Eutrophication
In the Marine Environment

Noxious and Harmful Algal Blooms
Hypoxia

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http://www.gulfhypoxia.net
Global N Budget: ~1860 (Tg N/yr)

Galloway and Cowling 2002
Global N Budget: Present
(Tg N/yr)

Galloway and Cowling 2002
Terrestrial Phosphorus Fluxes (Tg/yr)

Pre-Industrial

change-in-storage = 1 to 6 Tg P yr⁻¹

10 to 15
weathering

Freshwater and Terrestrial Ecosystems of Earth

current

change-in-storage = 10.5 to 15.5 Tg P yr⁻¹

18.5
mining

15–20
weathering

Freshwater and Terrestrial Ecosystems of Earth

1
atmospheric output

8
fluvial drainage

22
fluvial drainage

Bennett et al., 2001
Nutrients, Increased Growth, Low Oxygen

Nutrient-rich water flows in

Algae grow, feed and die

Zooplankton eat algae

Bacteria feed on fecal pellets and dead algae

Bacteria deplete the water of oxygen

Marine life flees (2.0mg/l) or dies (1.0mg/l)

Oxygen-deficient water

DEPTH

0 ft.

-20

-40

-60

-80

MILES FROM THE COAST

Time Magazine
No trawlable fish, shrimp, crabs
Hypoxia = Dissolved $O_2 < 2\text{ mg/L} (=2\text{ ppm})$
$n \text{ now} > 550$

Data from Water Resources Inst.
Increases in people (coastal populations and increased fertilizer usage) increase # of hypoxic systems
Chesapeake Bay, Maryland/Virginia: 1989 severe oxygen depletion. Bay is about 180 km long. Maximum depth is about 40 m.

Red = <1 mg/l  Yellow = <2mg/l
Oxygen content 2 m above the bottom during August-September in the northern Adriatic Sea from 1911 to 1984 for the periods indicated. Redrawn from Justić (1991) with permission.
They are increasing

Symptoms of Eutrophication

Developed Countries

Developing Countries

Humans, millions
Legumes/Rice, Tg N
Fertilizer, Tg N
NOx emissions, Tg N

(modified by N. Rabalais; Galloway and Cowling 2002; Boesch 2002)
East China Sea

14,000 km²
Annual Hypoxia

Li and Daler 2004

Figure 3. The Yangtze River drainage basin and the estimated hypoxia areas in the ECS (3).

Figure 5. Historical variations of nitrate concentrations at Datong station (33).
“Our rivers are too large to have nutrient problems and dead zones”

Land-Ocean Interactions in the Coastal Zone (LOICZ/IGBP) Open Science Meeting, Bahia Blanca, Argentina, November 1999
Effects are more far reaching than suspended sediment plume, esp. N & somewhat P

Source: N. Rabalais
• Mid-summer shelfwide cruise
• Monthly lines C and F
• Deployed oxygen meters
Extensive Field Measurements
Stratification (mid-summer)

Density (sigma-t)

Dissolved Oxygen (mg/L)

Salinity ‰
Temperature °C

Dissolved Oxygen (mg/L)

km

Depth (m)

C6B
Harmful and Noxious Algal Blooms

Northern Gulf of Mexico May 2011

Heterosigma akashiwo
Nutrients, Increased Growth, Low Oxygen

50% C↓

(Turner et al. 2005)
Mississippi River Discharge at Tarbert Landing, 1935 – 2015

Discharge (m$^3$ s$^{-1}$)

Jan     Feb    Mar    Apr    May    Jun    Jul      Aug    Sep     Oct    Nov    Dec

2014

max

mean

min

2015
Source: N. Rabalais
Dissolved Oxygen  DO
Conductivity  C
Temperature  T
Turbidity  TB
In vivo Fluorescence  F
Currents  ADCP
Nutrient Experiments (selected)
Light Meter Deployments (selected)

Station CSI-6, LSU/WAVCIS

Full meteorological suite & wave meters

Station C6C/BIO2

C/T/DO/TB/F  2.4 m
C/T  6.6 m
C/T/DO/TB/F  10.7 m
C/T  14 m
C/T/DO/TB/F  19 m

Source: N. Rabalais
Dissolved Oxygen (mg l$^{-1}$)

cold front

respiration

tropical storm

respiration

deep water intrusion

cold fronts

cold fronts

Rabalais et al. 2007
More Nutrients >>>
More Phytoplankton >>>
More Carbon Reaches the Bottom >>>
More Oxygen Consumed >>>
More Hypoxia
Verified by Paleoindicators

Photo: N. Rabalais, LUMCON
Nitrogen Inputs to the Mississippi Watershed

Goolsby et al. 1999
We know where it comes from, what it does, and what we should do. Unfortunately, this is not the EU. Multi-jurisdictional authorities and engrained social structure create a quagmire that does not overcome the inertia for nutrient mitigation and control.
Predicting Hypoxia in summer (nitrate flux in May, year)

Similar analyses with PO$_4$, TP, TN, Si, various Si:N:P ratios indicate that N, in the form of NO$_3$+NO$_2$, is the major driving factor influencing the size of hypoxia on the Louisiana shelf.
Turner et al., unpubl. data

Km$^2$ per 1000 mt N as NO$_{3+2}$

2015 actual
Relationship Between Biogenic Silica and Nutrient Loading

Turner and Rabalais 1994
A shift from heavily silicified to less silicified, including the HAB

*Pseudo-nitzschia*

(indicates potential Si limitation but competitive advantage of *Pseudo-nitzschia* with increased nitrogen)

Parsons et al. 2003
**Quinqueloculina**

Not an abundant species but a definite decline

1945 in 60 m
1950 in 35 m
1900 in 27 m

An increase of hypoxia in time with depth?

Platon et al. 2005
The Consequences

- Fisheries resources at risk
- Altered migration
- Reduced habitat
- Changes in food resources
- Susceptibility of early life stages
- Growth & reproduction
Size of bottom-water hypoxia in mid-summer

Data source: Nancy N. Rabalais, LUMCON, and R. Eugene Turner, LSU
Funding sources: NOAA Center for Sponsored Coastal Ocean Research and U.S. EPA Gulf of Mexico Program
Reduce Nutrients, Reduce Hypoxia

Northwestern Shelf
Black Sea

Hypoxic Area Up to 40,000 km²
Currently, non-existent or minimal

N and P Loads Correspond to Fertilizer Use

[Graphs showing N and P loads vs. fertilizer use over time]
The Future

Climate Change
Biofuels
Increased Population
Increased Agribusiness
Increased Atmospheric Deposition
Anthropogenic activities

- Reactive N (mostly +)
- Nutrient loads (+) (-)

Hydrologic cycle (+) (-)

- Nutrient-enhanced productivity
- Vertical carbon flux
- Sedimentary carbon and nutrient pools

Climate variability climate change

- Sea level rise (+)
- Water temperature (mostly +)
- Winds

Physical environment (Stratification +)
- (Oxygen saturation -)
- (Current shifts)
- (Tropical storms)

Biological responses
- (Metabolic rates mostly +)
- (Primary production +)
- (Respiration +)

Harmful & noxious algal blooms

Bottom-water hypoxia
- pCO₂ (+)
- pH (-)
- H₂S (+)
- efflux of NH₄⁺, PO₄⁻³, silicate (+)

Nutrient loads (+) (-)

Hydrologic cycle (+) (-)

- Nutrient-enhanced productivity
- Vertical carbon flux
- Sedimentary carbon and nutrient pools

Sedimentary carbon and nutrient pools

Rabalais et al., 2014