What is a “Dead Zone”? and, is it really “dead”?

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Linked Land, River, Ocean Ecosystem
Mississippi River Discharge, Tarbert Landing, MS

1935–2012

Daily discharge (cubic feet x 1000 s⁻¹)

- Maximum
- Mean 1935-2012
- Minimum

<table>
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<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<tbody>
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<td>2012</td>
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Nutrients, Increased Growth, Low Oxygen

Nutrients (N, P, Si), Sediments, & organic carbon

Healthy benthic community (worms, snails, bivalves, crustaceans)

O₂ flux blocked

Organic material flux

Pycnocline

Mortality

Organic matter decomposed & oxygen consumed

Heavier, saltier, cooler lower layer

Lighter, fresher, warmer, surface layer

Upwelled nutrients & oxygen (effects unquantified)
Effects are more far reaching than suspended sediment plume, esp. N & somewhat P

dominant wind direction

Source: N. Rabalais, LUMCON
Hypoxia = Dissolved O$_2$ < 2 mg/L (=2 ppm)
Nutrients, Increased Growth, Low Oxygen

**Diagram Description:**
- Nutrient-rich water flows in from the coast.
- Algae grow, feed, and die as they consume the nutrients.
- Zooplankton eat algae.
- Bacteria feed on fecal pellets and dead algae, depleting the water of oxygen.
- Oxygen-deficient water is indicated at 1.0 mg/l and 2.0 mg/l.
- Marine life flees (2.0 mg/l) or dies (1.0 mg/l) due to the low oxygen levels.

*Time Magazine*
• Mid-summer shelfwide cruise
• Monthly/bimonthly samples along transects C & F
• Deployed oxygen meters
Extensive Field Measurements & Experiments
Distribution of bottom-water dissolved oxygen July 18-21 (east of the Mississippi River delta) and July 24-30 (west of the Mississippi River delta), 2011. Black line indicates dissolved oxygen level of 2 mg/L. Data source: Nancy N. Rabalais, LUMCON, and R. Eugene Turner, LSU. http://www.gulfhypoxia.net
Area of Mid-Summer Bottom Water Hypoxia (Dissolved Oxygen < 2.0 mg/L)

Data source: N.N. Rabalais, Louisiana Universities Marine Consortium, R.E. Turner, Louisiana State University
Funded by: NOAA, Center for Sponsored Coastal Ocean Research
Mississippi River Discharge, Tarbert Landing, MS
1935–2013
Distribution of bottom-water dissolved oxygen July 24-30, 2014. Black line indicates dissolved oxygen level of 2 mg/L.
Data source: Nancy N. Rabalais, LUMCON, and R. Eugene Turner, LSU.
http://www.gulfhypoxia.net
Predicting Hypoxia in summer (nitrate flux in the spring, Apr-Jun, year)

Similar analyses with PO4, TP, TN, Si, various Si:N:P ratios indicate that N, in the form of NO3+NO2, is the major driving factor influencing the size of hypoxia on the Louisiana shelf.
More Nutrients >>>
More Phytoplankton >>>
More Carbon Reaches the Bottom >>>
More Oxygen Consumed >>>
More Hypoxia
Verified by Paleoindicators

Photo: N. Rabalais, LUMCON

Turner et al. 2012
Station CSI-6, LSU/WAVCIS

Station C6C/BIO2

Dissolved Oxygen  DO
Conductivity  C
Temperature  T
Turbidity  TB
In vivo Fluorescence  F
Currents ADCP
Nutrient Experiments  (selected)
Light Meter Deployments  (selected)

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
Bottom Dissolved Oxygen at 20 m, CSI-6, August 2005

Hurricane Katrina approaches

Oxygen meter stripped from mooring
<table>
<thead>
<tr>
<th>Nekton</th>
<th>Demersal invertebrates</th>
<th>Epibenthic invertebrates</th>
<th>Larger infauna</th>
<th>Macro-infauna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most present</td>
<td>Most present</td>
<td>Present</td>
<td>Present &amp; burrowed</td>
<td>Present &amp; burrowed</td>
</tr>
<tr>
<td>Absent</td>
<td>Few mantis &amp; penaeid shrimp</td>
<td>Stressed (starfish, brittle stars)</td>
<td>Stressed (anemones, gastropods)</td>
<td>Moribund polychaetes</td>
</tr>
<tr>
<td>(fish kills)</td>
<td>Absent</td>
<td>Dead</td>
<td>Dead</td>
<td>Dead</td>
</tr>
</tbody>
</table>

Rabalais et al. 2001

Anoxic sediment, H$_2$S in sediment and water

Bacterial mats
NGOMEX02 Cruise

Atlantic croaker

Brown shrimp

Dissolved oxygen (mg/l)
- 0-1
- 1-2
- 2-4
- >4

Catch percentiles
- 0
- 1-25%
- 25-50%
- 50-75%
- 75-100%

(Kevin Craig, unpubl. data)
The Consequences

- Fisheries resources at risk
- Altered migration
- Reduced habitat
- Changes in food resources
- Susceptibility of early life stages
- Growth & reproduction
Nitrogen Inputs to the Mississippi Watershed

Goolsby et al. 1999
Nutrients Delivered to GoMx

**Sources**
- Corn and soybean crops
- Other crops
- Pasture and range
- Urban and population-related sources
- Atmospheric deposition
- Natural land

**Total Phosphorus**

**Total Nitrogen**

300% increase in N load
80% due to NO$_3^-$ concentration ↑
20% due to discharge ↑

Turner et al. 2007
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.
Baltic Sea and Coastal Waters

Conley et al., 2009
East China Sea

14,000 km²

Annual Hypoxia

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

Li and Daler 2004

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
Symptoms of Eutrophication

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

(Rabalais et al., 2009; modified from Galloway and Cowling 2002; Boesch 2002)
GOALS

Coastal. By 2015, reduce hypoxia below 5,000 km² (over a 5-yr running average).

Basin. Restore and protect the waters of Basin States and Tribes.

Communities. Improve social and economic conditions in the Basin.

- Estimated N reduction required:
- 30% at time of Action Plan
- Voluntary actions, incentives, education
Supports and Strengthens the Science

- N loading drives timing and extent of hypoxia
- P loads significant in watershed and Gulf of Mexico
- HAP recommends dual N & P reduction strategy
- Currently requires a 35 to 45% reduction of both N & P

Coastal Goal Supported
Reduce Nitrogen (1000 MT/yr)

- Farm N management: 1,400 - 1,900
- Alt. crop systems: 500
- Wetlands: 300
- Riparian Buffers: 300
- Tertiary treatment (point sources): 20
- Coastal Diversion: 50
Potential N Reduction (1000 mt N/yr)

- Farm N Mgt: 900 (35%)
- Manure Mgt: 500 (19%)
- Alt Crop Syst: 500 (19%)
- Tertiary: 500 (19%)
- Wetlands: 300 (12%)
- Riparian: 20 (1%)
- Coastal: 300 (12%)

Data Source: Mitsch et al. 1999, 2001; CENR 2000
Consumer-modified food system

- Increasing fertilizer use, TgN yr⁻¹
- Decreasing grain exports
- Standard US diet

Howarth et al. 2002

eat more fish
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

Zaitsev 1992
Mee 2006
The Future

Climate Change
Biofuels
Increased Population
Increased Agribusiness
Increased Atmospheric Deposition
Questions?