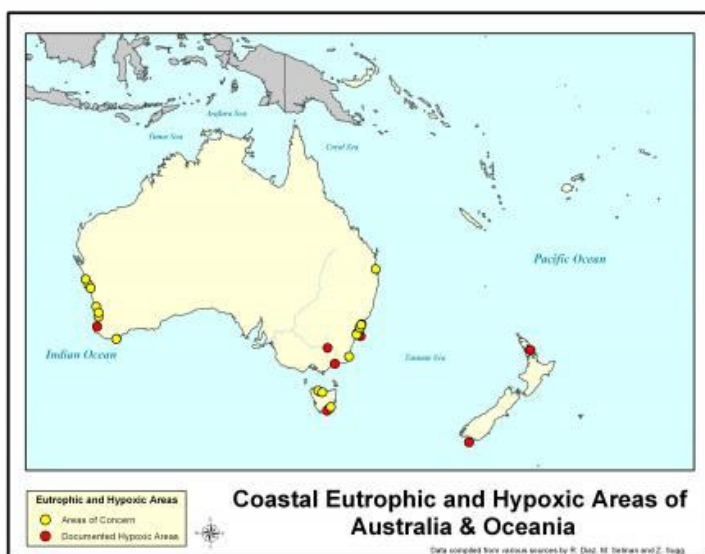
SOUTHAMERICA



This map identifies 25 eutrophic and hypoxic zones, with 3 having documented hypoxia and 22 areas of concern. Most are found in Brazil, Chile, and Peru. This is most likely an undercount for the continent given recent increases in nutrient delivery to coastal waters related to agriculture, growing industry, fossil fuel combustion, and population growth. It is estimated that only 14 percent of wastewater, a key source of nutrients, is treated in Latin America and the Caribbean. Improved water quality monitoring and assessment is required to identify problem areas and their sources, and to develop strategies to reduce eutrophication.

Figure 9: Coastal eutrophic and hypoxic areas of South America © WRI 2008

AUSTRALIA/ OCEANIA



This map identifies 36 eutrophic coastal zones; 9 with documented hypoxia and 27 areas of concern. The majority of information on eutrophic areas in Australia is derived from a national water quality audit conducted in 2001.

New Zealand's Cape Rodney is among the top 10 hypoxic zones of our globe.

In Australia mainly the areas in the South, near Perth and around Tasmania are concerned.

Figure 10: Coastal eutrophic and hypoxic areas of Australia/ Oceania © WRI 2008

AFRICA

This map identifies only 20 eutrophic coastal zones in all of Africa, of which 8 have documented hypoxia and 12 are areas of concern. There are undoubtedly many more, but a lack of reliable water quality data makes it difficult to assess the true scope of eutrophication in Africa.

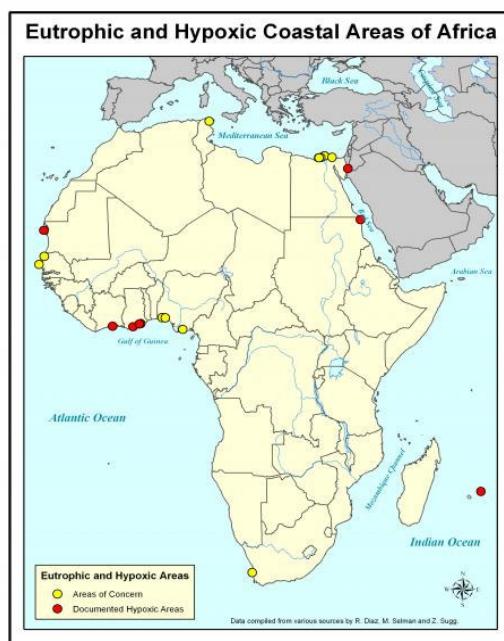


Figure 11: Coastal eutrophic and hypoxic areas of Africa © WRI 2008

SOUTH ASIA

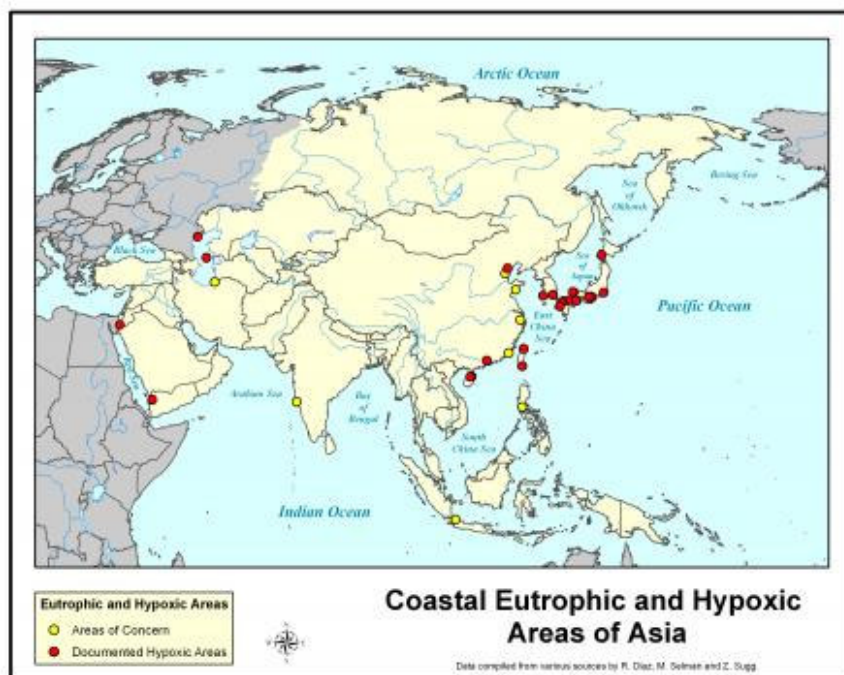


Figure 12: Coastal eutrophic and hypoxic areas of South Asia © WRI 2008

This map identifies just 24 eutrophic coastal areas with documented hypoxia and 9 areas of concern within Asia. Forty-two percent of these areas are located in Japan, where monitoring of eutrophication is well advanced. In China, some hypoxic and eutrophic systems are identified at a coarse scale. For example “South China Sea” and “Bohai Sea” are represented as single points because data were not avail-

able at a finer scale. Because of large increases in intensive farming methods, industrial development, and population growth in Asia over the past 20 years, we know that eutrophication and hypoxia are greatly underrepresented in this map. Better water quality monitoring and assessment in China and throughout Asia are needed in order to understand the full extent and nature of eutrophication in Asia.

With regard to the estimates of Seitzinger et al., the riverine input of nutrients is very high in the coastal waters of Indonesia and also for many Chinese coastal areas. Changes in fish community structure, biomass and biodiversity in the Bohai Sea are described from four summer bottom trawl surveys conducted between 1959 and 1998. The mean catch in 1998 declined to only 4.0%, 4.3% and 3.6 % of that in 1959, 1982 and 1992, respectively.²⁷

Acknowledgements

WWF thanks Mindy Selman from the World Resource Institute (WRI) in Washington DC, USA, for allowing WWF to use the data from the WRI-Policy Note no.1 2008 : „Eutrophication and Hypoxia“ as a backbone for this briefing report. We also thank Mindy Selman for reviewing earlier drafts of this report and for valuable contributions during preparation.

WWF acknowledges Robert Diaz, College of William and Mary, Virginia Institute of Marine Science, Virginia, USA and Laurence Mee, University of Plymouth, UK, for contributing with help and information on specific areas.

Additionally, we thank Sybil Seitzinger, of the Rutgers State University of New Jersey, Brunswick, New Jersey, USA, for contributing with valuable information about the nutrient inputs from global watersheds and for the use of the graphs from her publications.



Photo 6: Algae blooms in the open Baltic Sea © Anders Modig



for a living planet®

WWF is one of the world's largest and most experienced independent conservation organisations, with almost 5 million members and supporters and a global network active in some 100 countries.

WWF's mission is to Stop the degradation of the planet's natural environment to build a future in which humans live in harmony with nature, by:

- conserving the world's biological diversity
- ensuring that the use of renewable natural resources is sustainable
- promoting the reduction of pollution and wasteful consumption.

WWF Germany

Rebstöcker Straße 55
60326 Frankfurt am Main
Tel.: 069 / 7 91 44 - 0
Fax: 069 / 61 72 21
E-Mail: info@wwf.de

