Eutrophication
In the Marine Environment

Noxious and Harmful Algal Blooms
Hypoxia

Nancy N. Rabalais

Louisiana State University

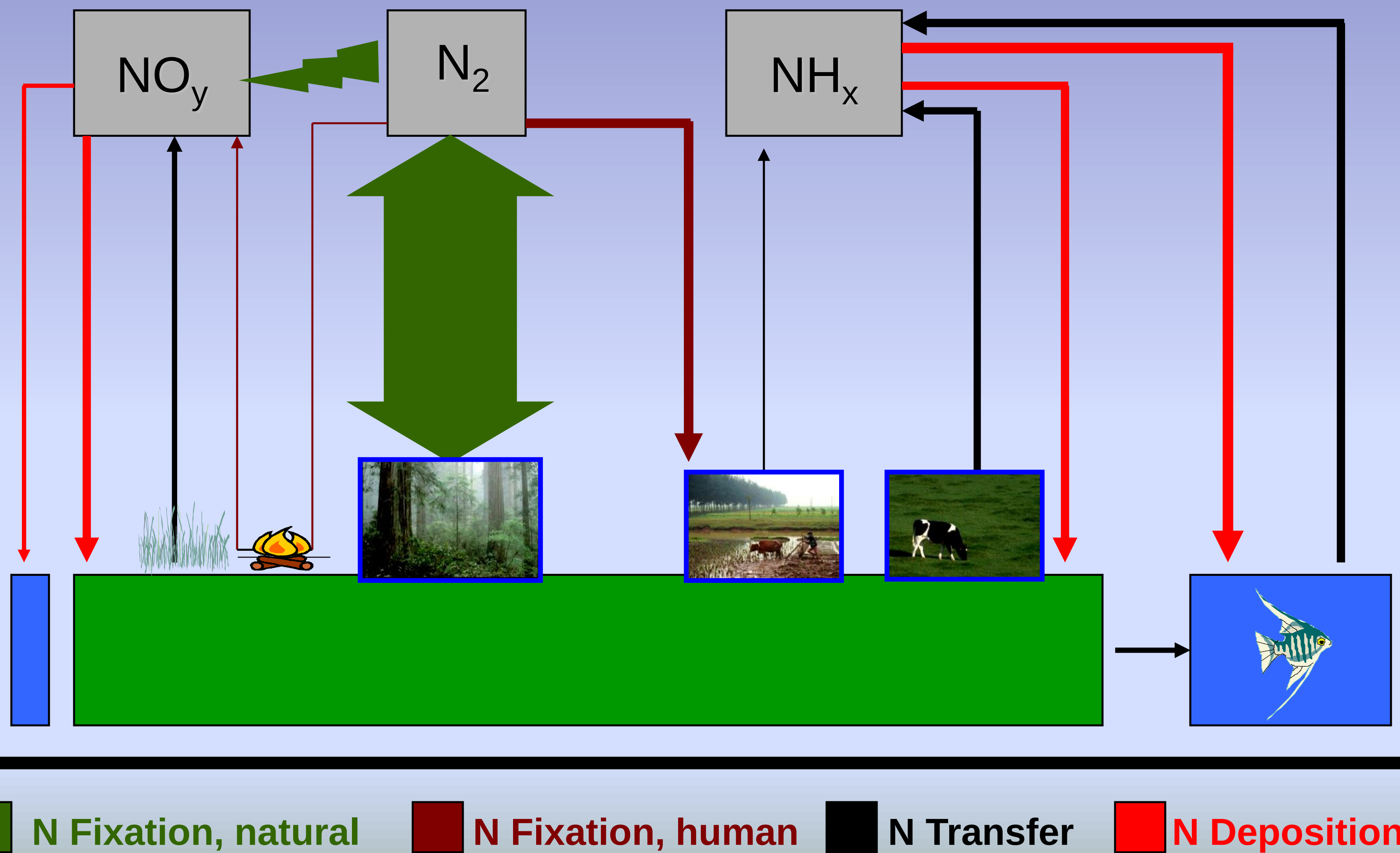
&

Louisiana Universities Marine Consortium

nrabalais@lumcon.edu

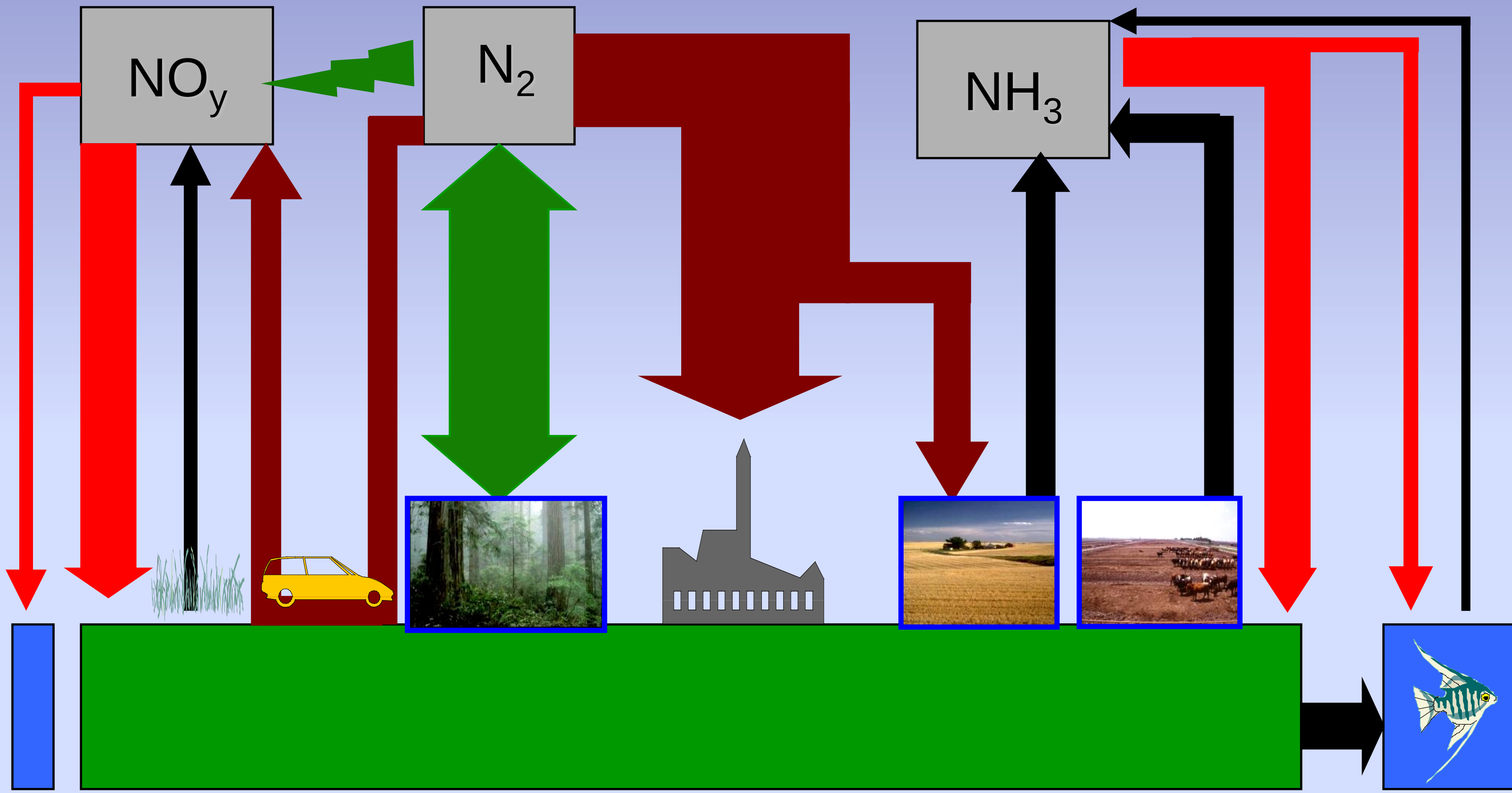
http://www.gulfhypoxia.net

Global N Budget: ~1860
(Tg N/yr)



Galloway and Cowling 2002

Global N Budget: Present
(Tg N/yr)

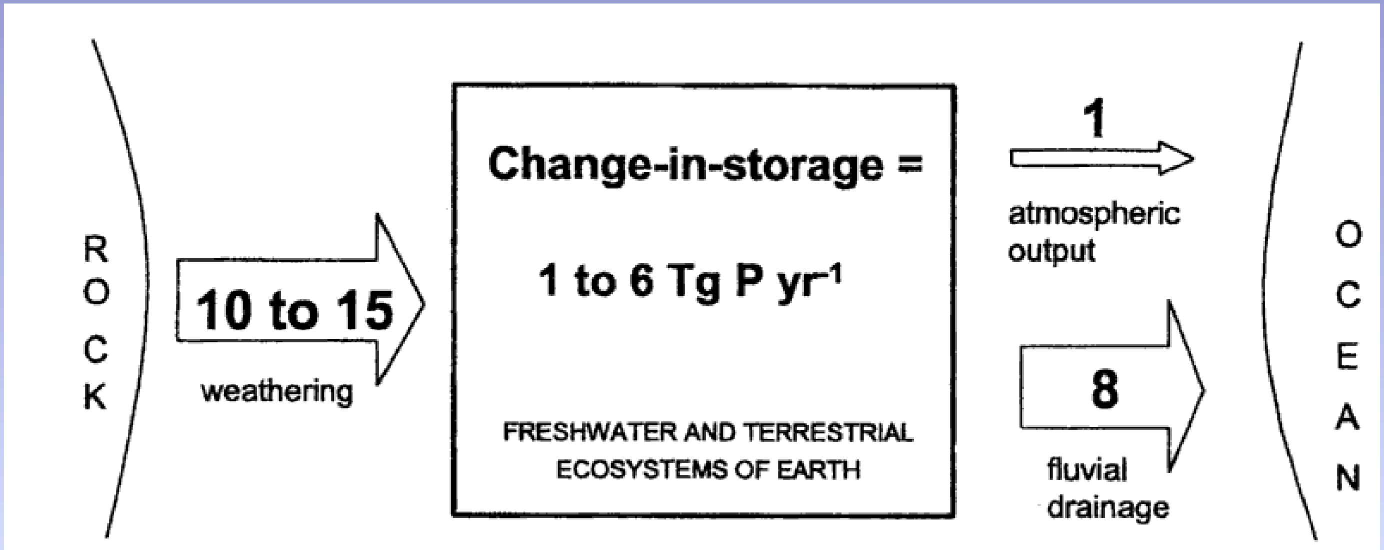


N Fixation, natural | N Fixation, human | N Transfer | N Deposition

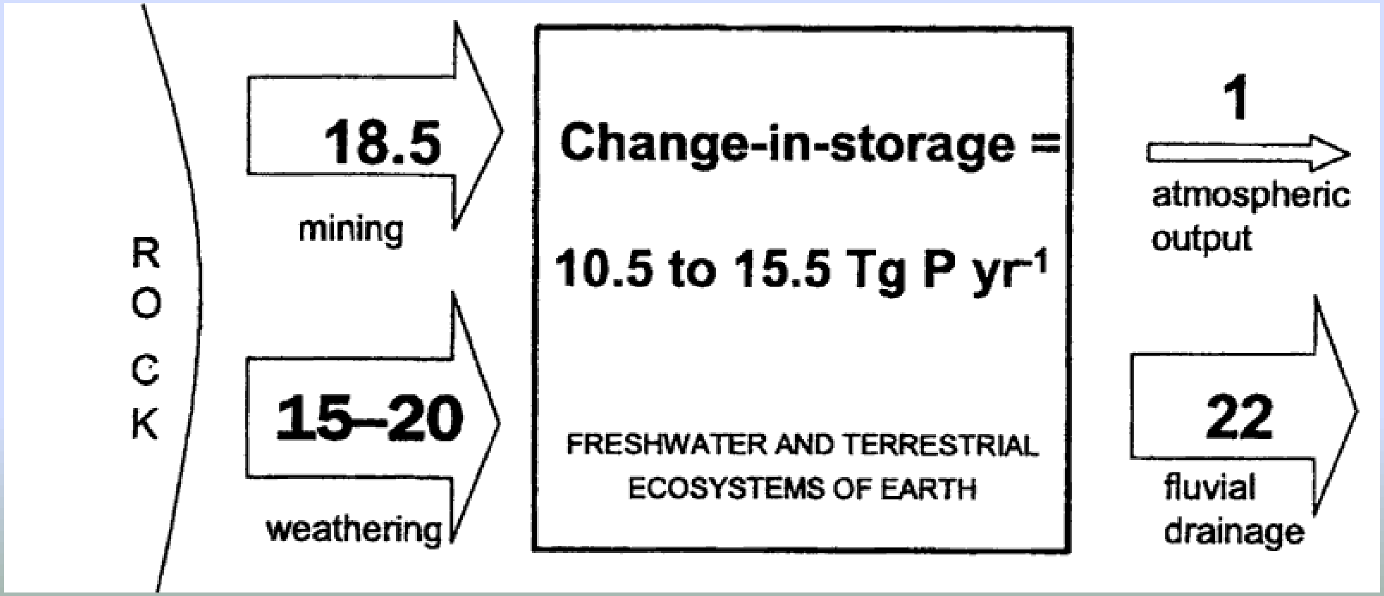
Galloway and Cowling 2002

Terrestrial Phosphorus Fluxes (Tg/yr)

Pre-Industrial

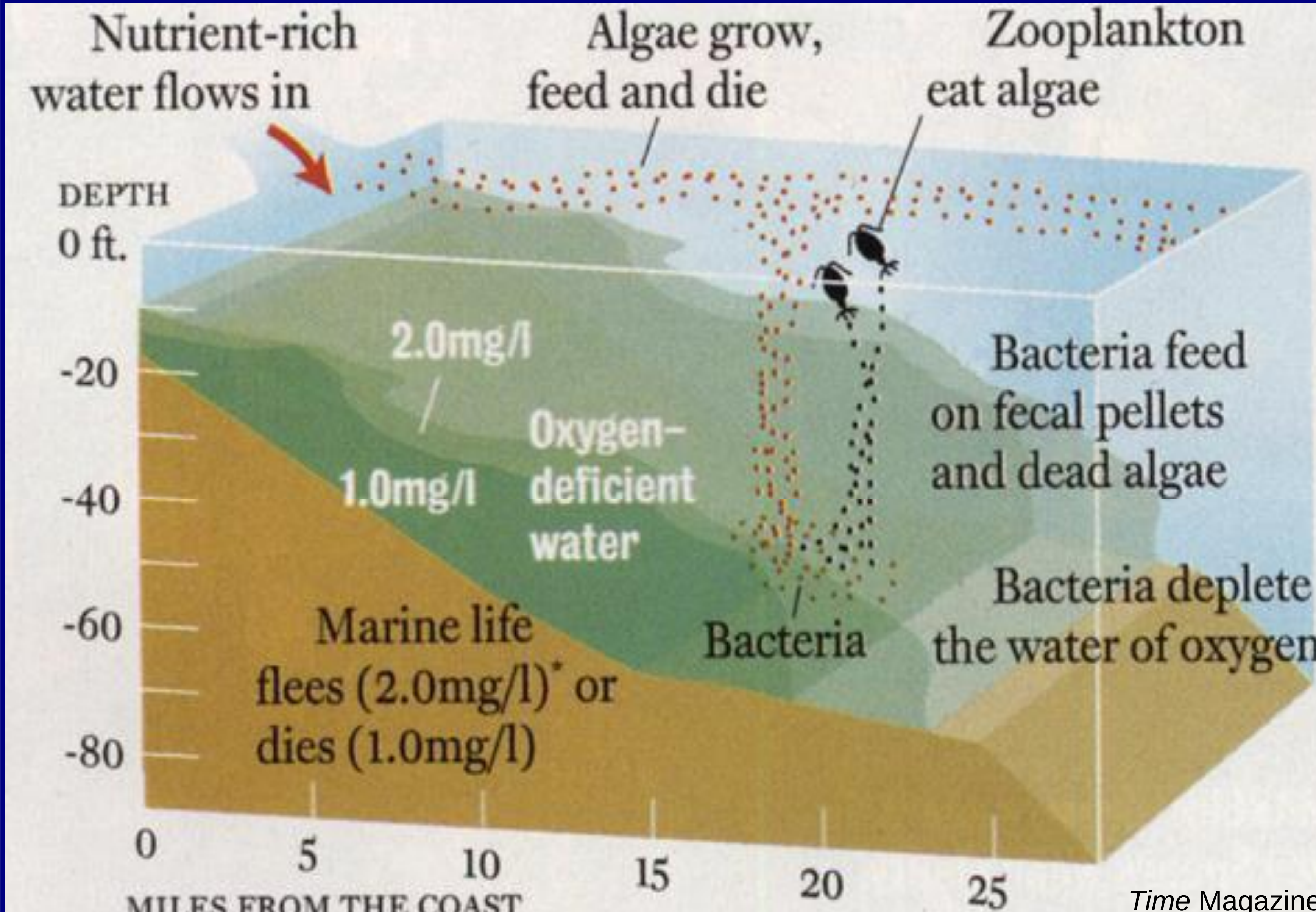


Current



Bennett et al., 2001

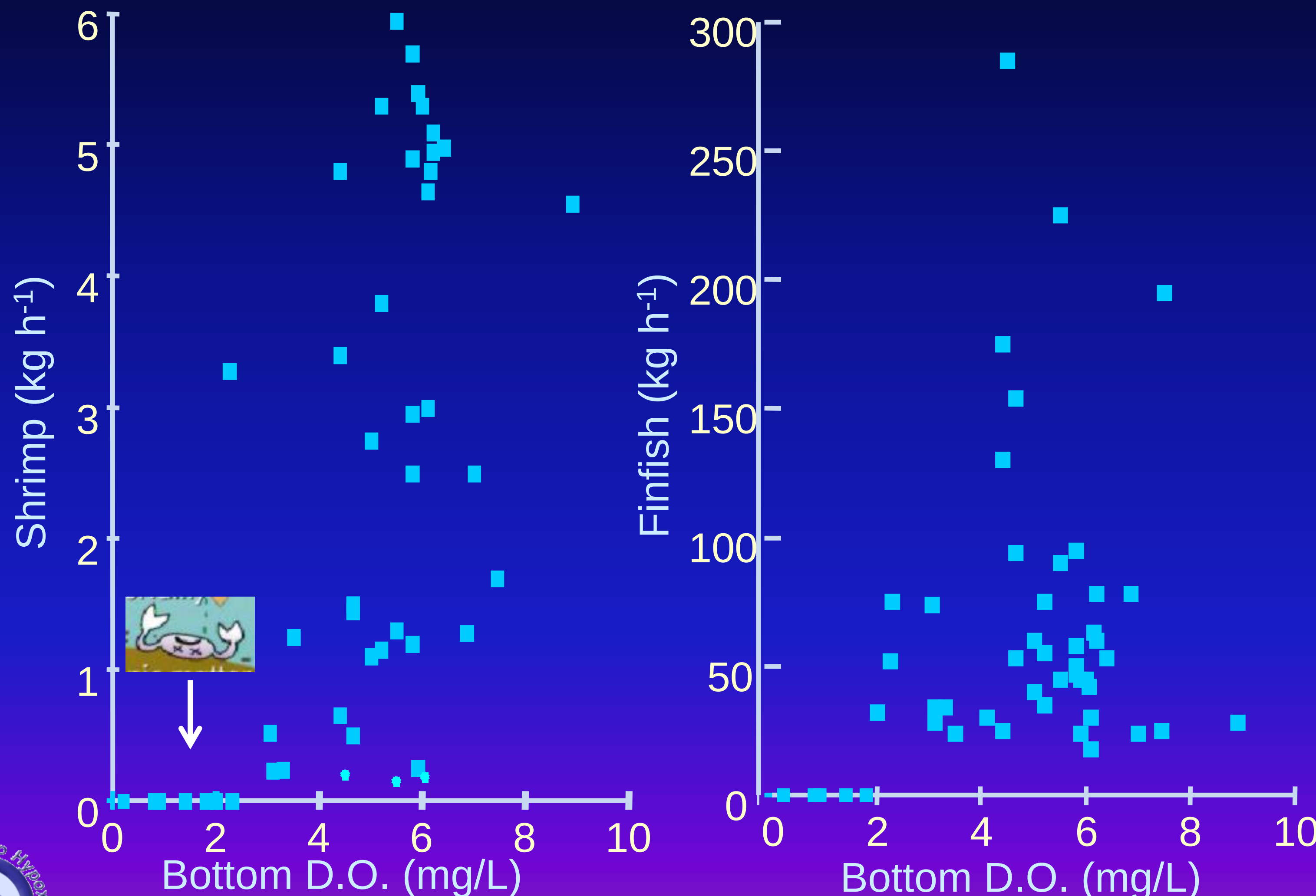
Nutrients, Increased Growth, Low Oxygen



Time Magazine

No trawlable fish, shrimp, crabs

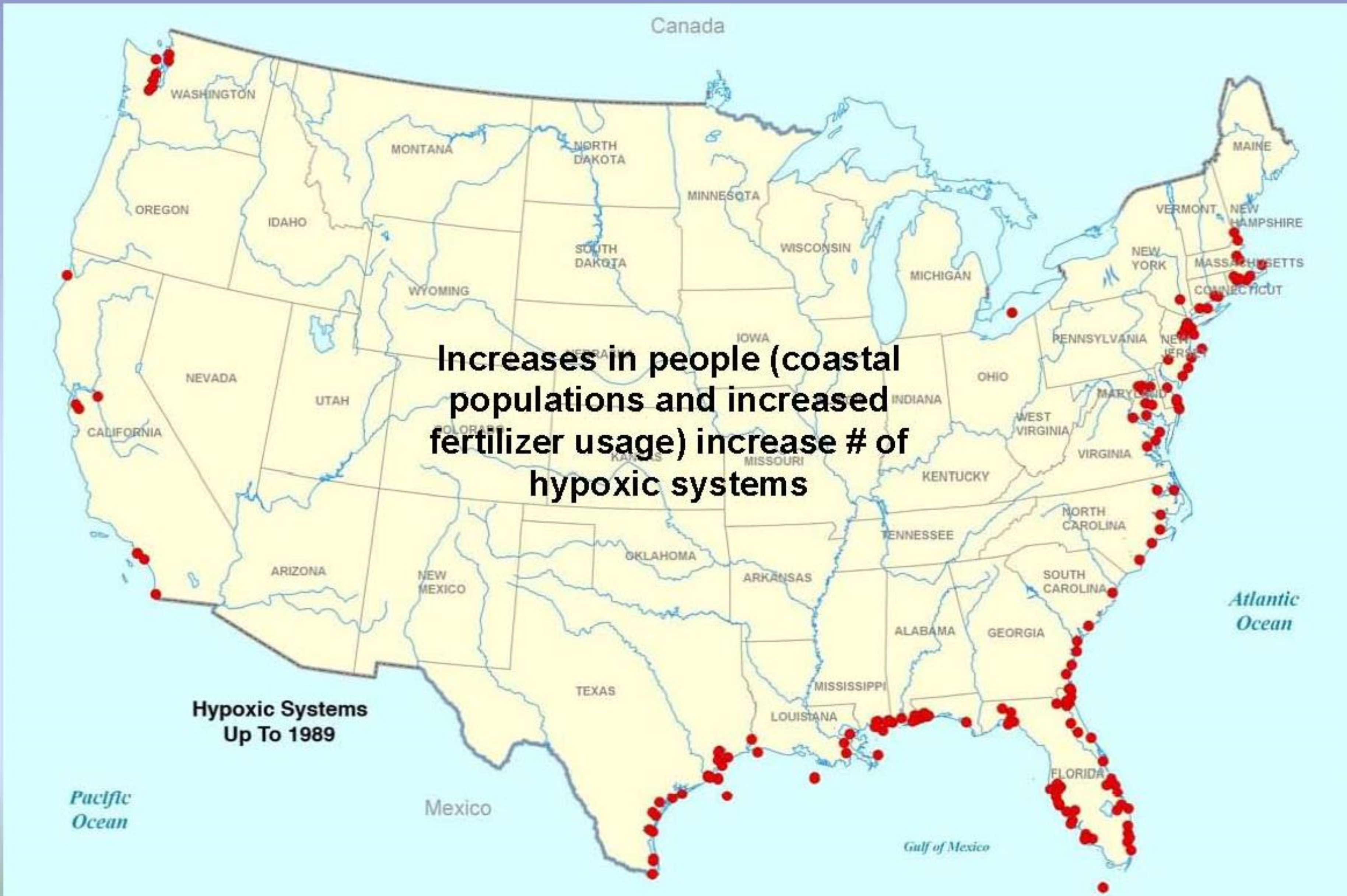
Hypoxia = Dissolved O_2 < 2 mg/L (=2 ppm)

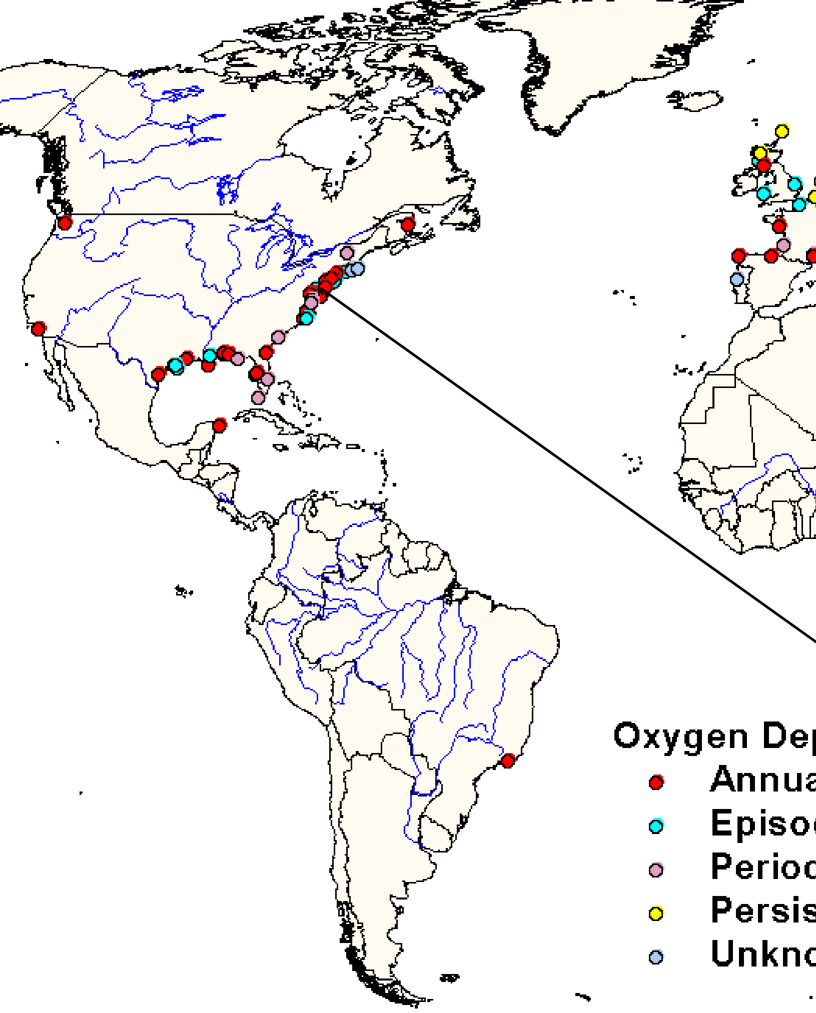


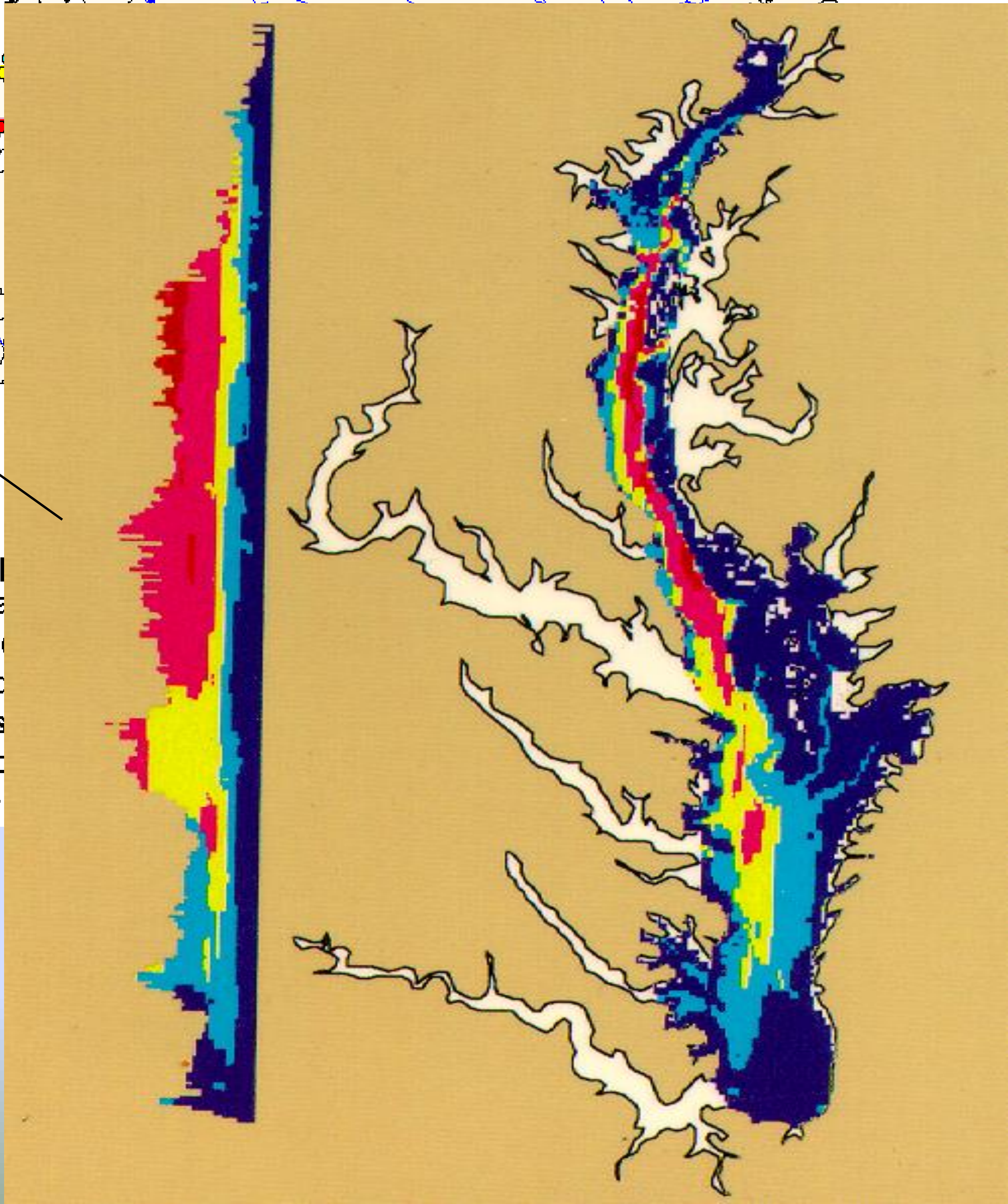
Leming and Stuntz 1984


n now > 550
Data from Water Resources Inst.

U.S. Hypoxic Trends for Estuarine and Coastal Systems

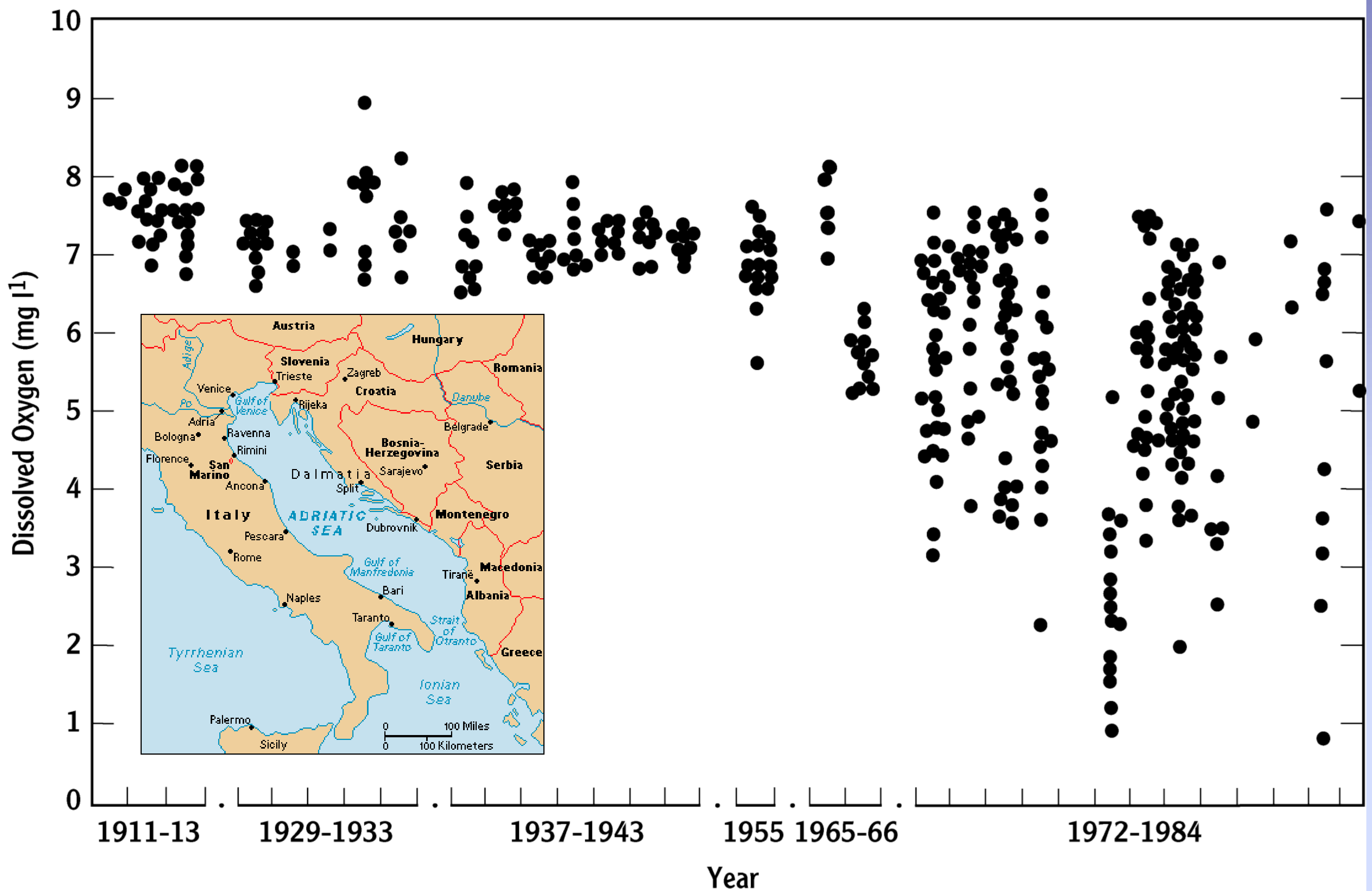




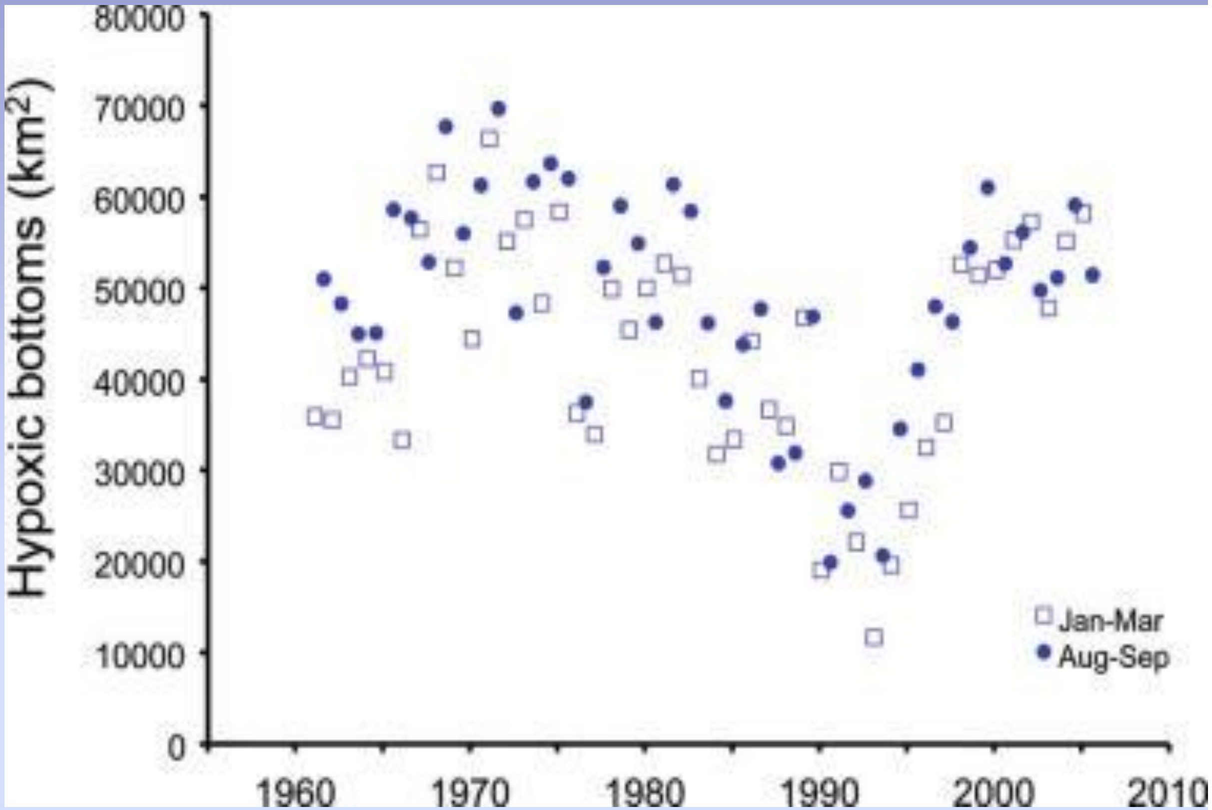


Chesapeake Bay, Maryland/Virginia:
1989 severe oxygen depletion.
Bay is about 180 km long.
Maximum depth is about 40 m.

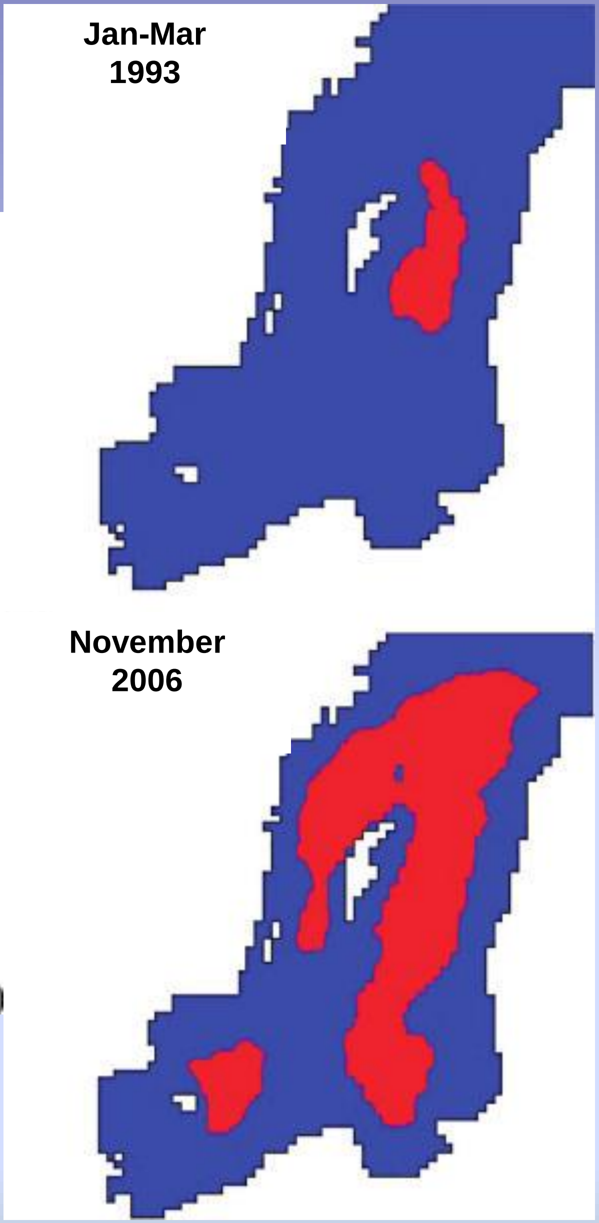
Red = <1 mg/l **Yellow** = <2mg/l



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.

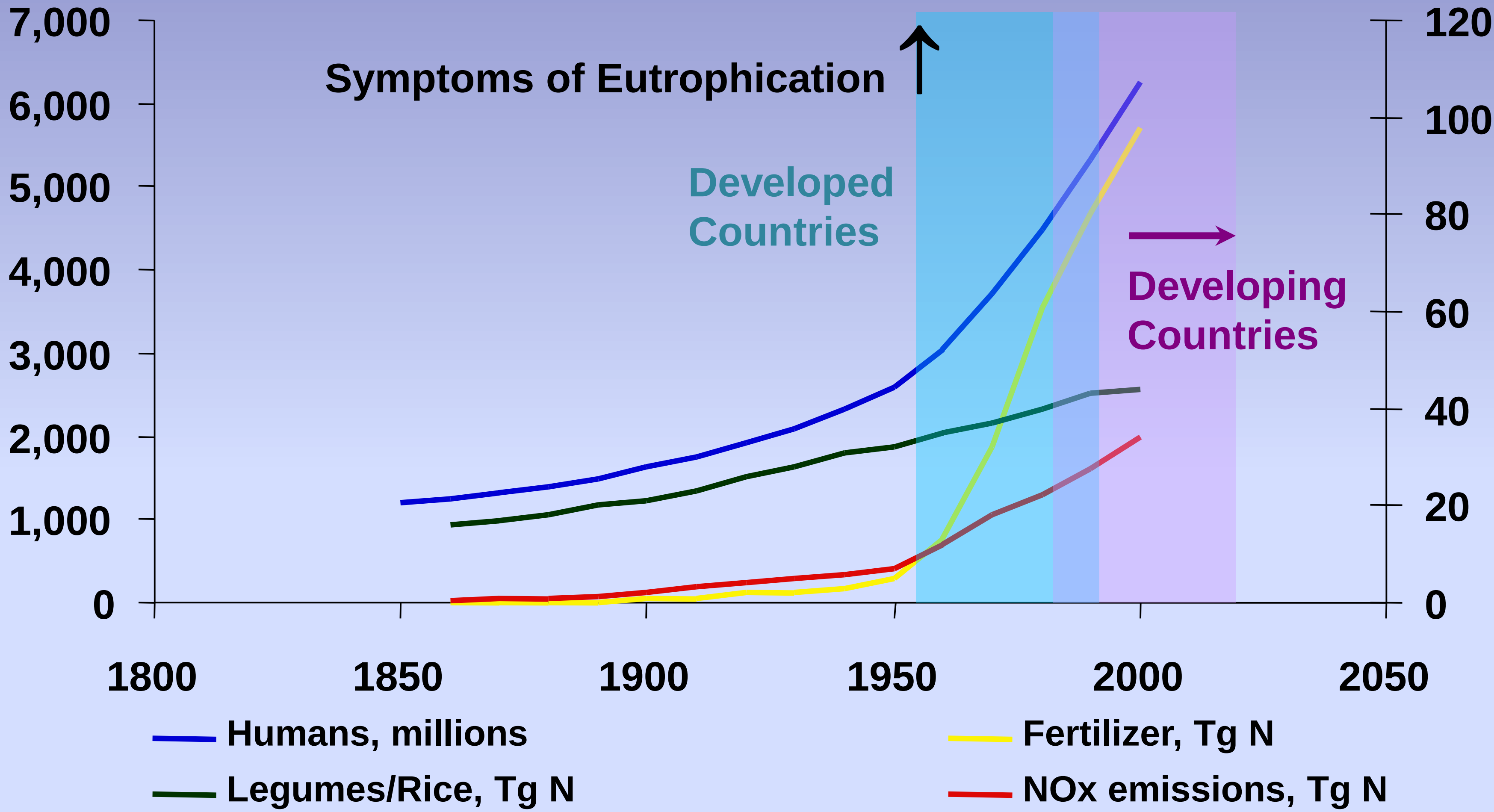


Conley et al., 2009



Baltic Sea and Coastal Waters

They are increasing



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

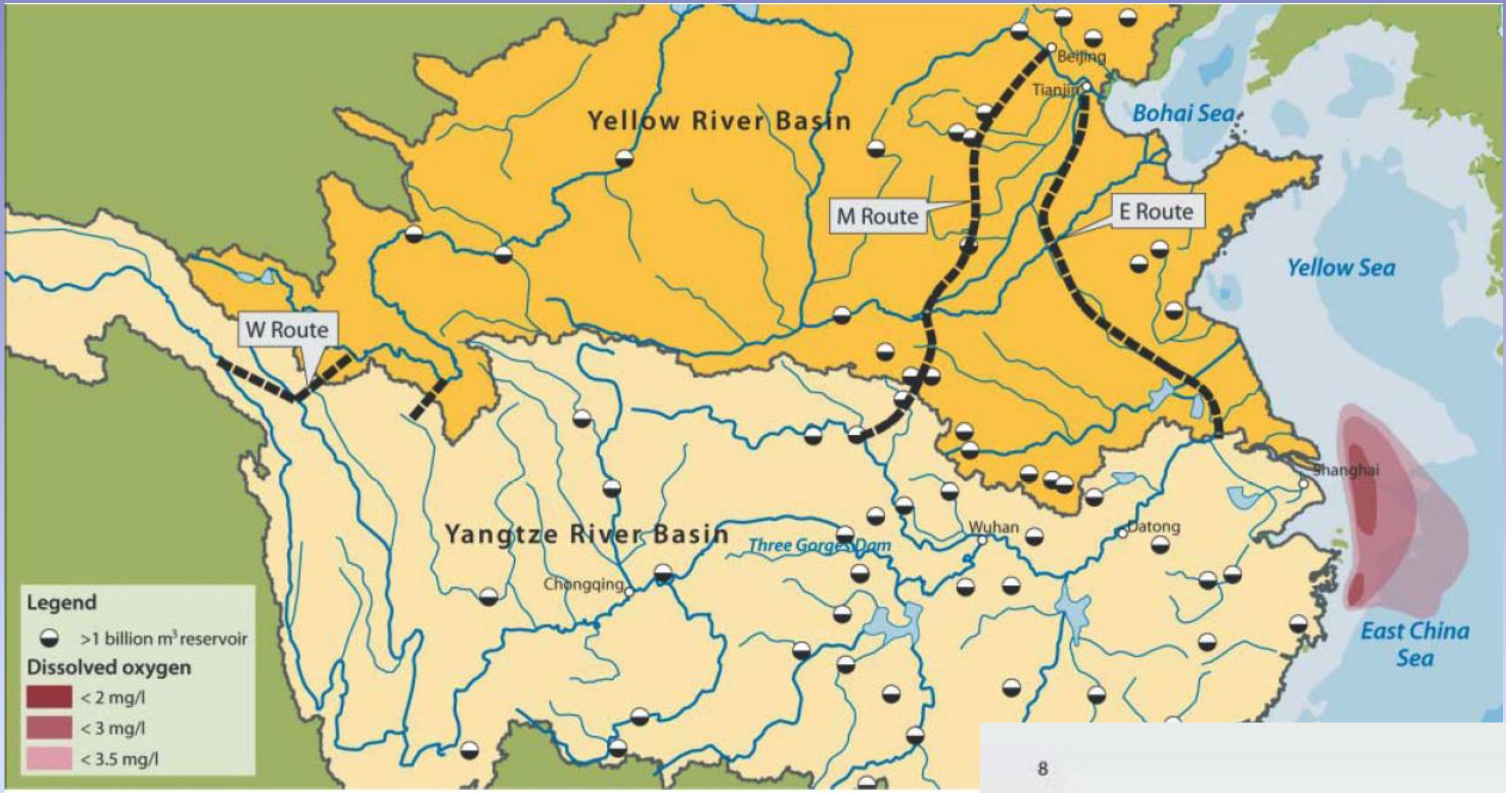


Figure 3. The Yangtze River drainage basin and the estimated hypoxy areas in the ECS (3

Li and Daler 2004

East China Sea

$14,000\ km^2$
Annual Hypoxia

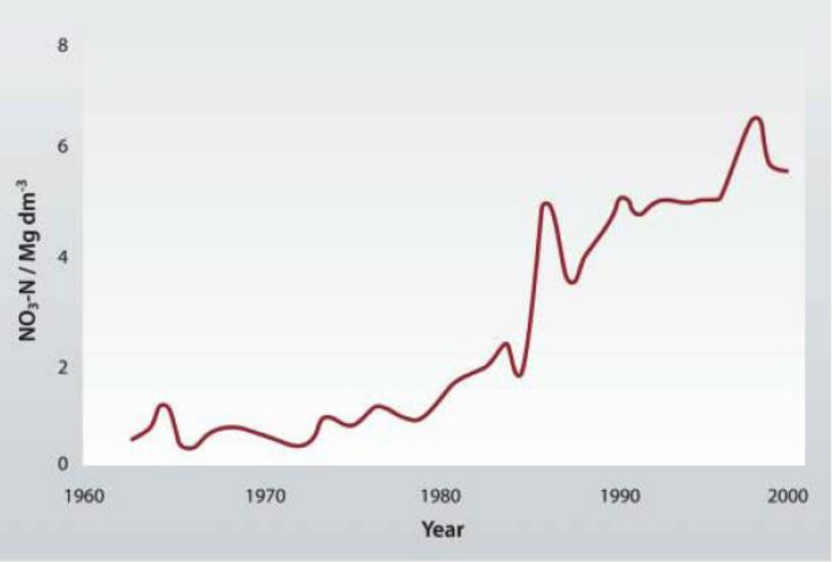
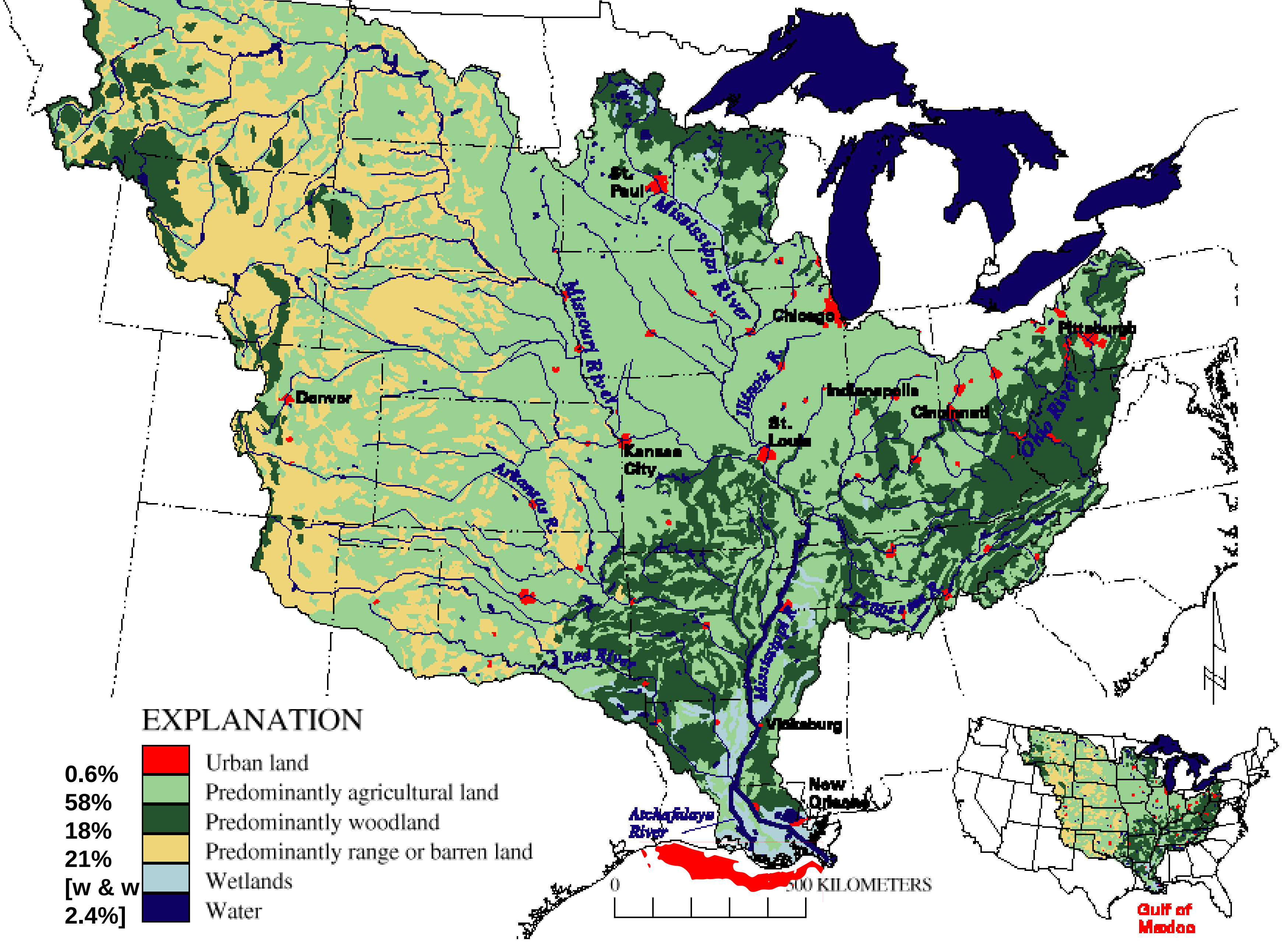


Figure 5. Historical variations of nitrate concentrations at Datong station (33).

“Our rivers are too large to have nutrient problems and dead zones”

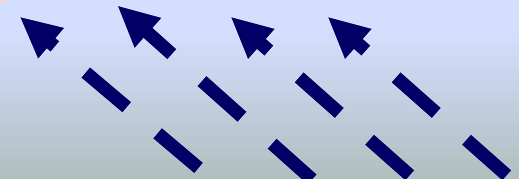
Land-Ocean Interactions in the Coastal Zone (LOICZ/IGBP) Open Science Meeting, Bahia Blanca, Argentina, November 1999

Goolsby et al. 1999, Rabalais 2002



Mississippi River – Gulf of Mexico Ecosystem Continuum

Effects are more far reaching than suspended sediment plume, esp. N & somewhat P



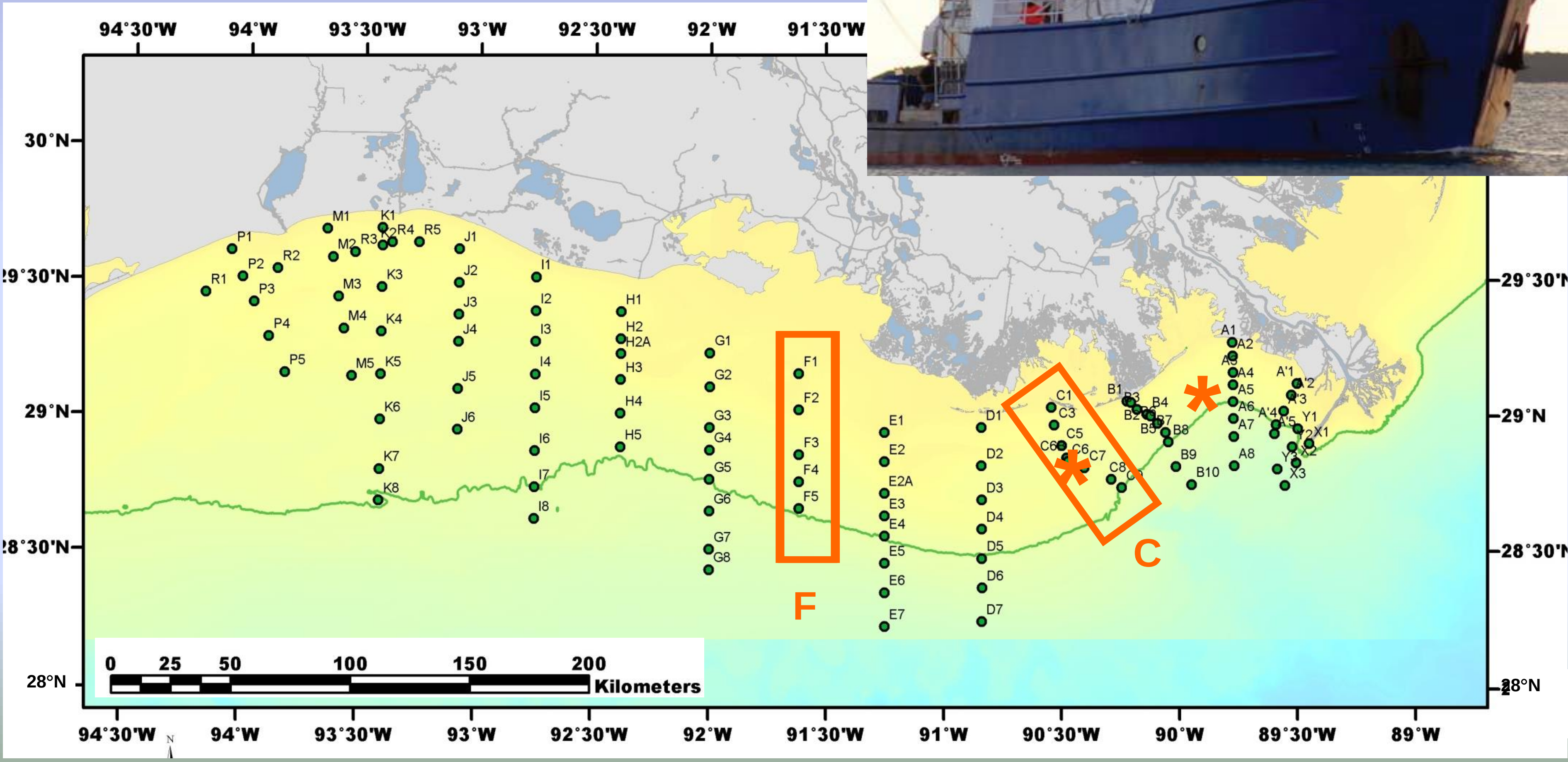
dominant wind direction

Source: N. Rabalais

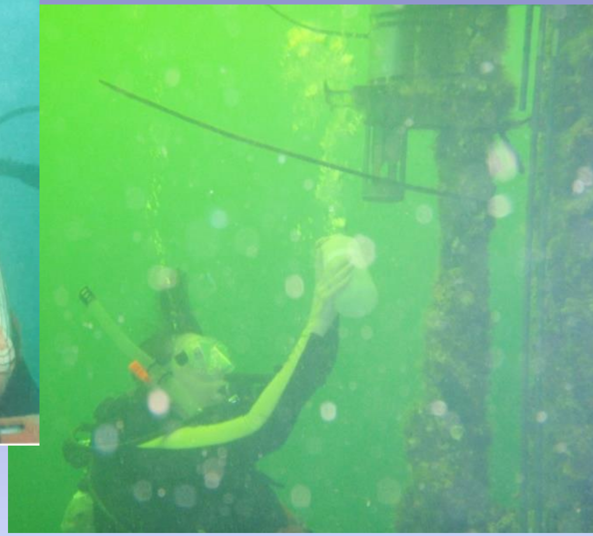
•Mid-summer shelfwide cruise

•Monthly lines C and F

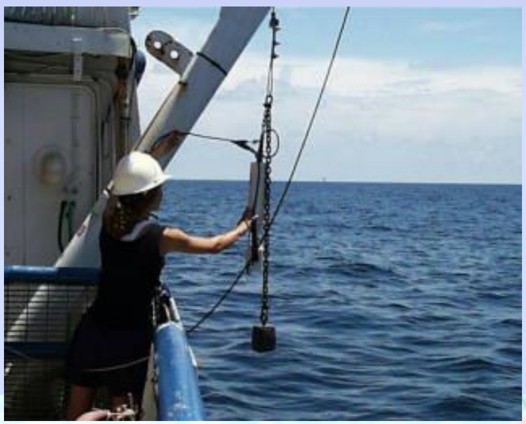
•Deployed oxygen meters



Extensive Field Measurements

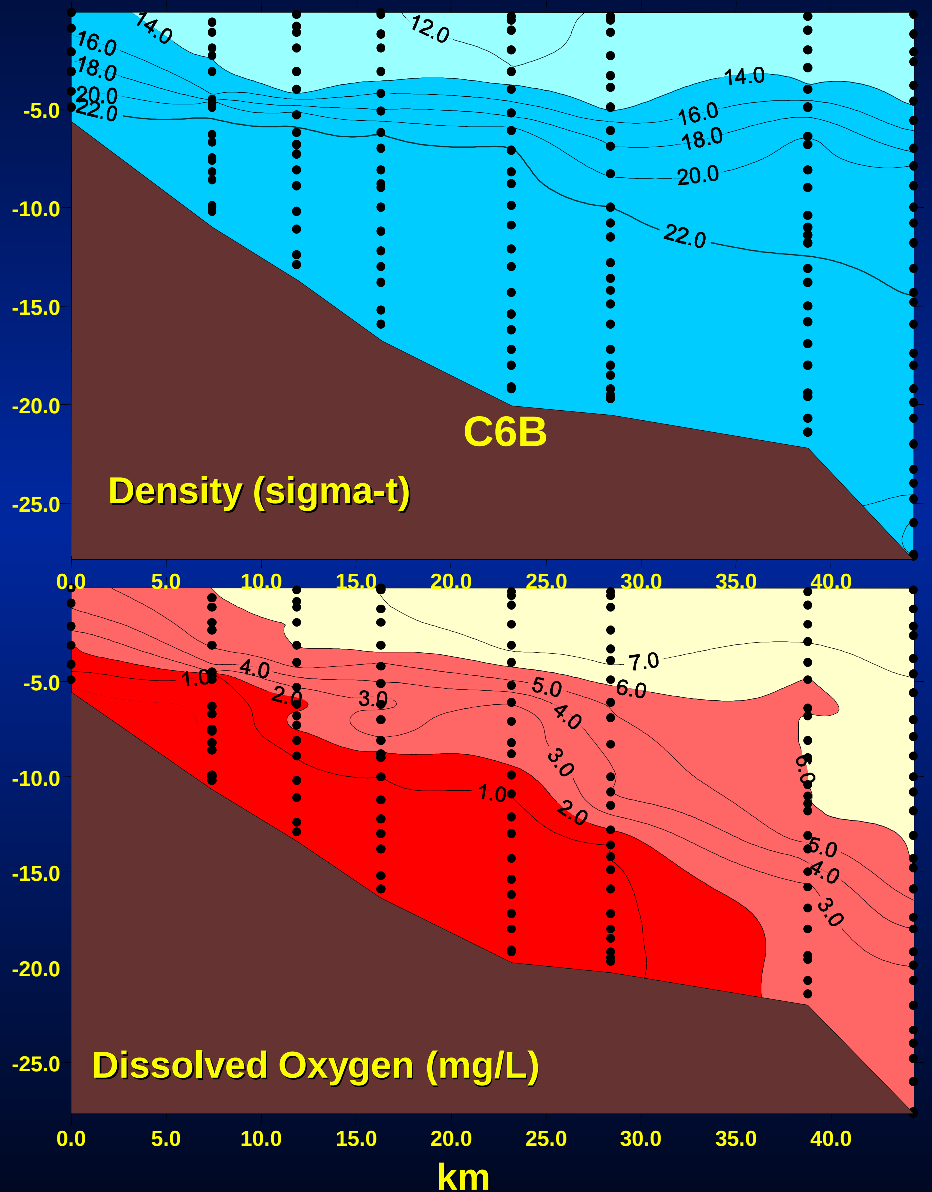



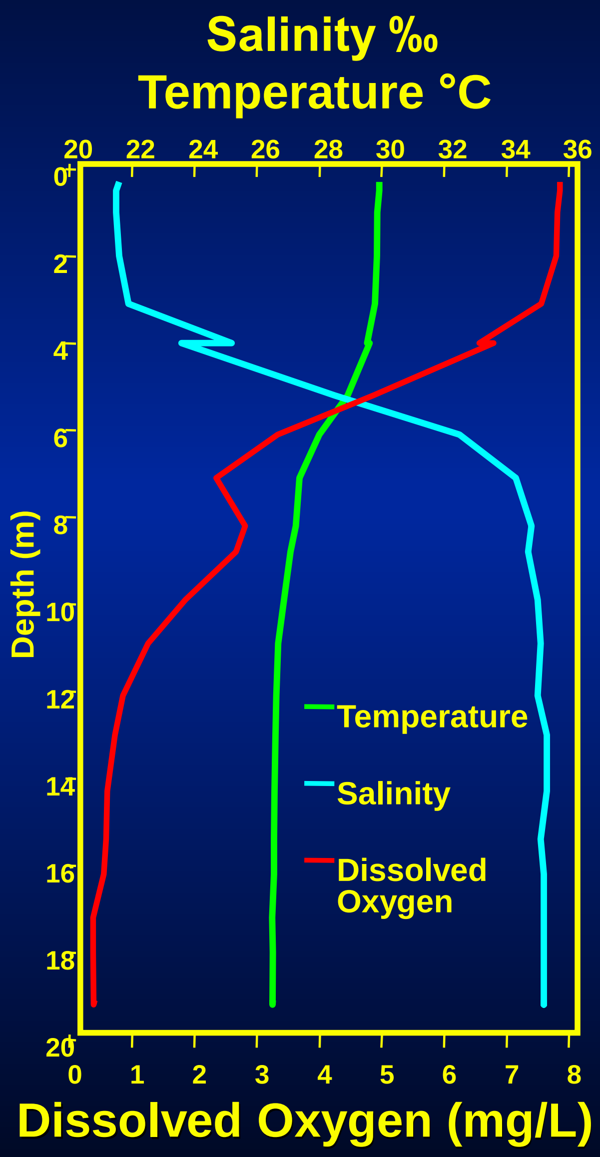




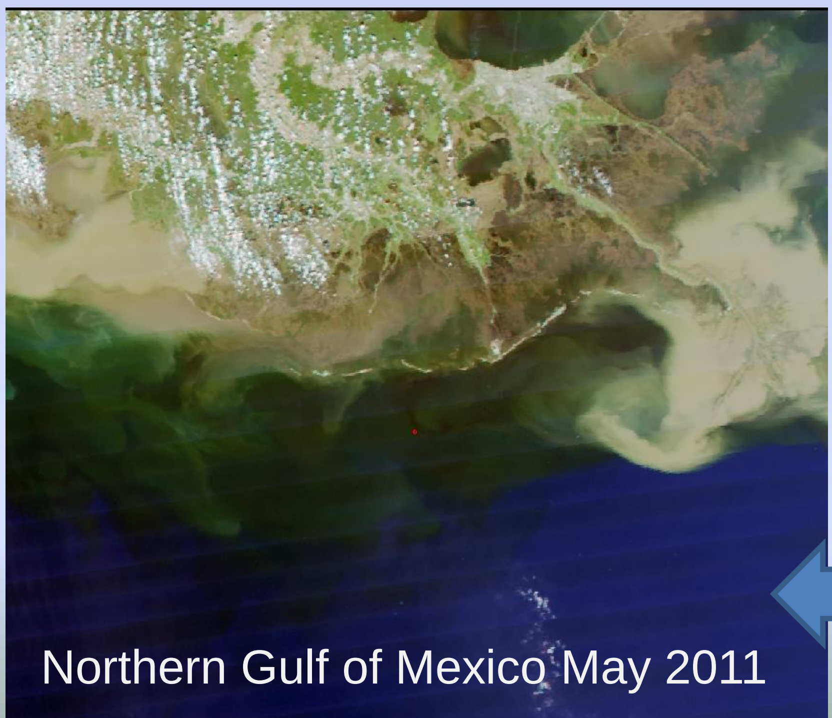
Stratification

(mid-summer)





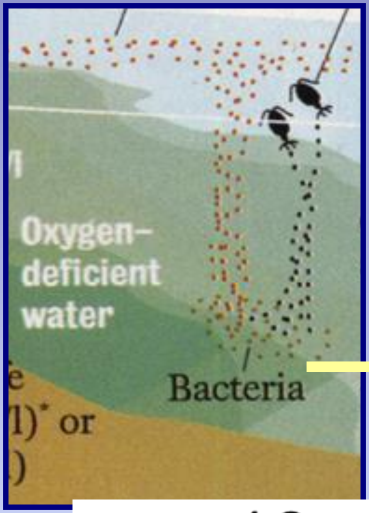
Harmful and Noxious Algal Blooms



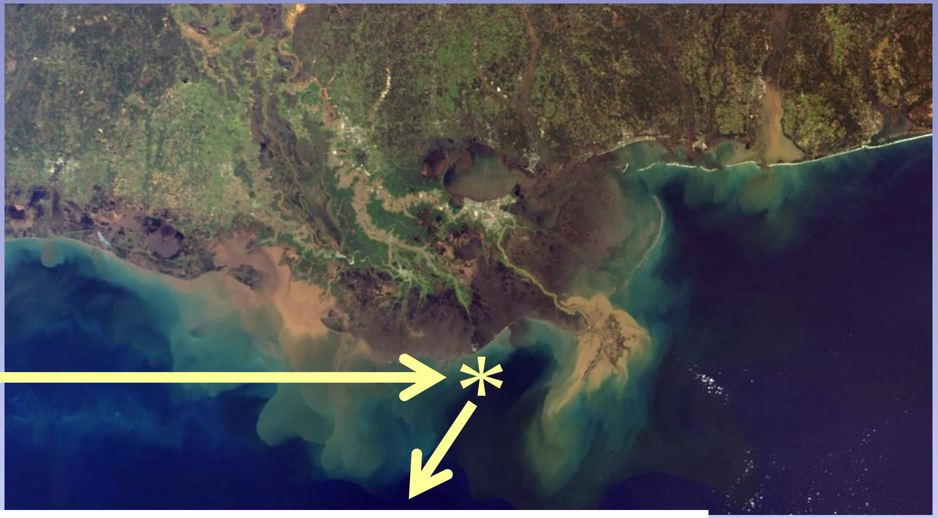
Northern Gulf of Mexico May 2011

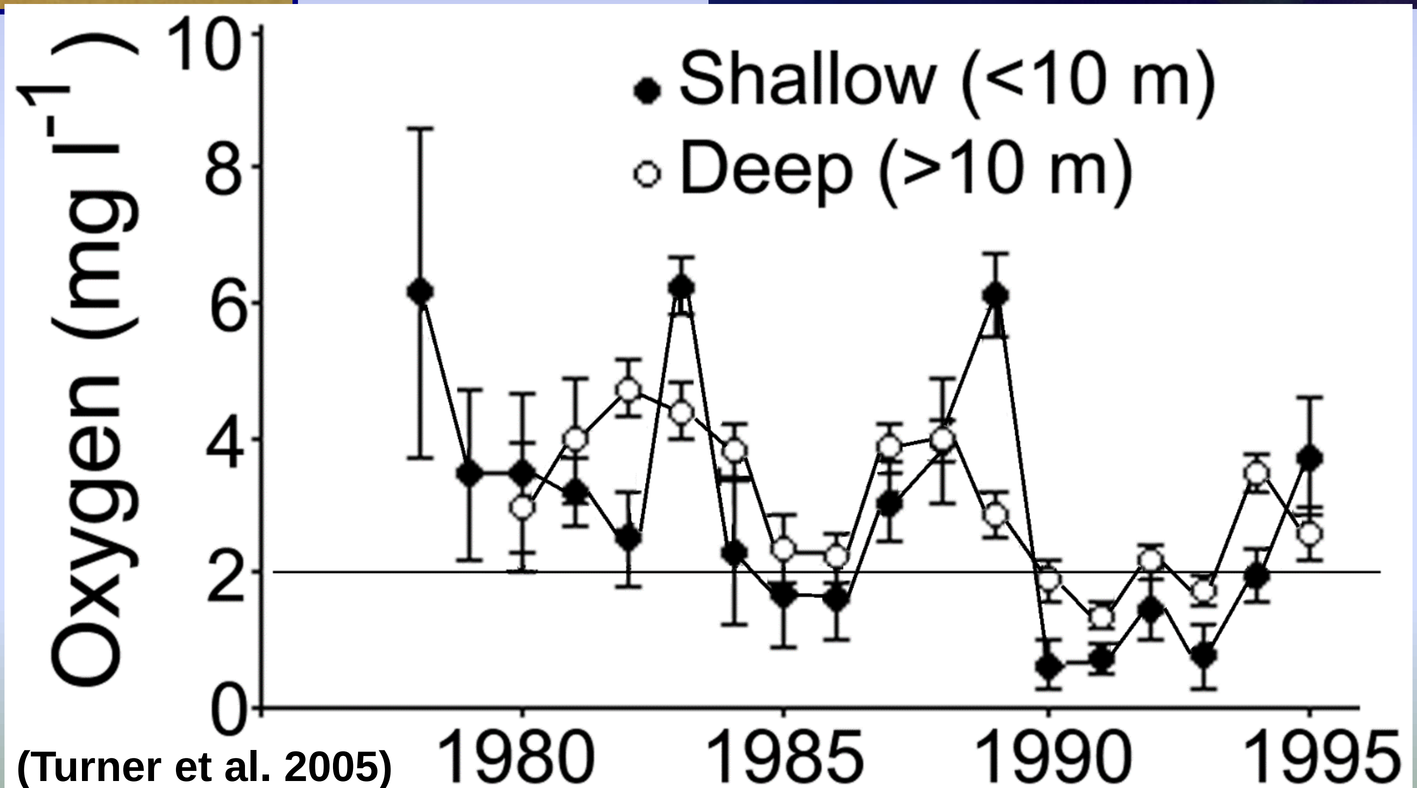
Heterosigma akashiwo

Nutrients, Increased Growth, Low Oxygen



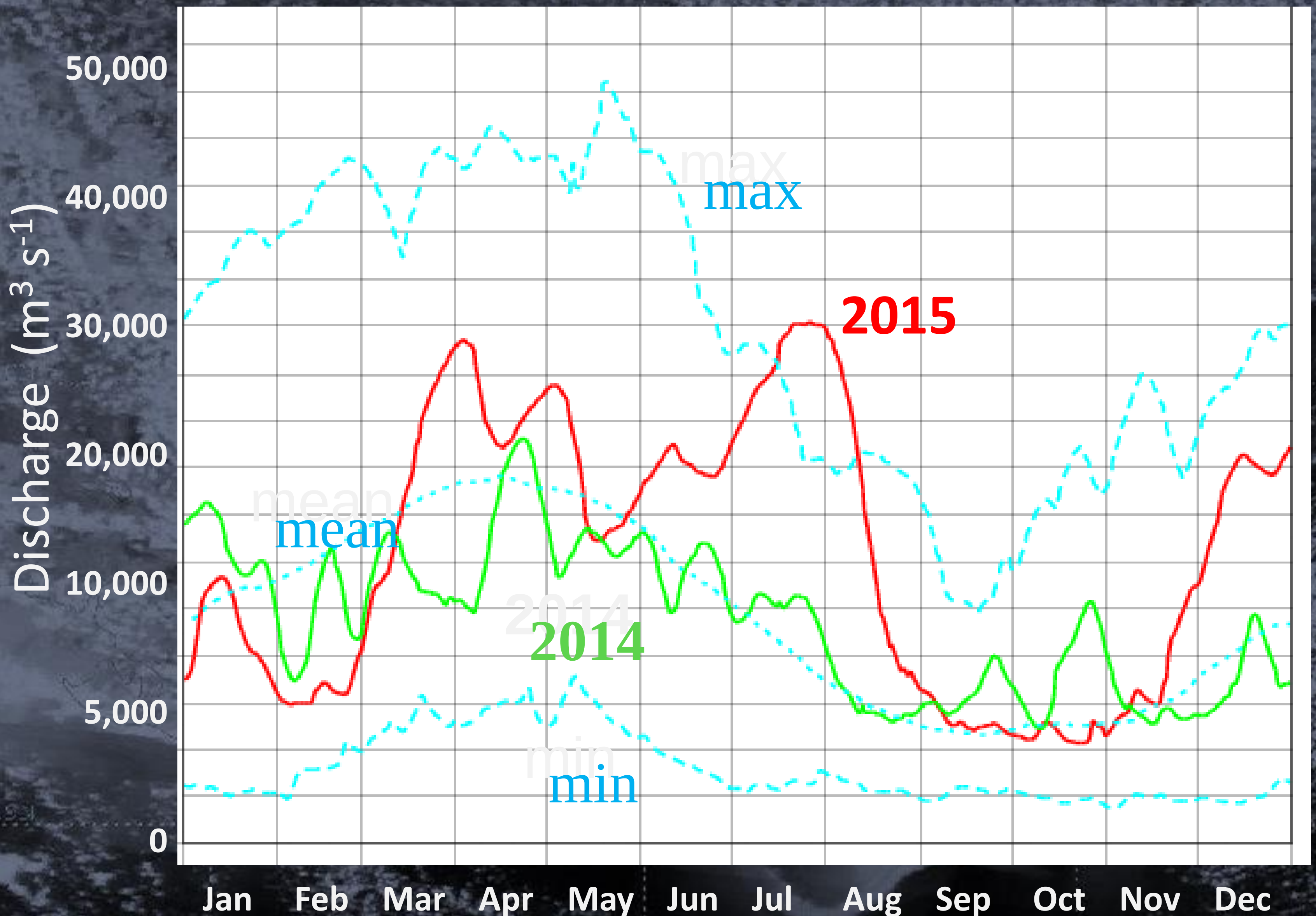
50% C↓

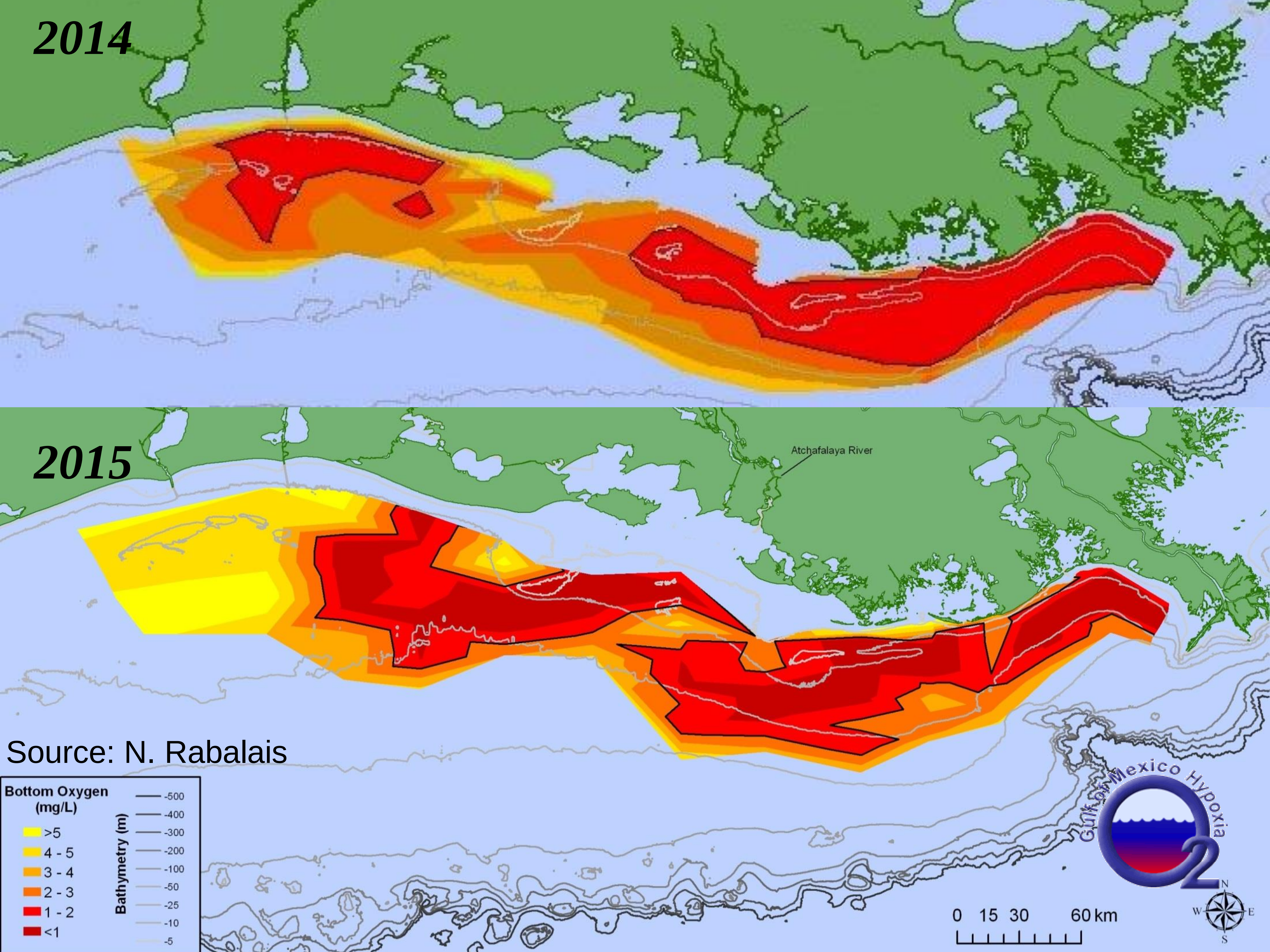


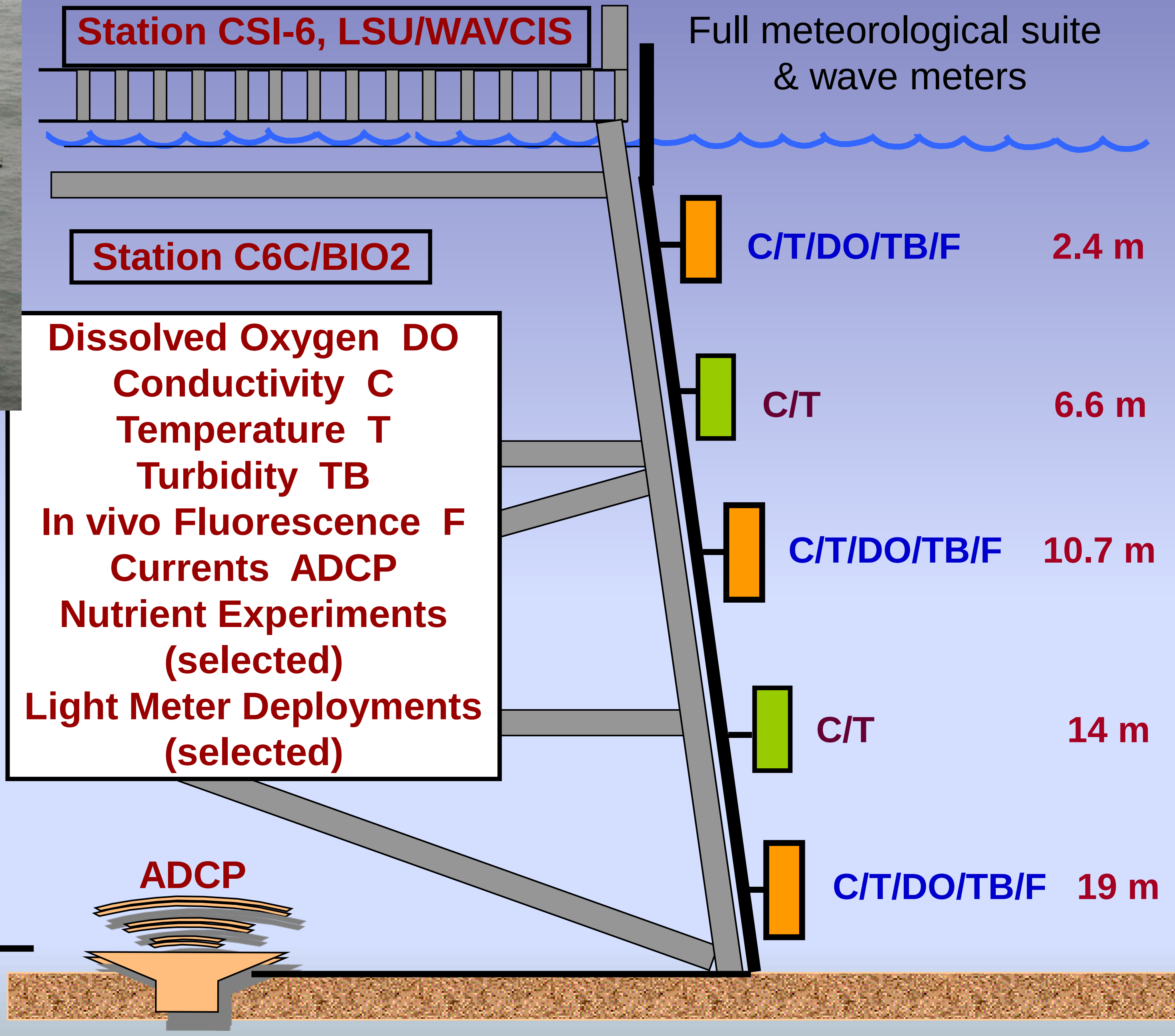


(Turner et al. 2005)

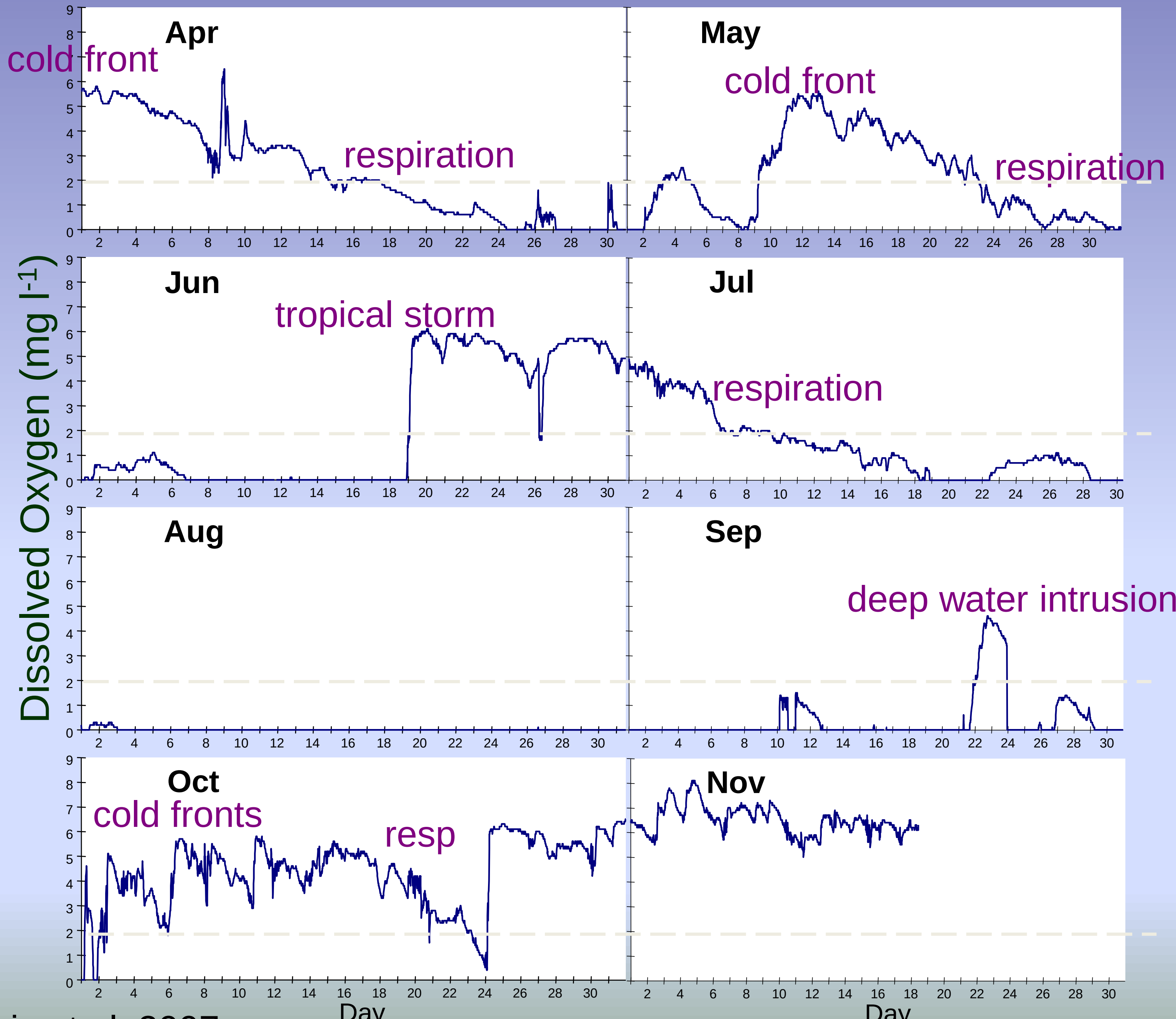
Mississippi River Discharge at Tarbert Landing, 1935 – 2015




2014
2015
Atchafalaya River
Source: N. Rabalais
Bottom Oxygen (mg/L)
>5
4 - 5
3 - 4
2 - 3
1 - 2
<1
Bathymetry (m)
-500
-400
-300
-200
-100
-50
-25
-10
-5
Gulf of Mexico Hypoxia
0 15 30 60 km
N
W
E
S



Source: N. Rabalais



Rabalais et al. 2007

More Nutrients >>>

More Phytoplankton >>>

More Carbon Reaches the Bottom >>>

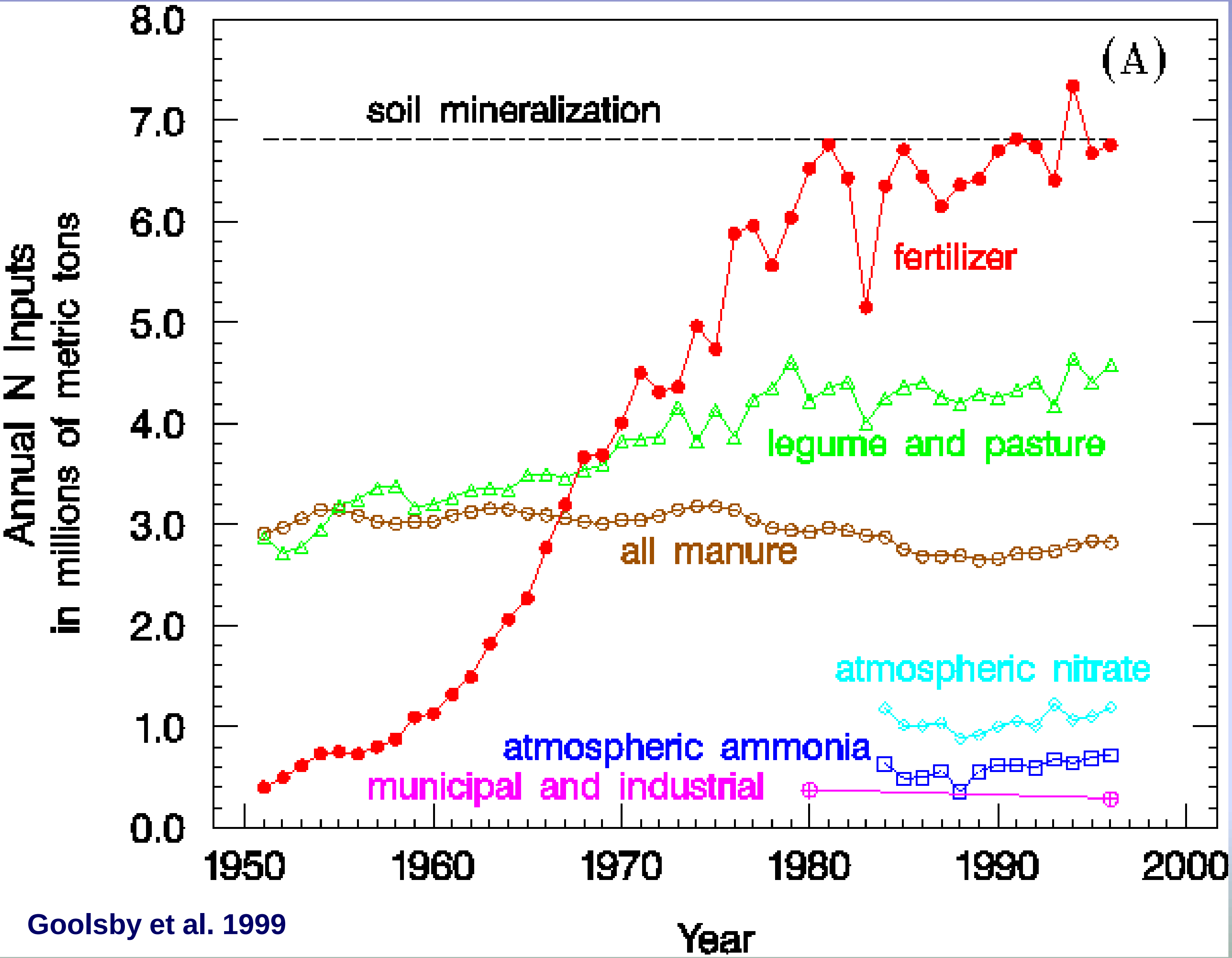
More Oxygen Consumed >>>

More Hypoxia

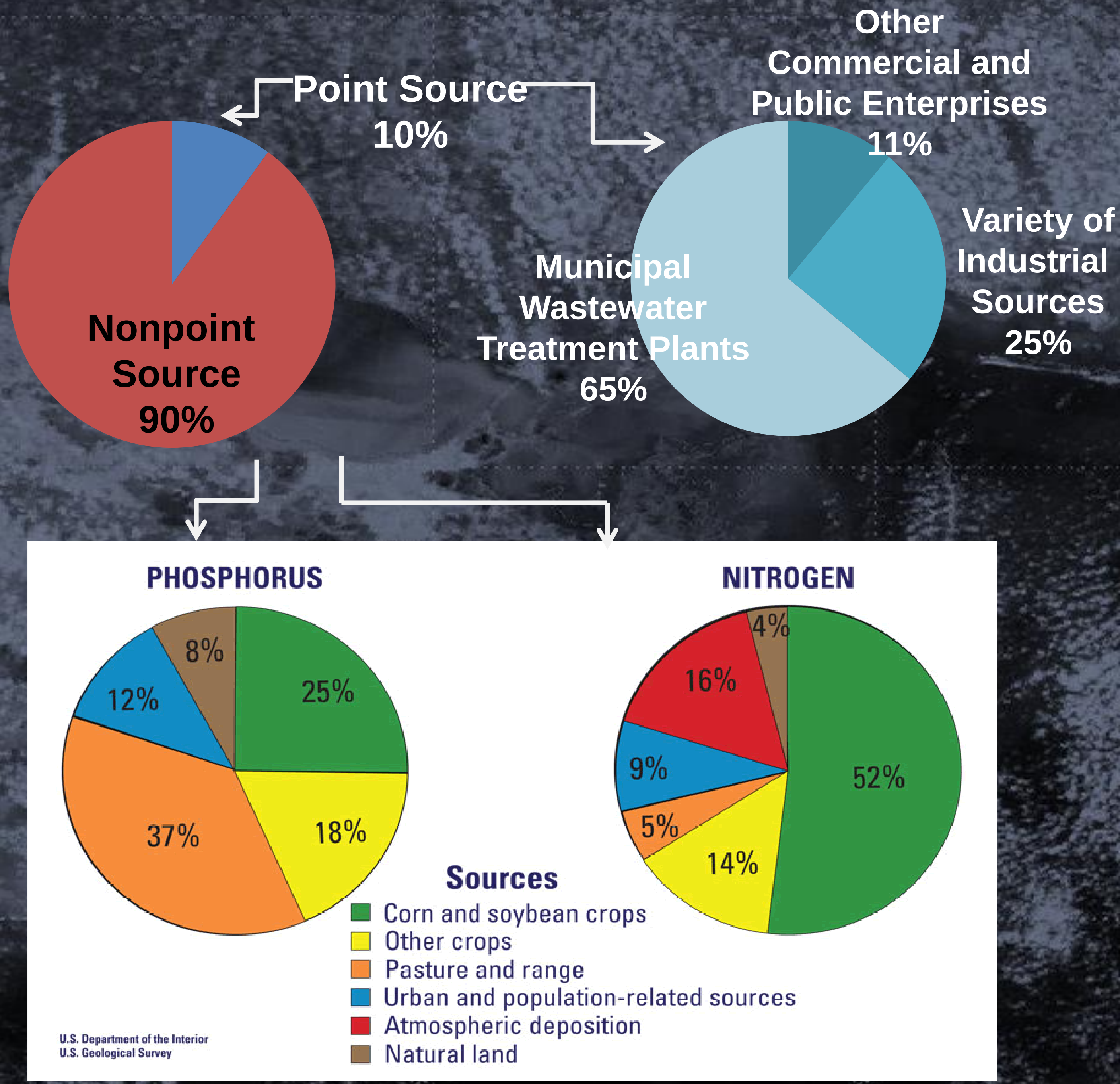
Verified by Paleoindicators

Photo: N. Rabalais, LUMCON

Nitrogen Inputs to the Mississippi Watershed

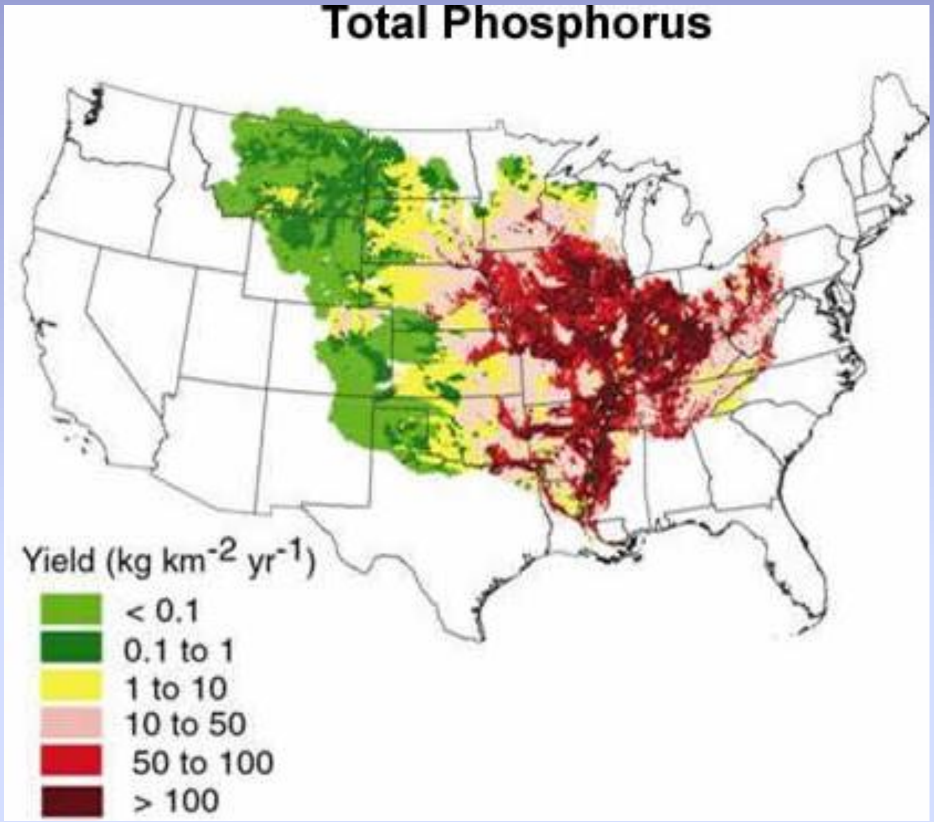


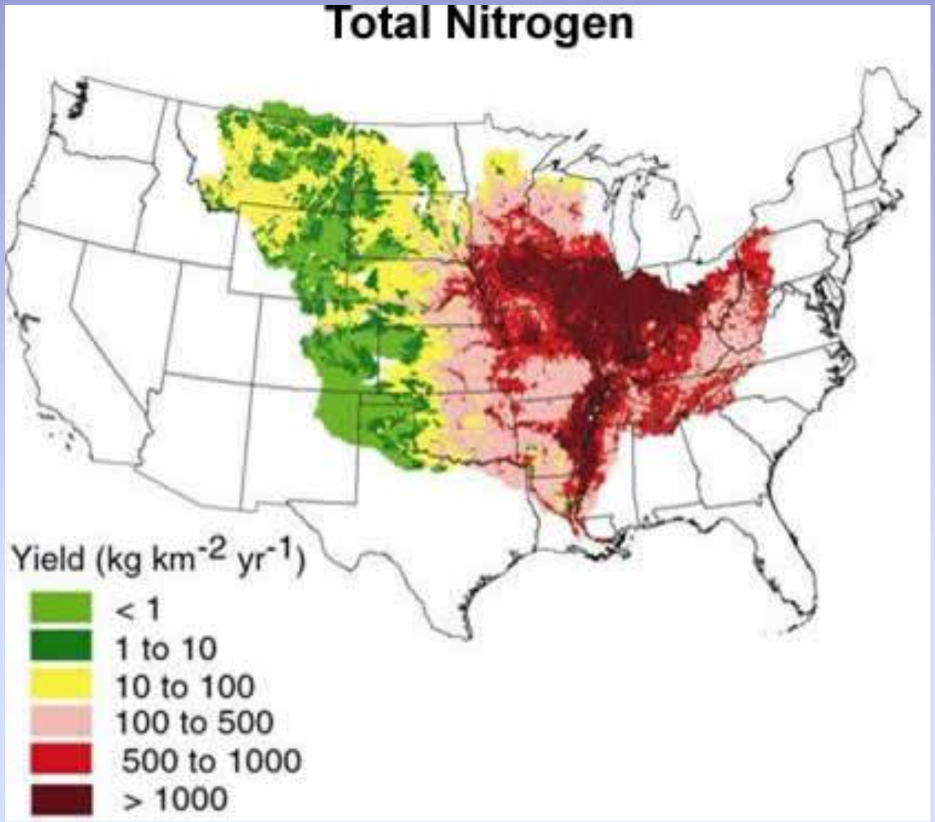
Goolsby et al. 1999



Alexander et al. 2008 & http://water.usgs.gov/nawqa/sparrow/gulf_findings/

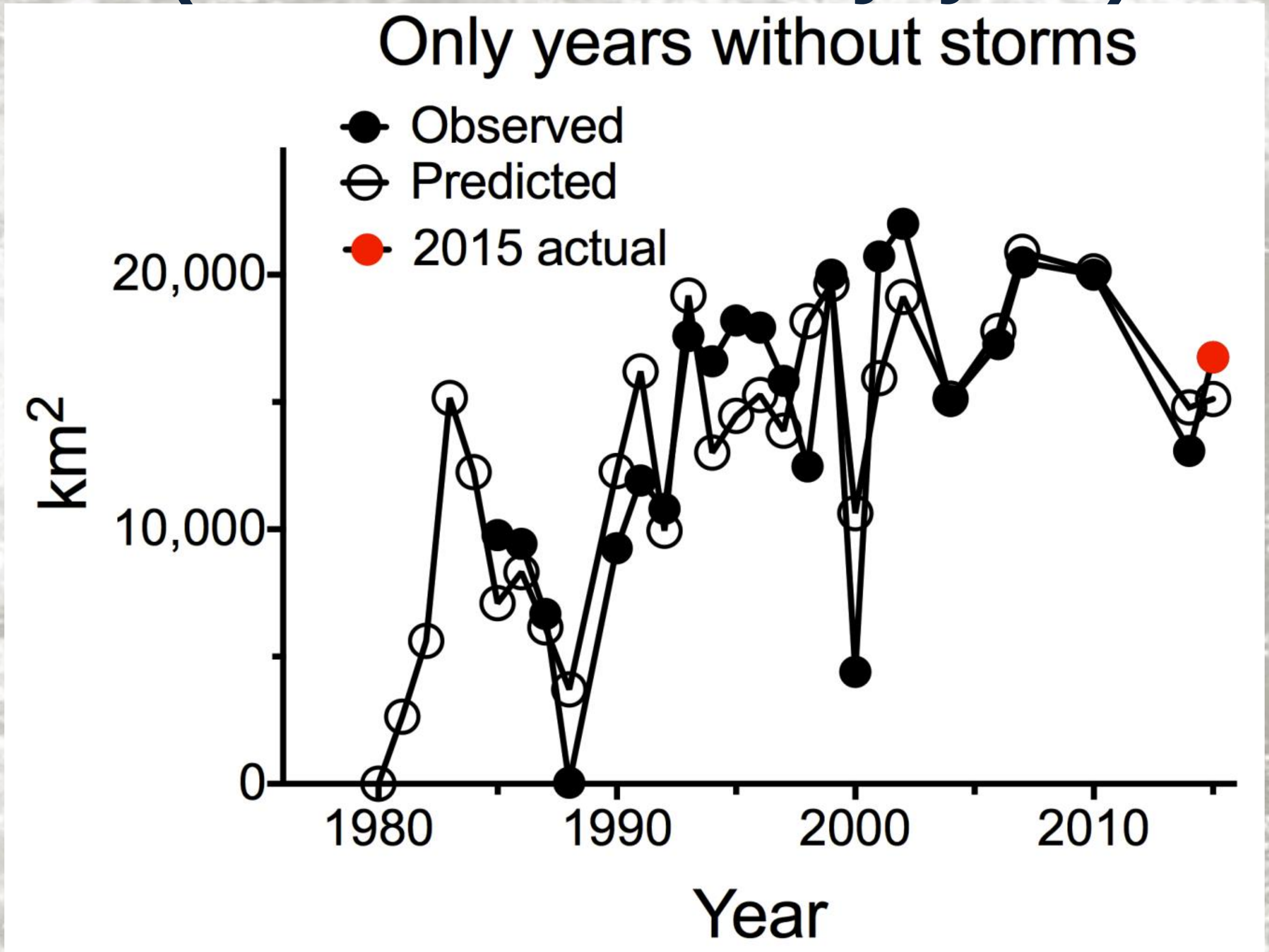
Nutrient Yields from the Mississippi Basin



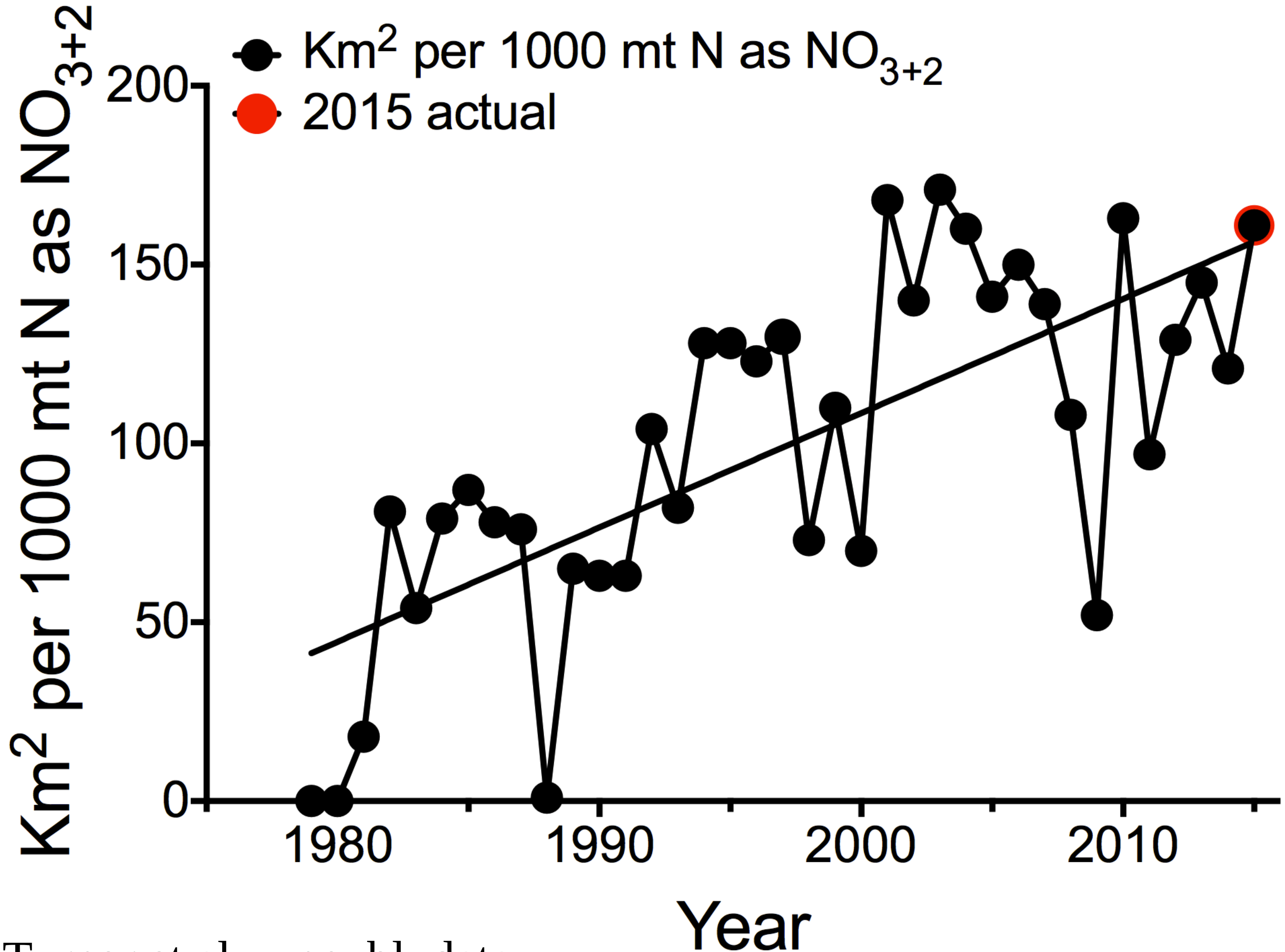


We know where it comes from, what it does, and what we should do.
Unfortunately, this is not the EU.
Multi-jurisdictional authorities and engrained social structure create a quagmire that does not overcome the inertia for nutrient mitigation and control.

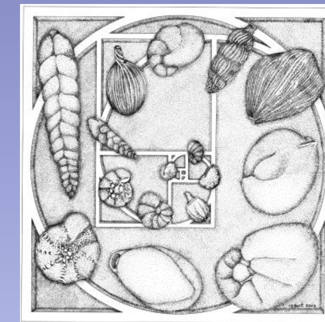
Predicting Hypoxia in summer (nitrate flux in May, year)



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.

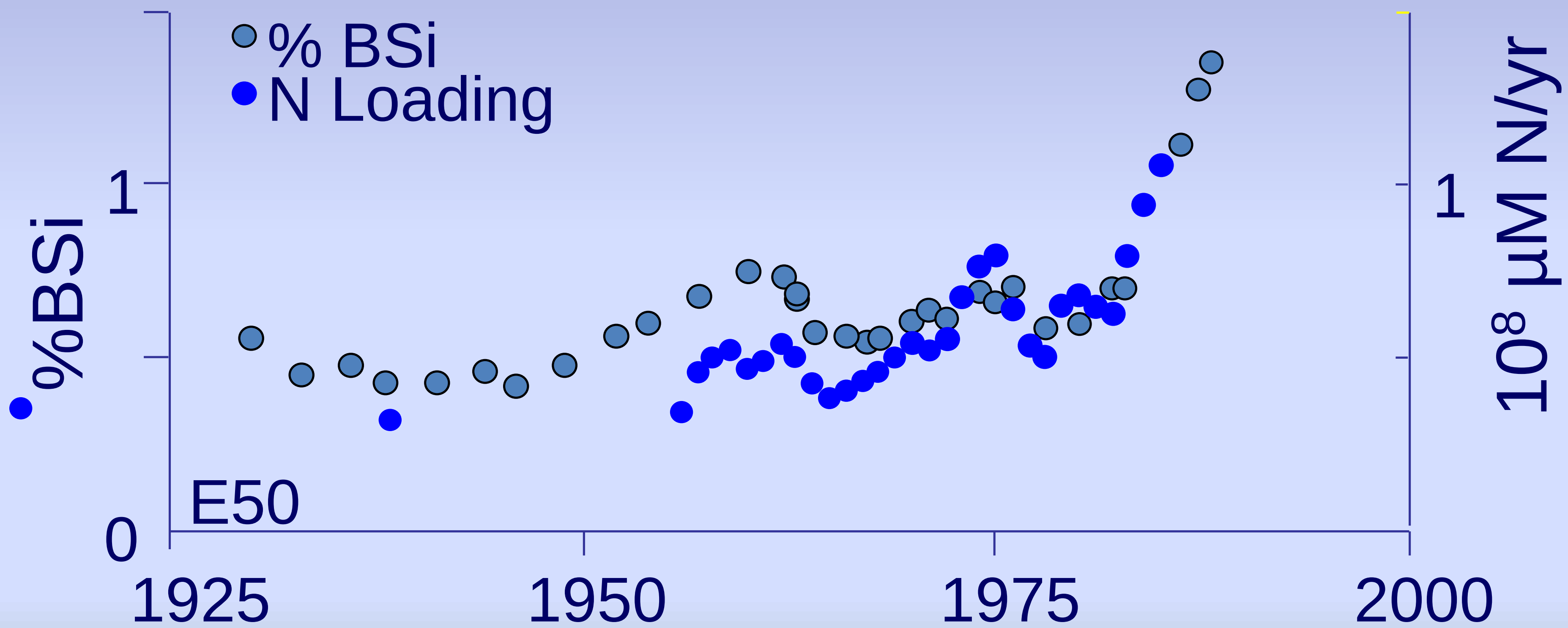


Turner et al., unpubl. data



Gulf of Mexico Hypoxia

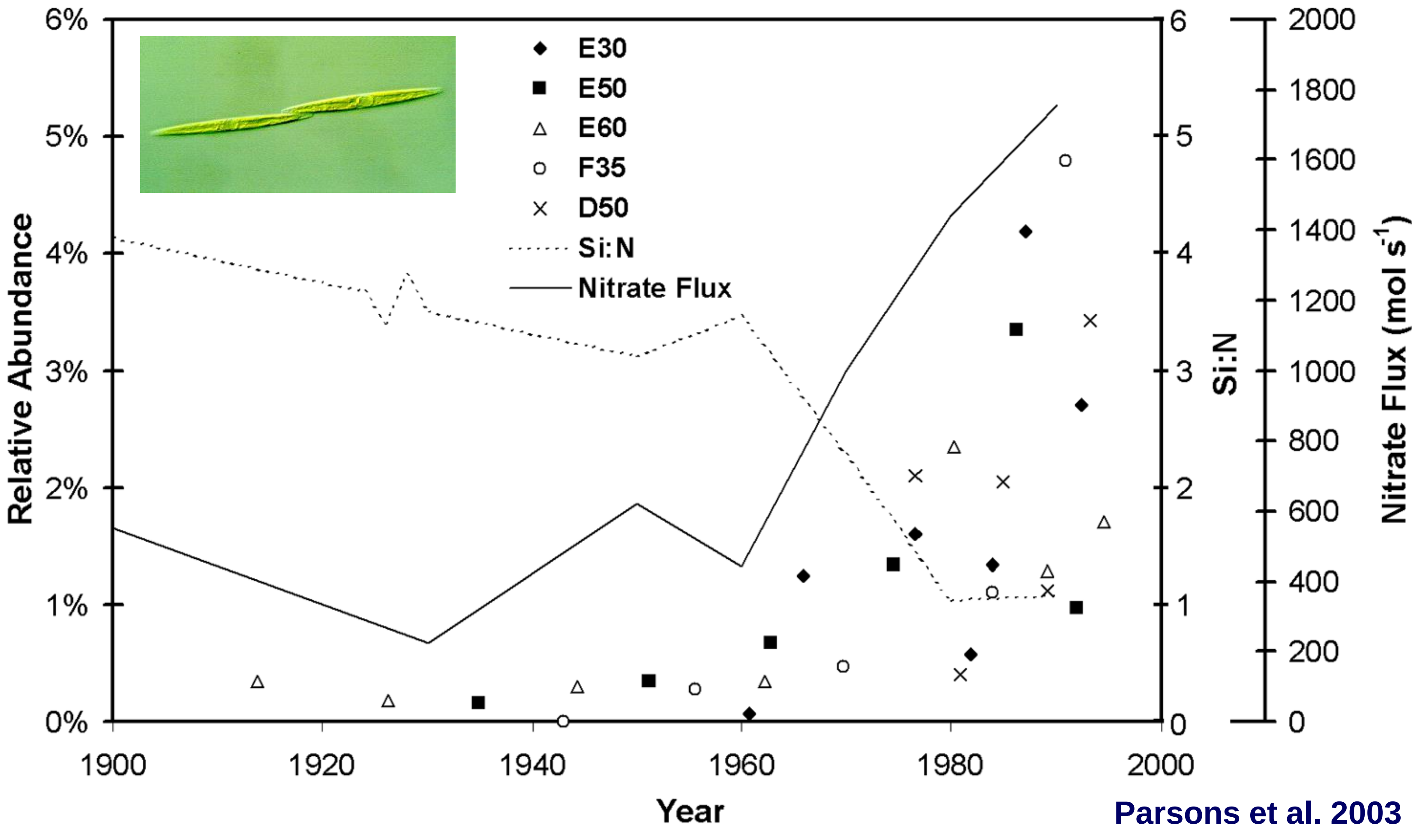
Relationship Between Biogenic Silica and Nutrient Loading



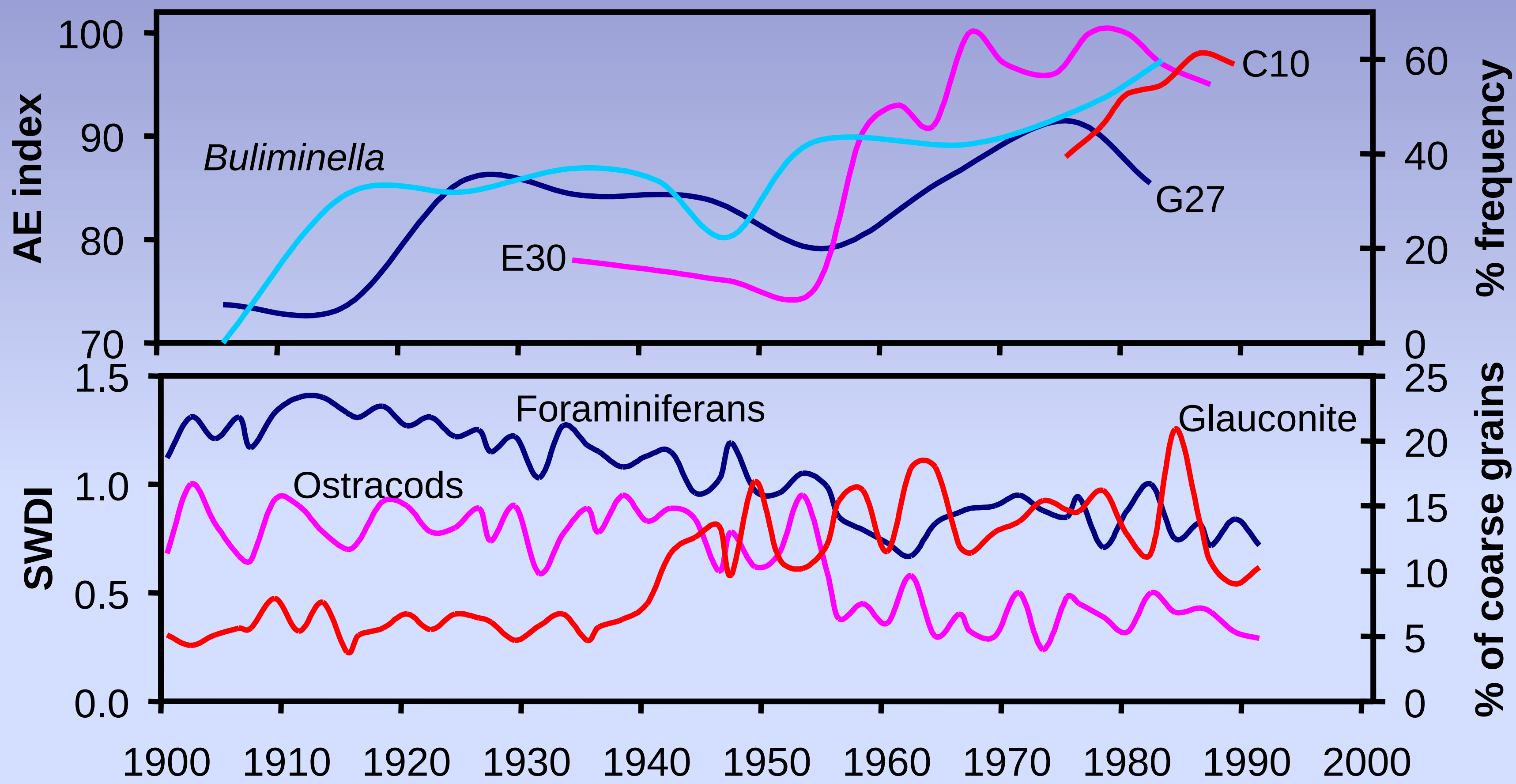
Turner and Rabalais 1994

A shift from heavily silicified to less silicified, including the HAB *Pseudo-nitschia*

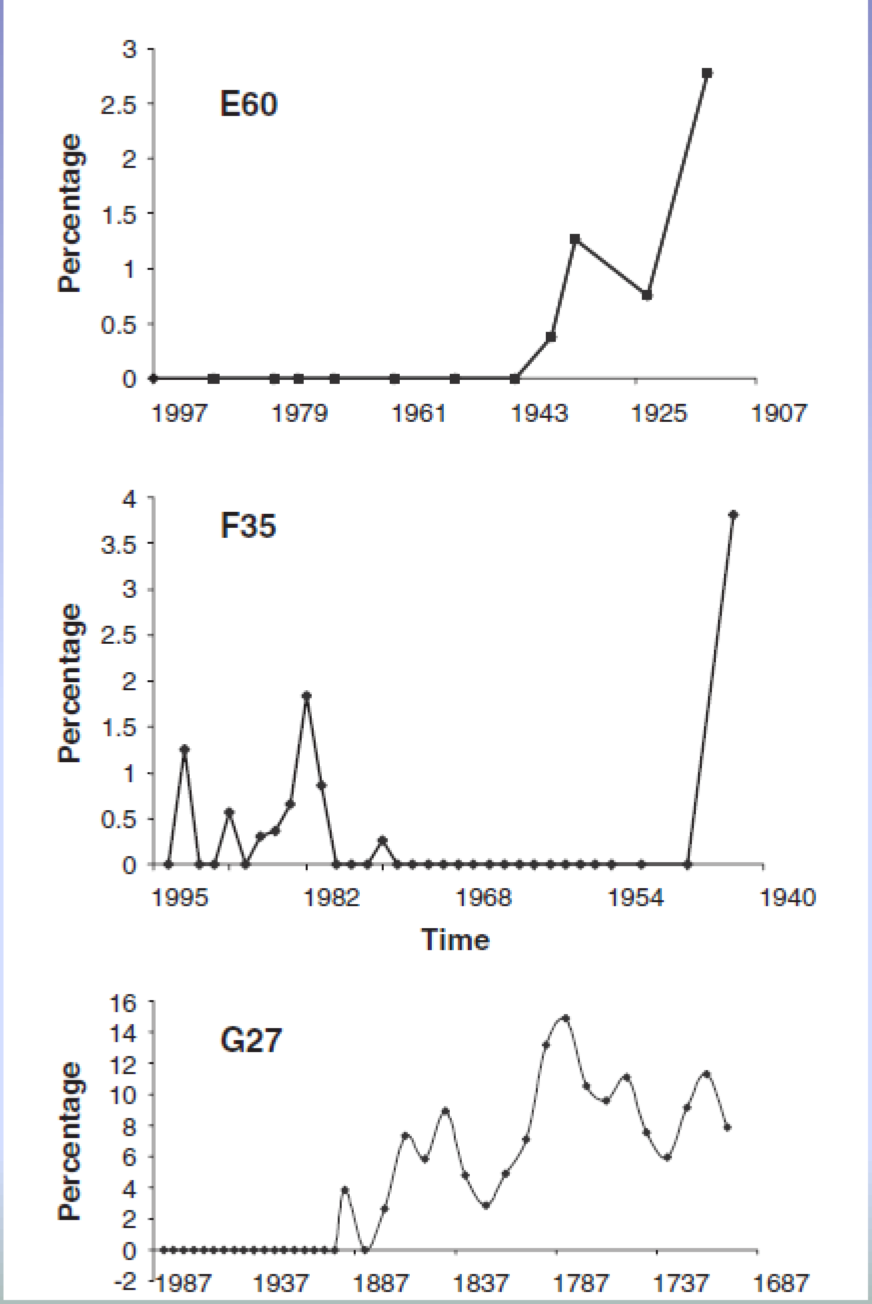
(indicates potential Si limitation but competitive advantage of *Pseudo-nitzschia* with increased nitrogen)



Parsons et al. 2003



AE index
100
90
80
70
Buliminella
E30
G27
C10
60
40
20
0
% frequency
SWDI
1.5
1.0
0.5
0.0
Foraminiferans
Ostracods
Glauconite
25
20
15
10
5
0
% of coarse grains
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000



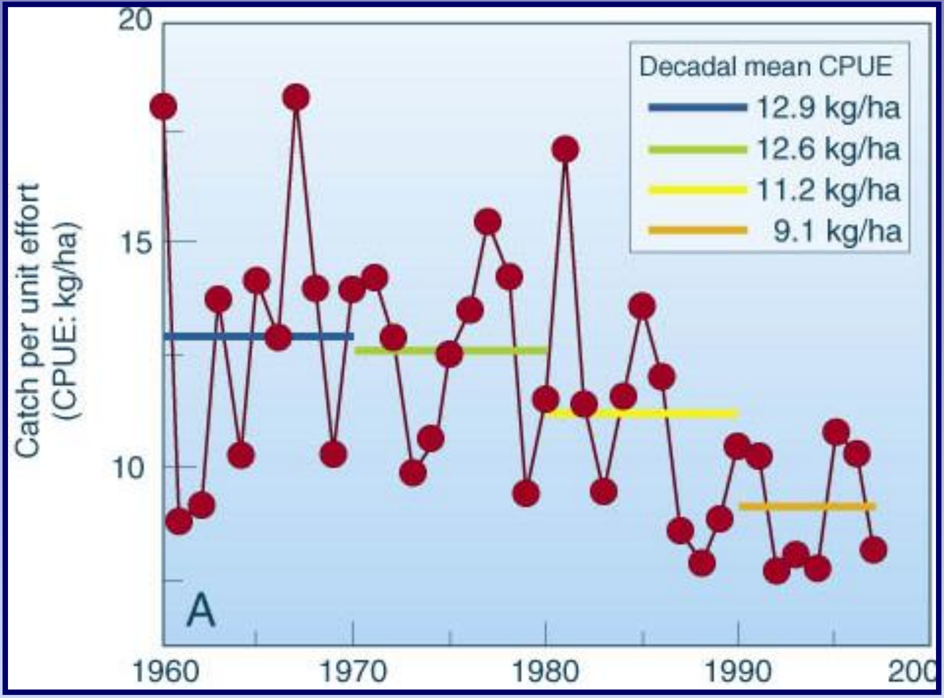
Quinqueloculina

Not an abundant species but a definite decline

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

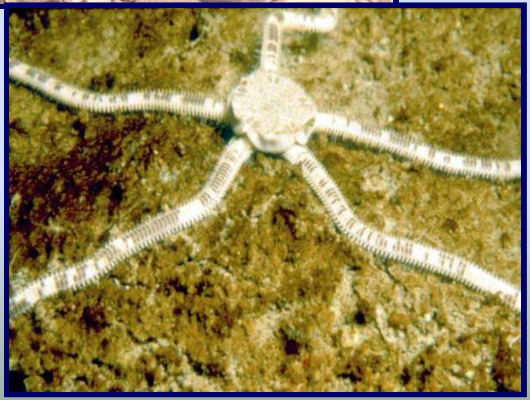
An increase of hypoxia in time with depth?

Platon et al. 2005

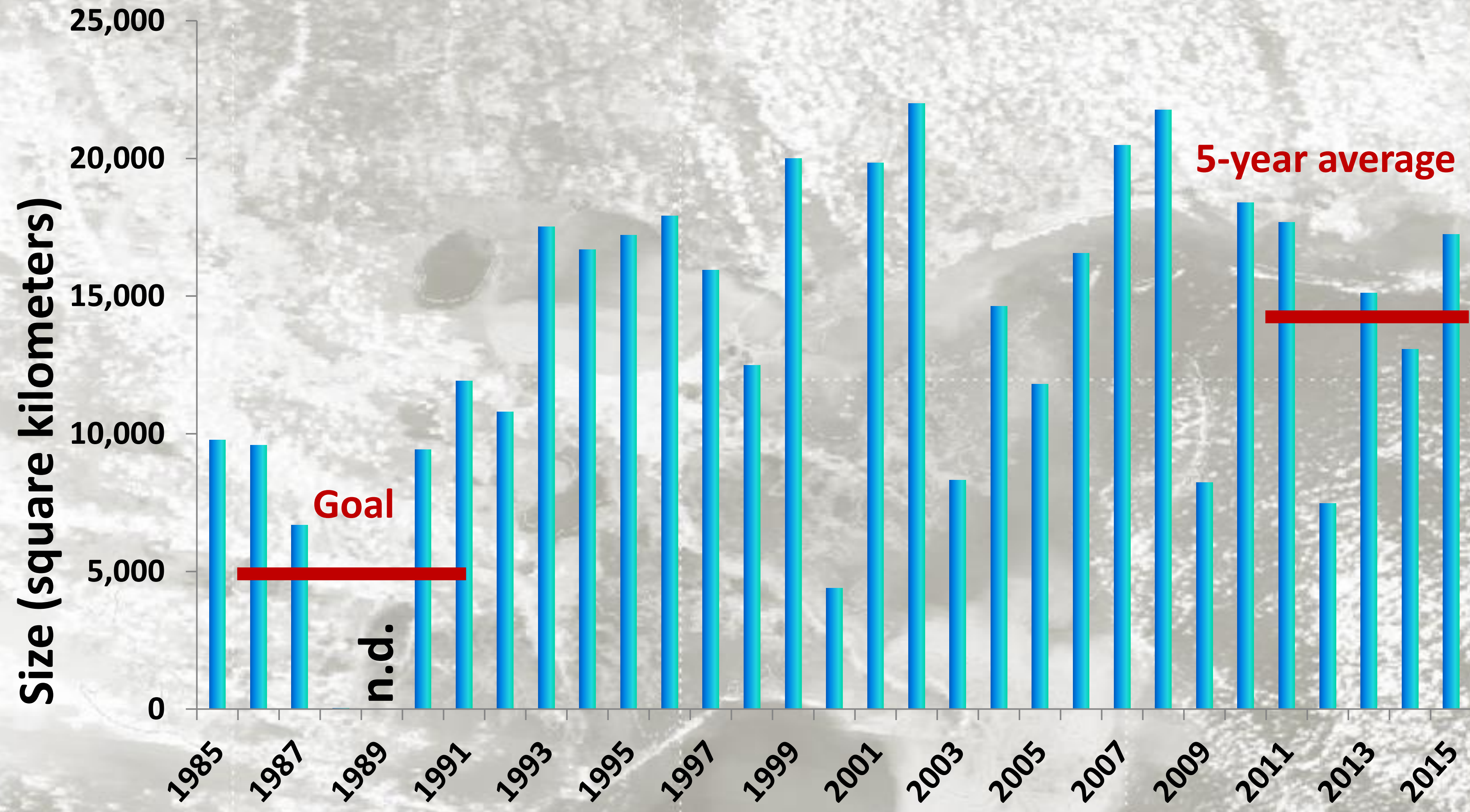


The Consequences

- Fisheries resources at risk
- Altered migration
- Reduced habitat
- Changes in food resources
- Susceptibility of early life stages
- Growth & reproduction

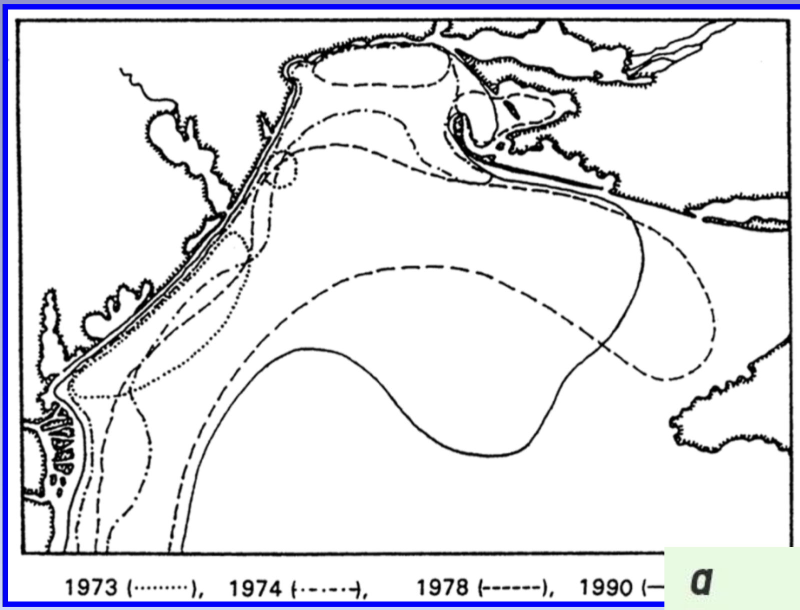


Size of bottom-water hypoxia in mid-summer



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

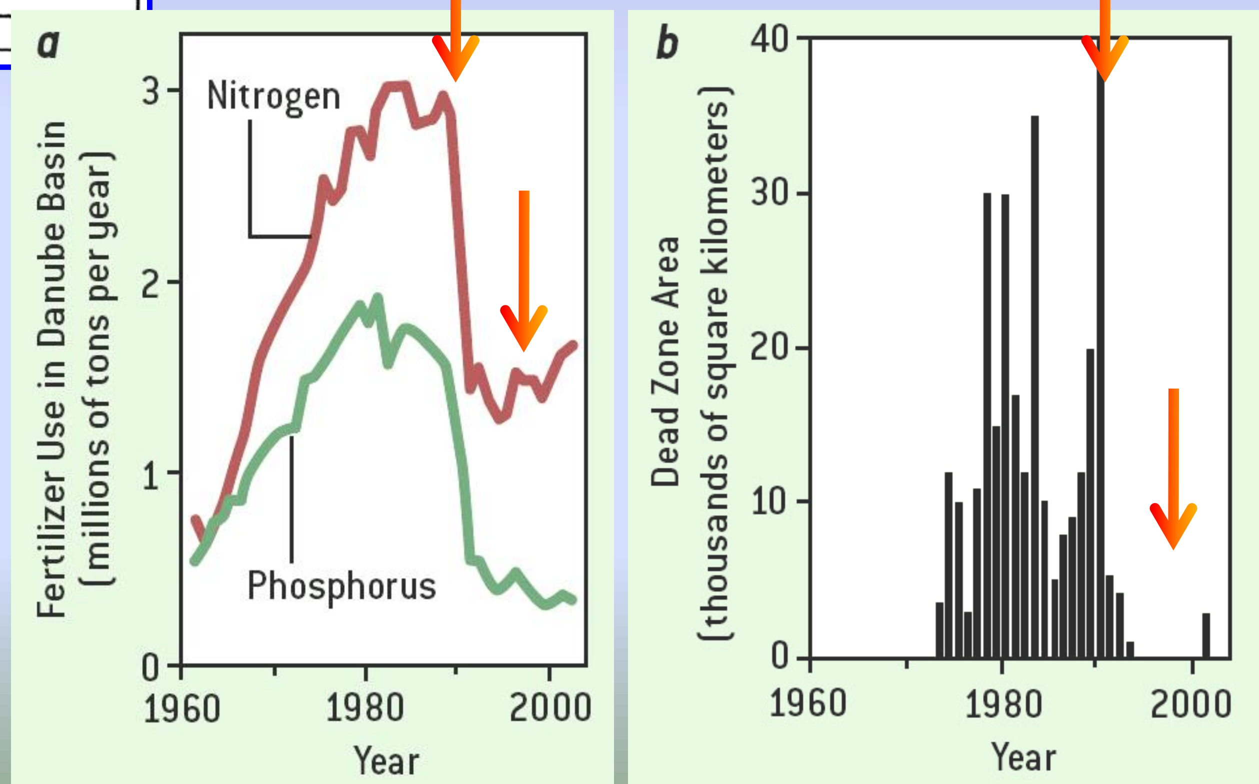


Zaitsev 1992

Northwestern Shelf
Black Sea

Hypoxic Area Up to 40,000 km^2
Currently, non-existent or minimal

N and P Loads Correspond to Fertilizer Use

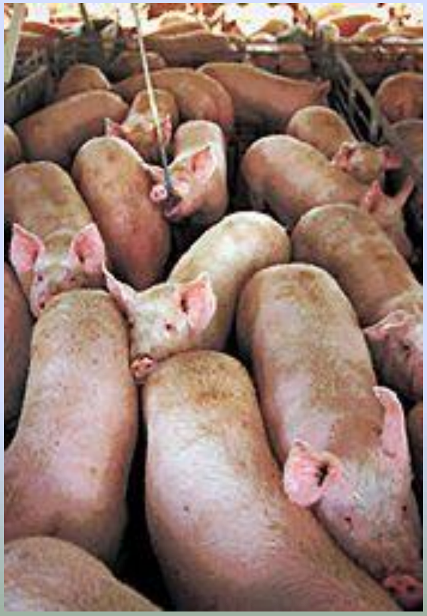


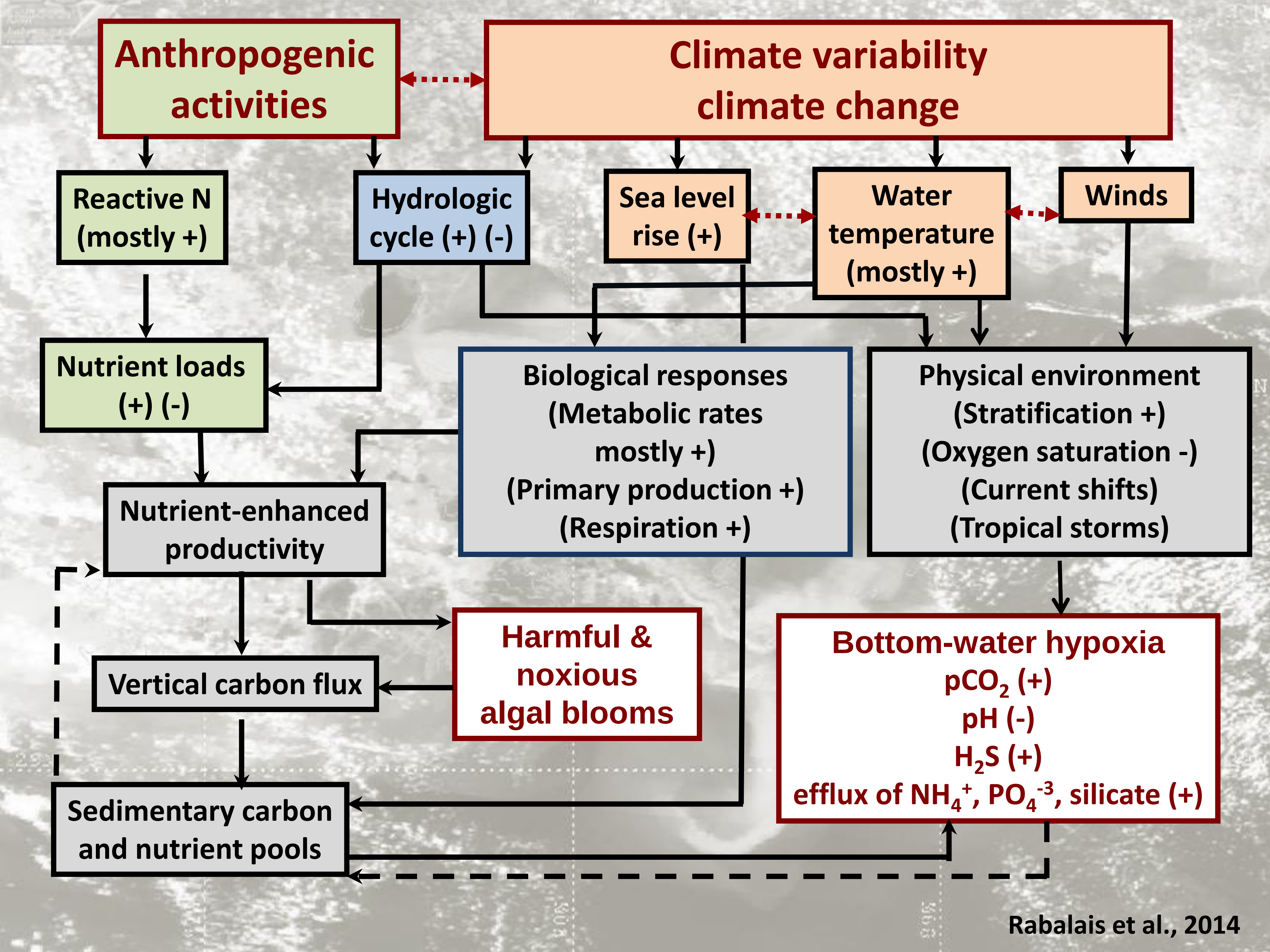
Mee 2006

The Future

Climate Change
Biofuels
Increased Population
Increased Agribusiness
Increased Atmospheric Deposition






Anthropogenic activities
Climate variability climate change
Reactive N (mostly +)
Hydrologic cycle (+) (-)
Sea level rise (+)
Water temperature (mostly +)
Winds
Nutrient loads (+) (-)
Biological responses (Metabolic rates mostly +) (Primary production +) (Respiration +)
Physical environment (Stratification +) (Oxygen saturation -) (Current shifts) (Tropical storms)
Nutrient-enhanced productivity
Harmful & noxious algal blooms
Vertical carbon flux
Bottom-water hypoxia
pCO_2 (+)
pH (-)
H_2S (+)
efflux of NH_4^+, PO_4^{-3}, silicate (+)
Sedimentary carbon and nutrient pools
Rabalais et al., 2014