# Causes of Gulf of Mexico Hypoxia

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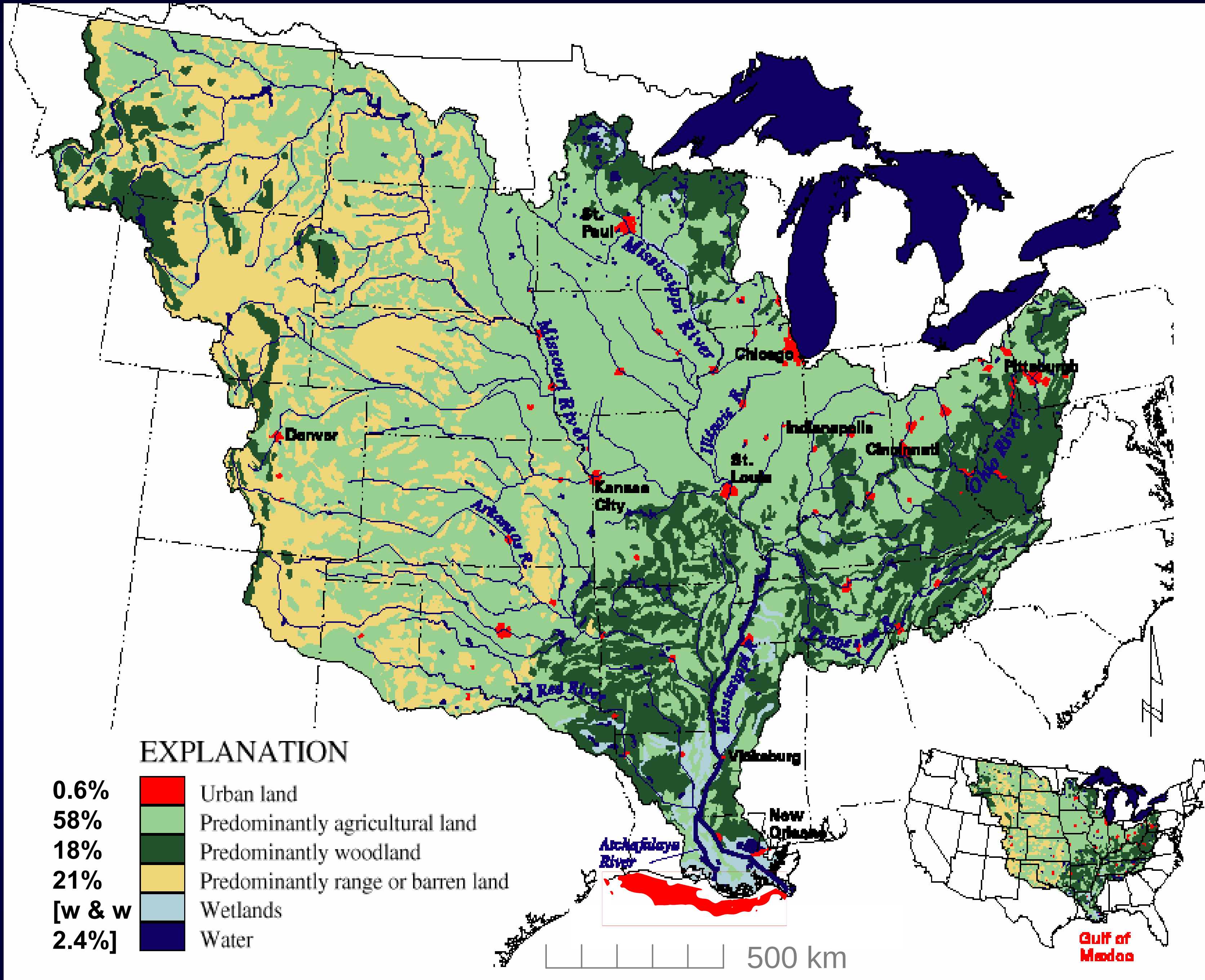
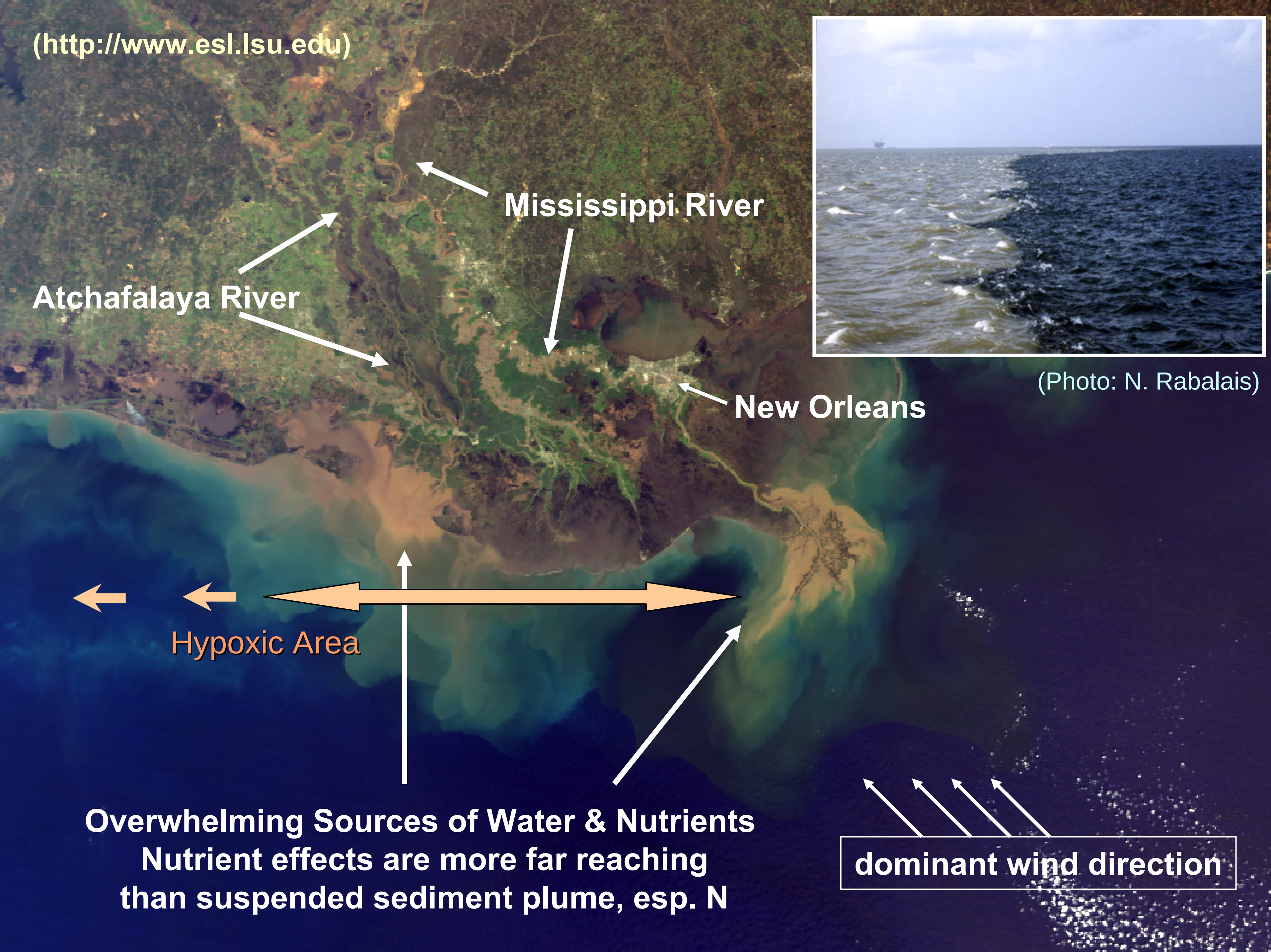
Center for Sponsored Coastal Ocean Research, Coastal Ocean Program, NGOMEX Hypoxia Studies

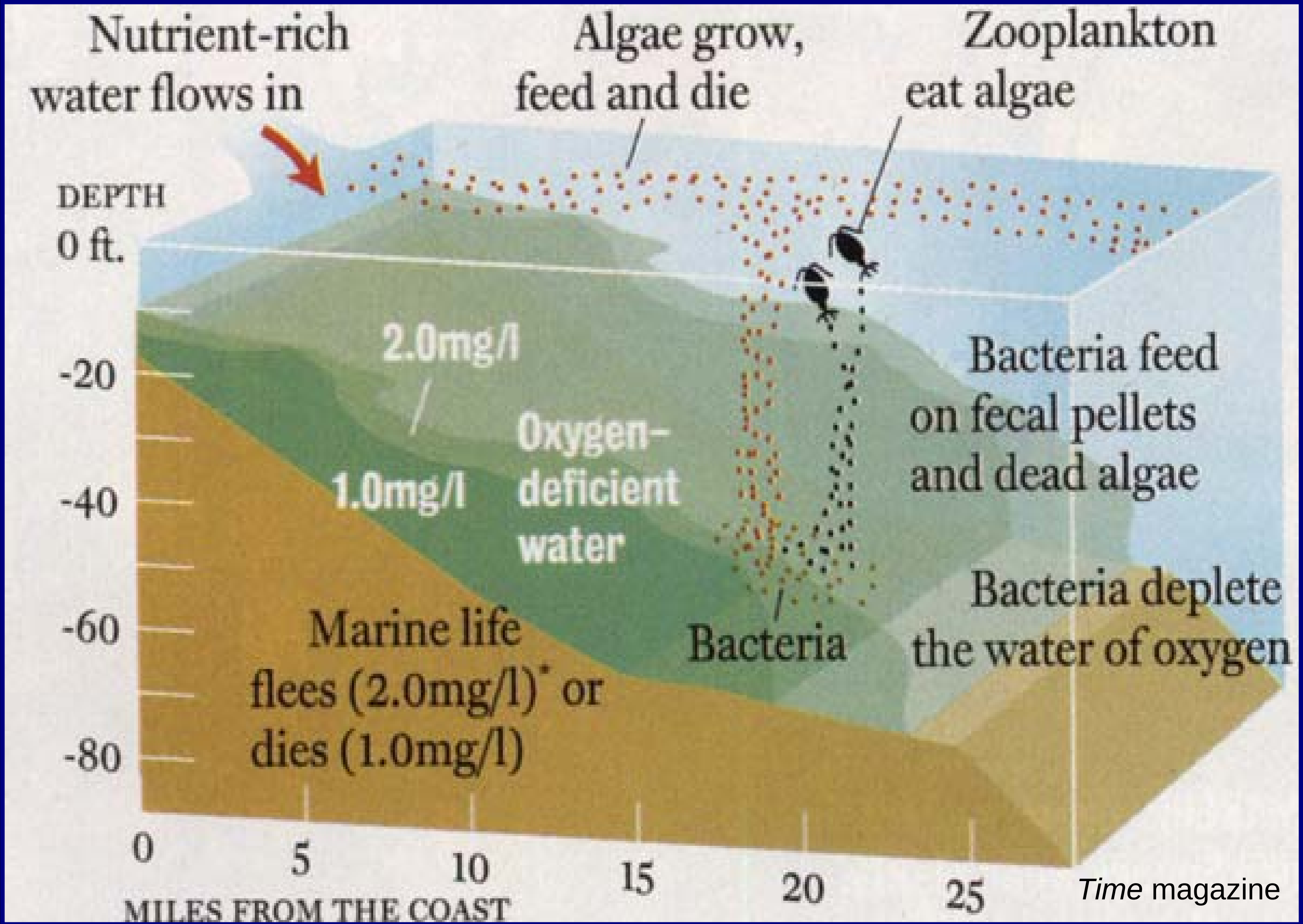



(Goolsby et al., 1999, Rabalais 2002)



(http://www.esl.lsu.edu)
Mississippi River
Atchafalaya River
New Orleans
(Photo: N. Rabalais)
Hypoxic Area
Overwhelming Sources of Water & Nutrients
Nutrient effects are more far reaching
than suspended sediment plume, esp. N
dominant wind direction

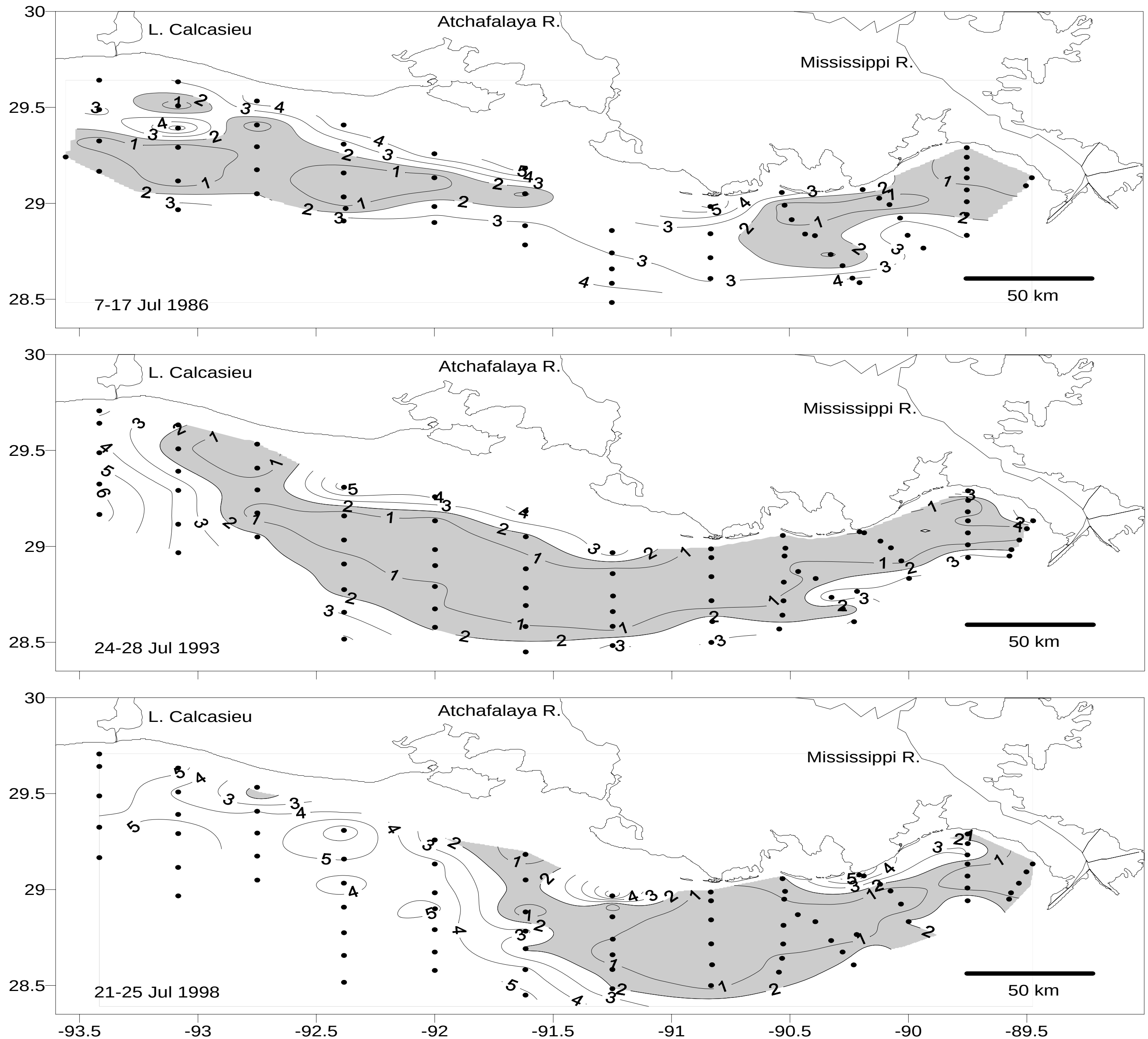
# Nutrients, Increased Growth, Low Oxygen




*Time* magazine

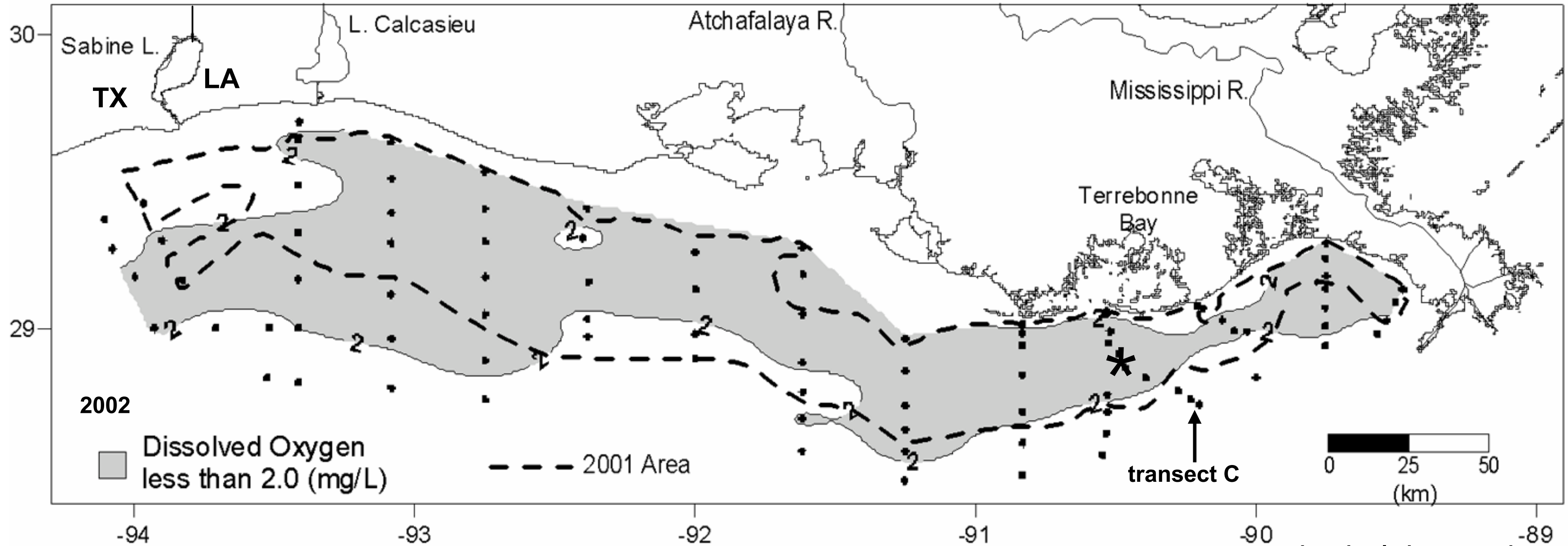
*Time* Magazine

# Coastal, No Upwelling, No OMZ




(Rabalais et al., 2002)

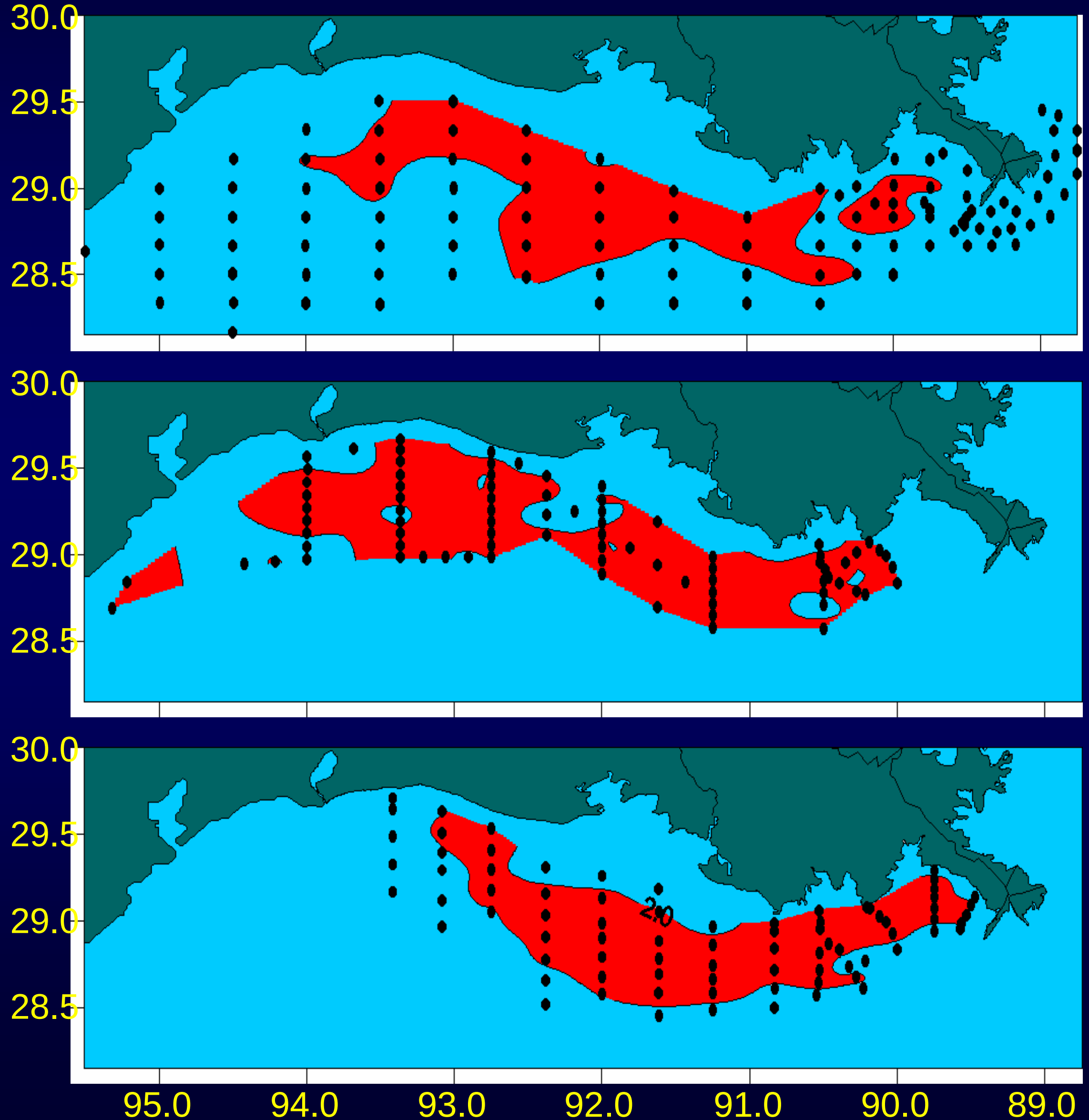
# Persistent, Annual, Bottom Water Hypoxia




(Rabalais 2003)

- Mississippi River delta onto upper Texas coast
- strong salinity and temperature stratification
- 4 - 5 m nearshore to 35 - 45 m offshore
- 0.5 km nearshore to $100^{+}$ km offshore
- seasonal; most widespread and severe in May - Sep
- 2001-2005 average 15,600 $km^2$ in mid summer

# Persistent Over Extended Periods



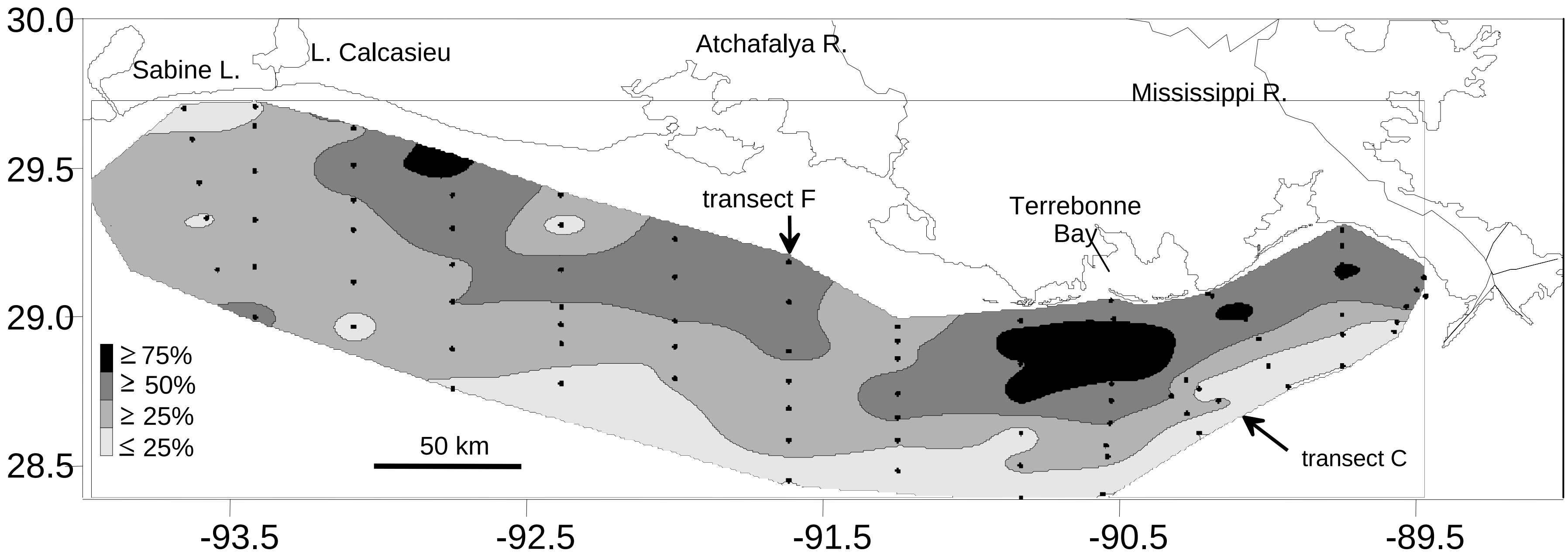

**July 1-12, 1993**
**NECOP**
**(Bratkovitch et al.)**

**July 13-21, 1993**
**LATEX**
**(Rabalais et al.)**

**July 24-30, 1993**
**NECOP**
**(Rabalais et al.)**

(Source: N. Rabalais, LUMCON)

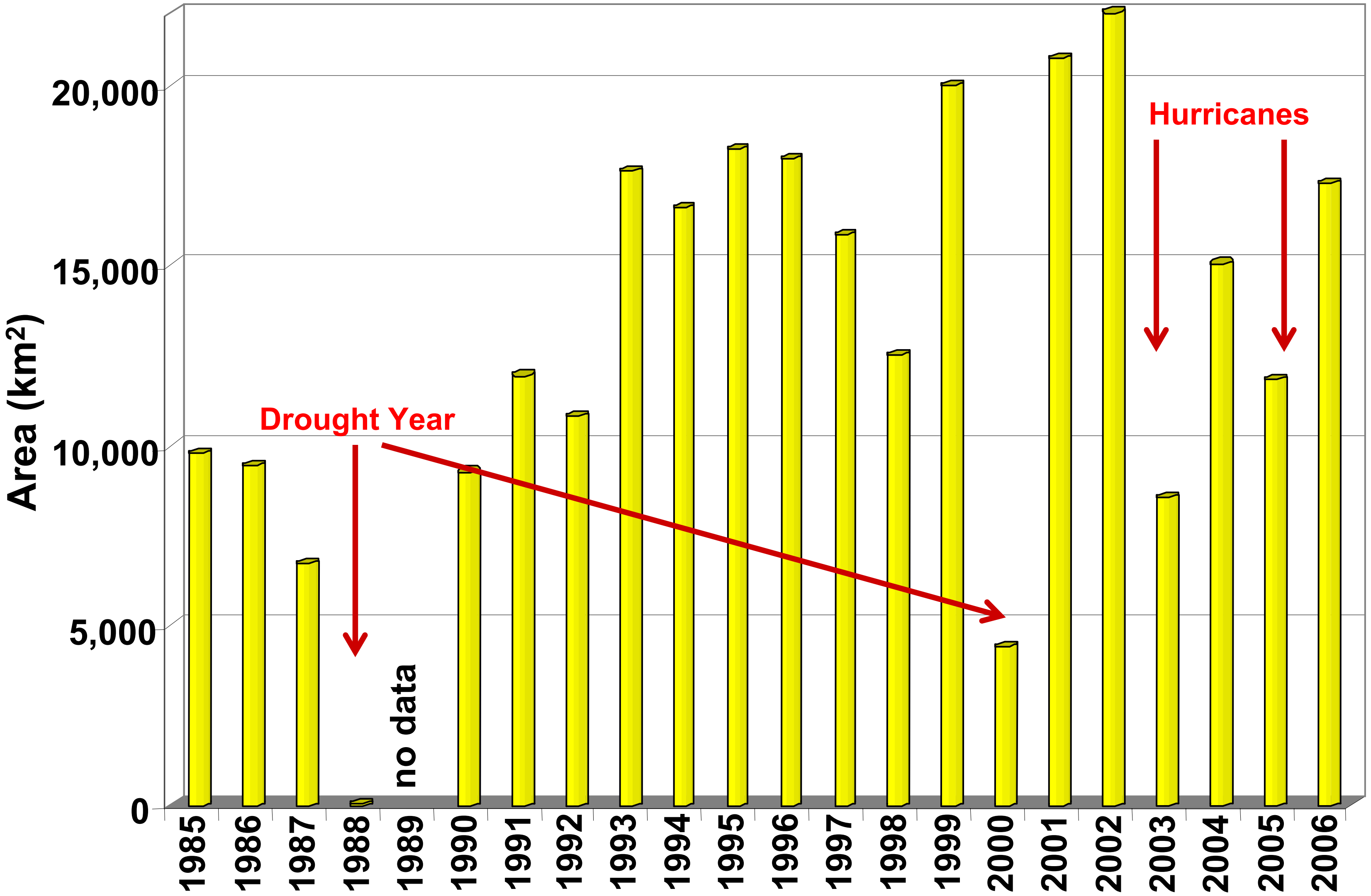
# Frequency of Hypoxia 1985 - 2005




(modified from Rabalais et al. 2002)

- **more frequent down current from Mississippi and Atchafalaya rivers discharges**
- **distribution varies monthly; nutrient flux, discharge, currents**
- **climate driven differences**

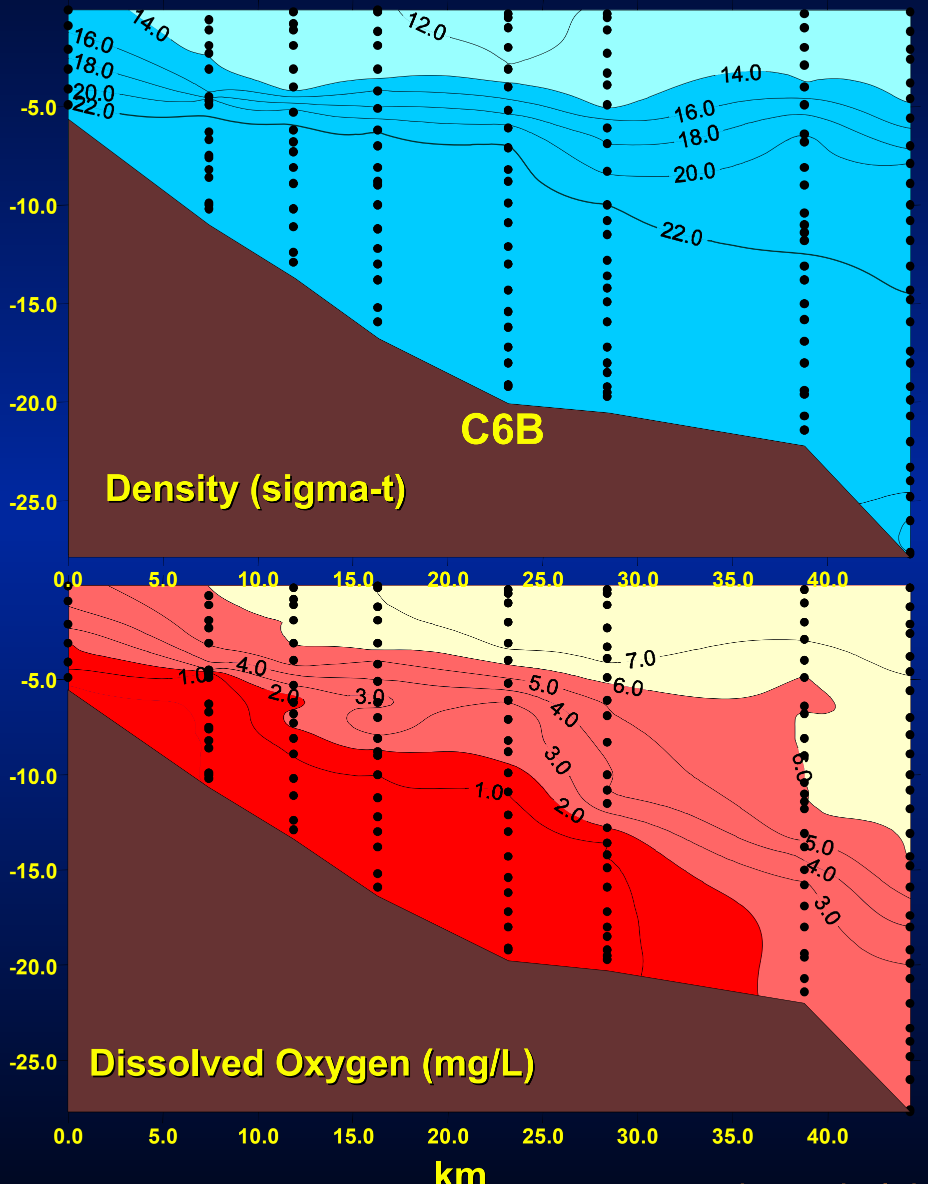
# Estimated Size of Bottom-Water Hypoxia in Mid-Summer

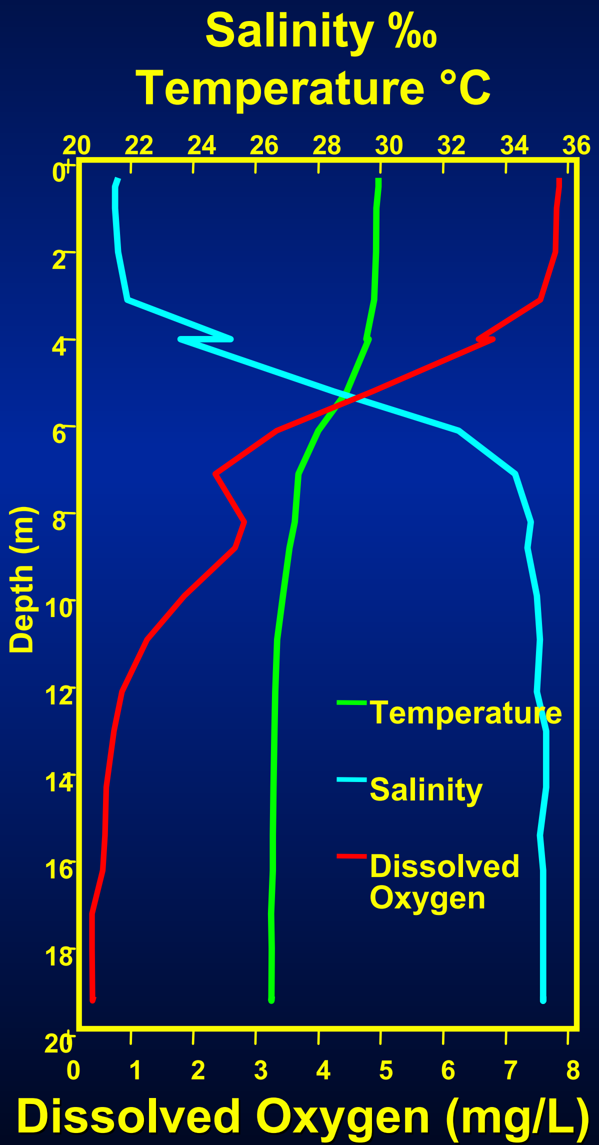



(updated from Rabalais et al. 2002)

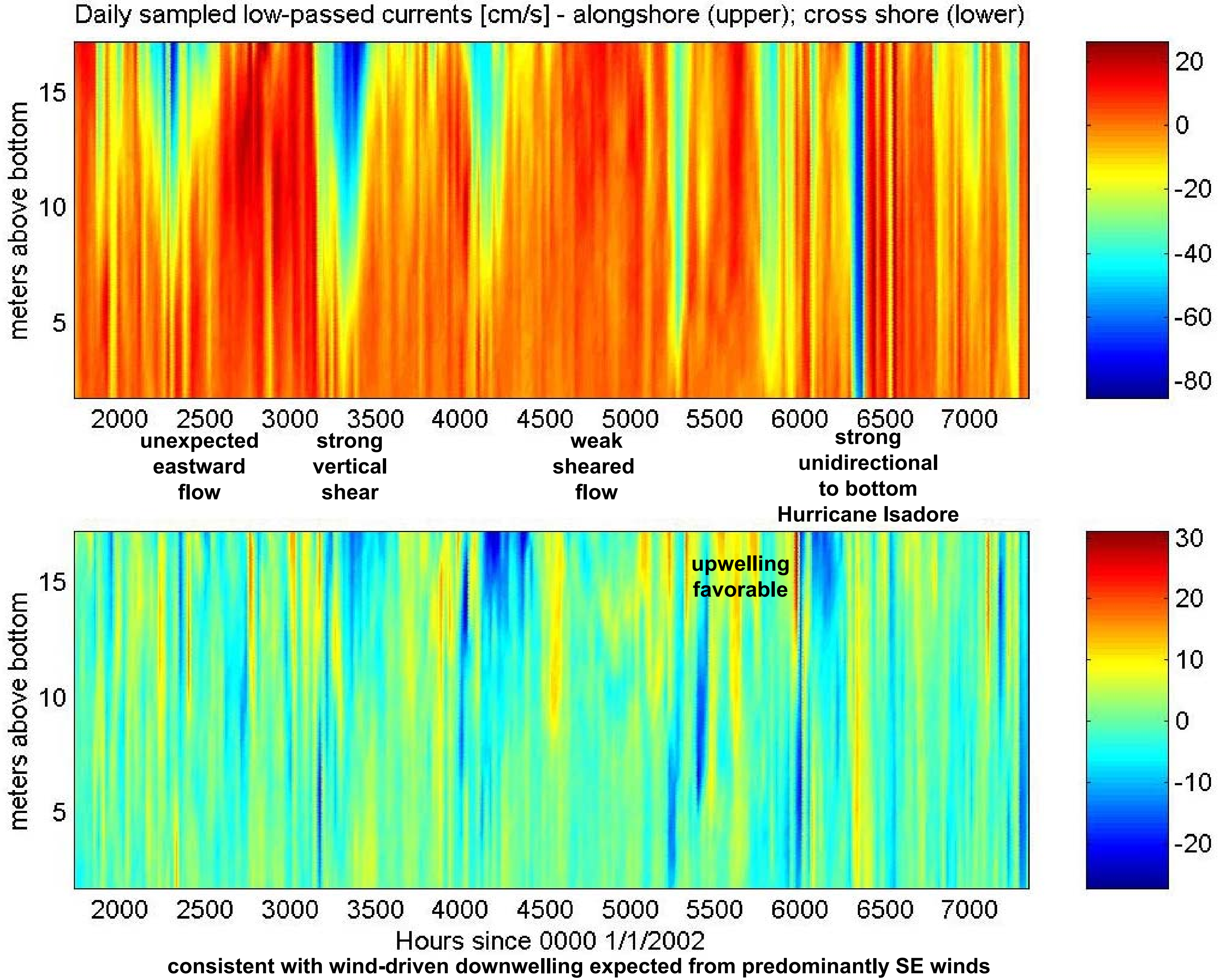
Nutrient-enhanced carbon production leads to oxygen depletion, and the distribution and dynamics are bounded by the physics of the system.

# Stratification
## (mid-summer)



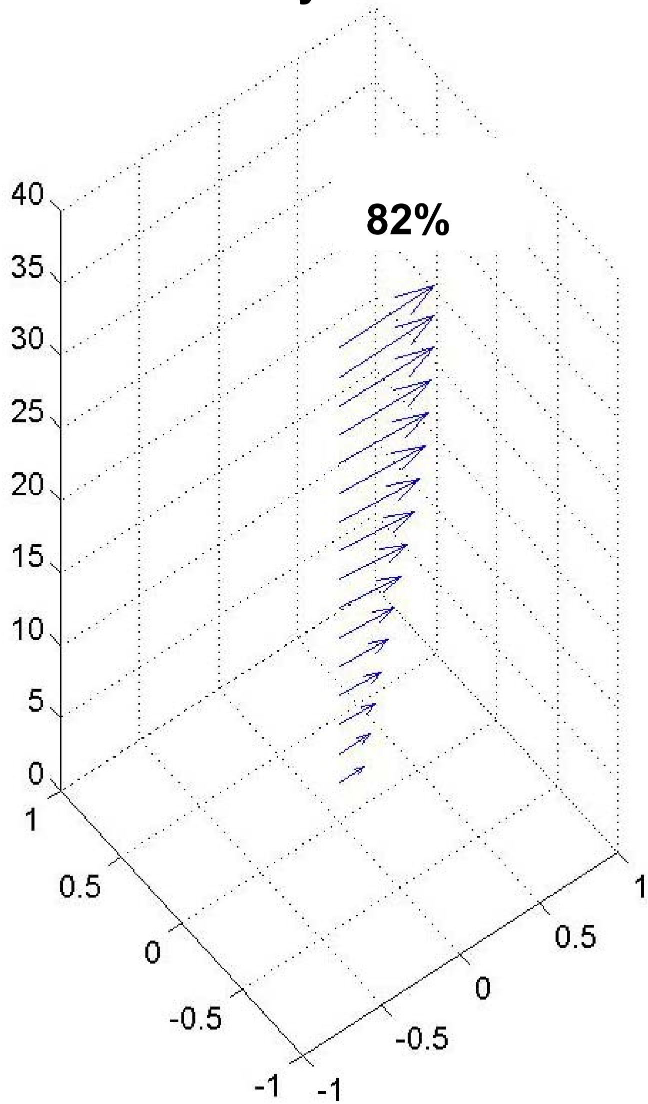

(N. Rabalais, LUMCON)



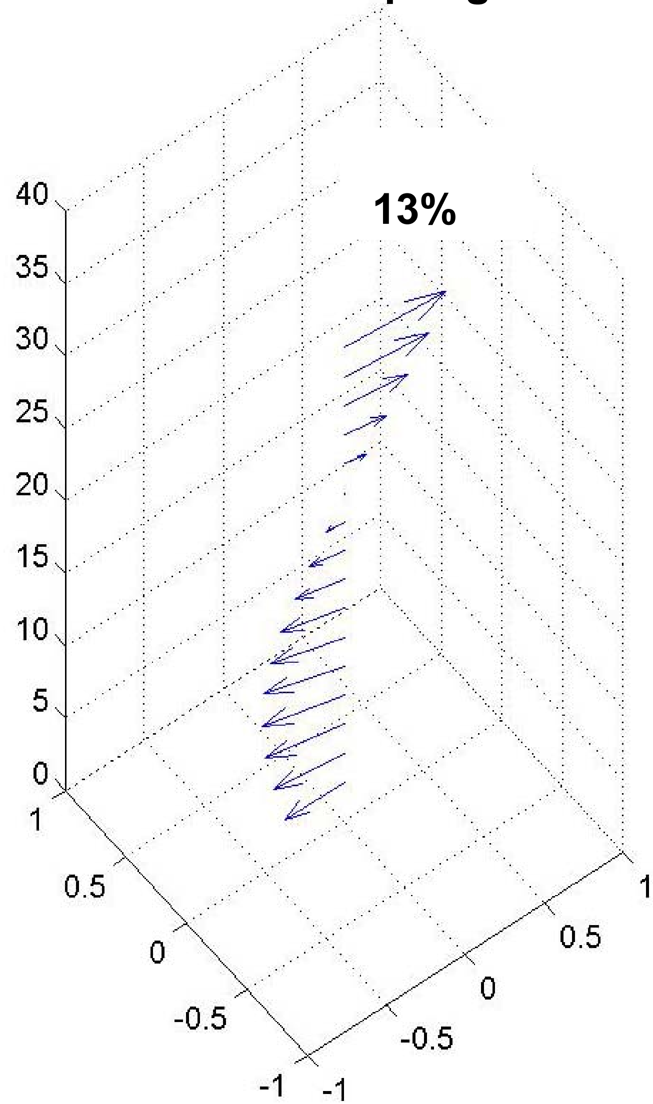

14 March through 12 November 2002

(Wiseman et al. 2004)

**1st mode: nearly unidirectional vertically-sheared flow**

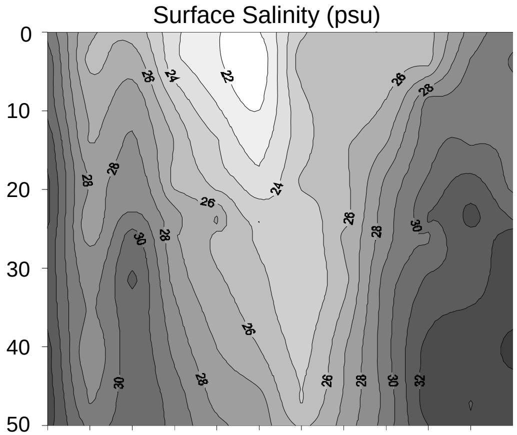


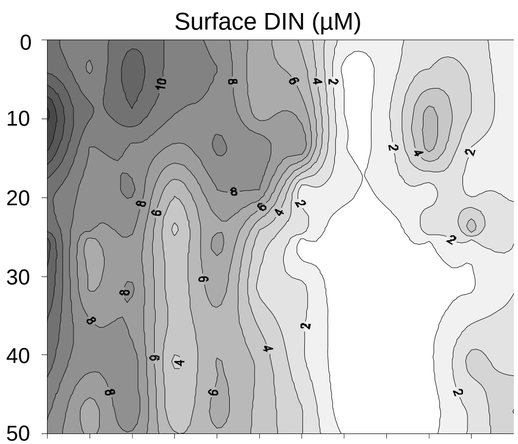

**2nd mode: two-layered flow summer > spring or fall**

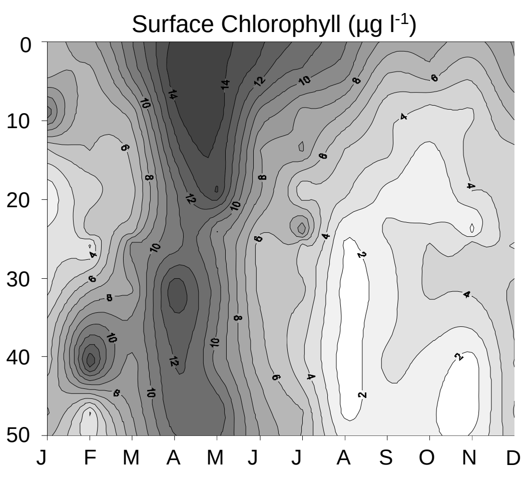


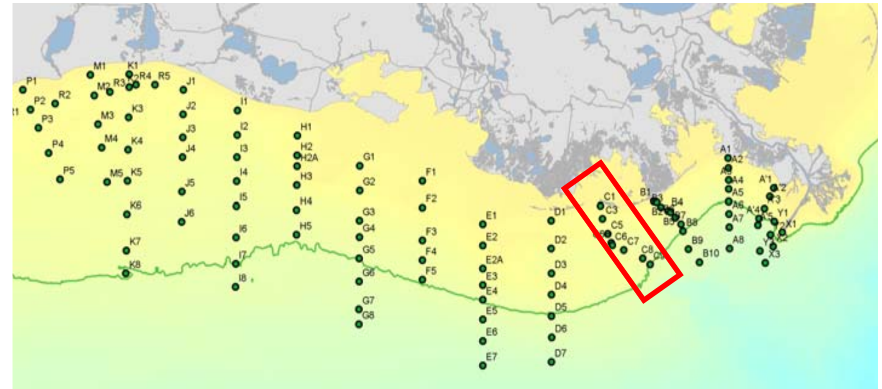

**EOF (empirical orthogonal flow) analysis**

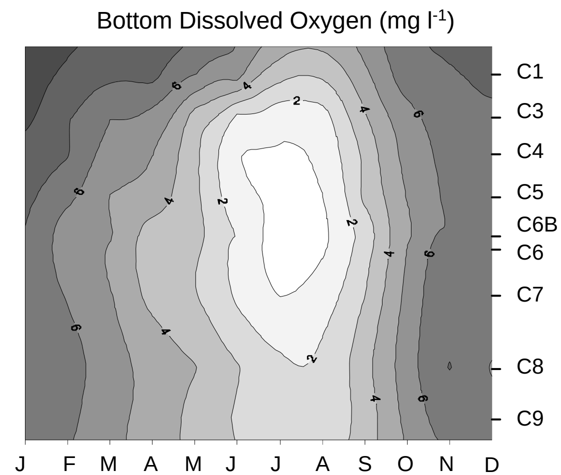
(Wiseman et al. 2004)



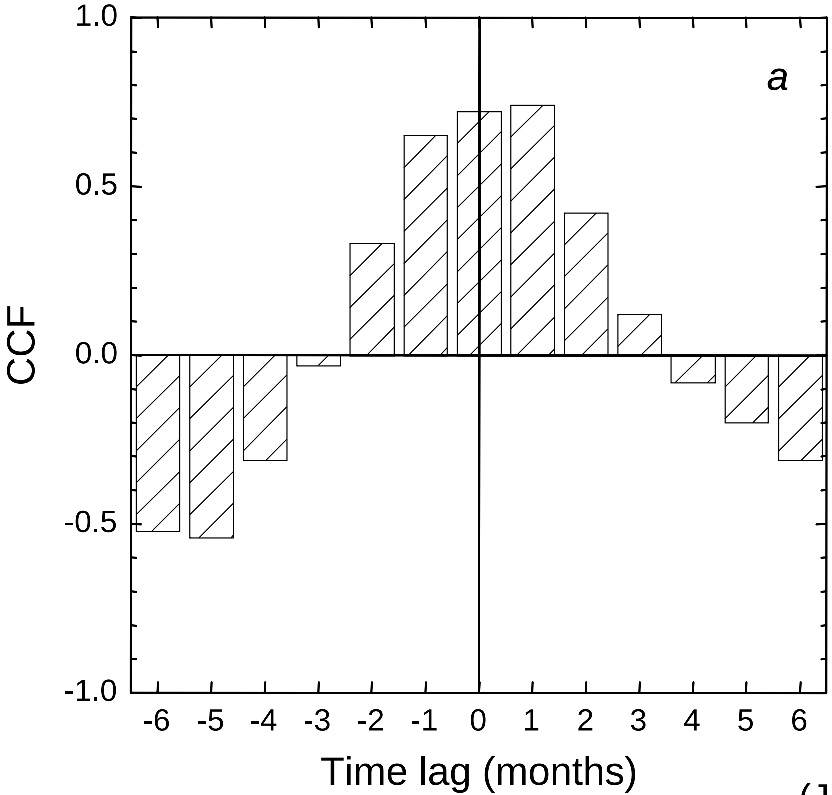



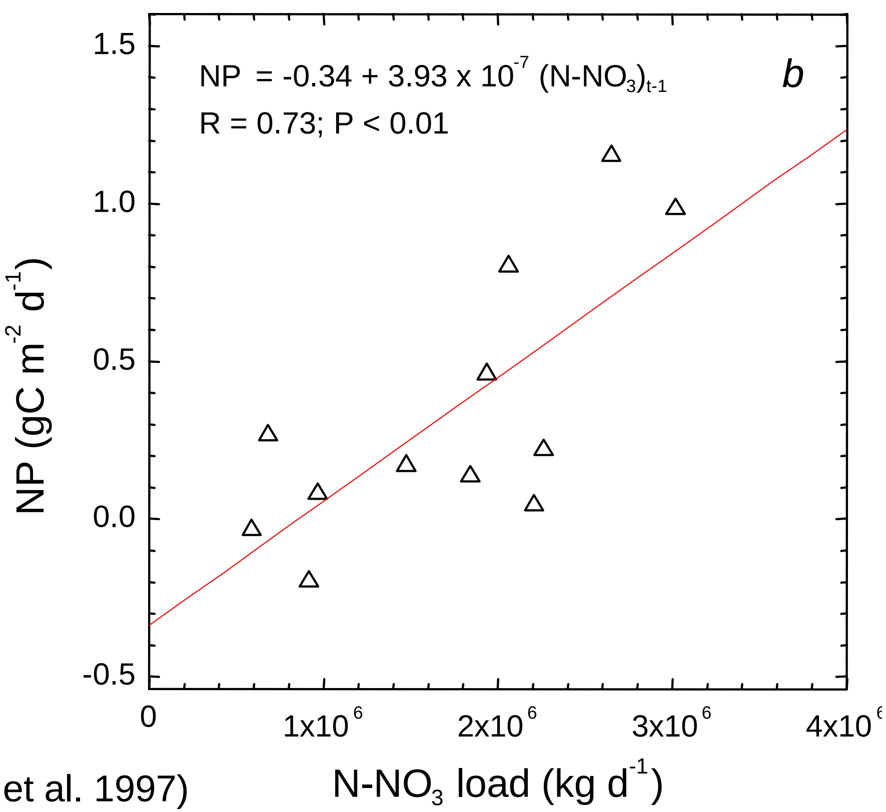





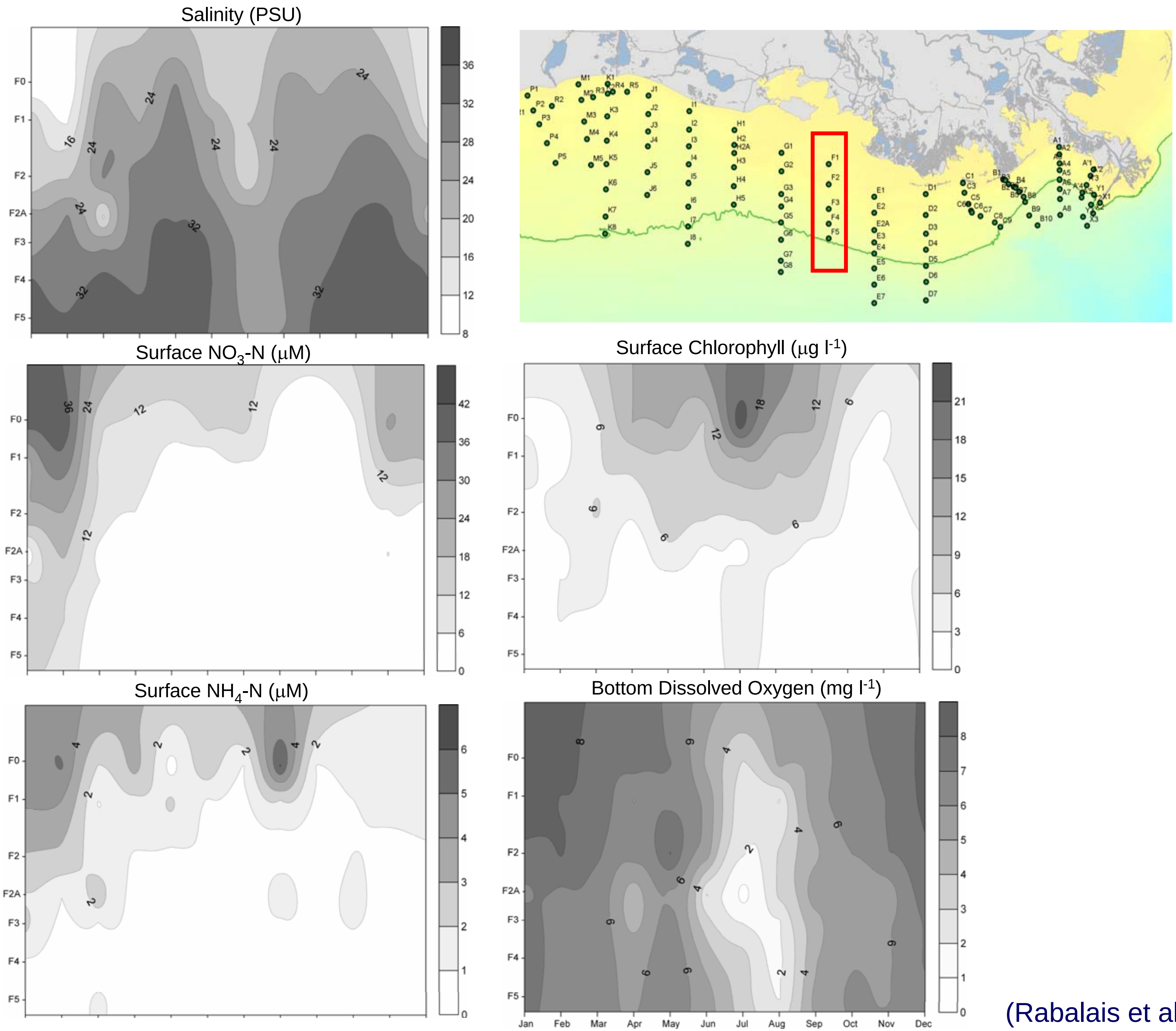

(Rabalais et al., in revision)



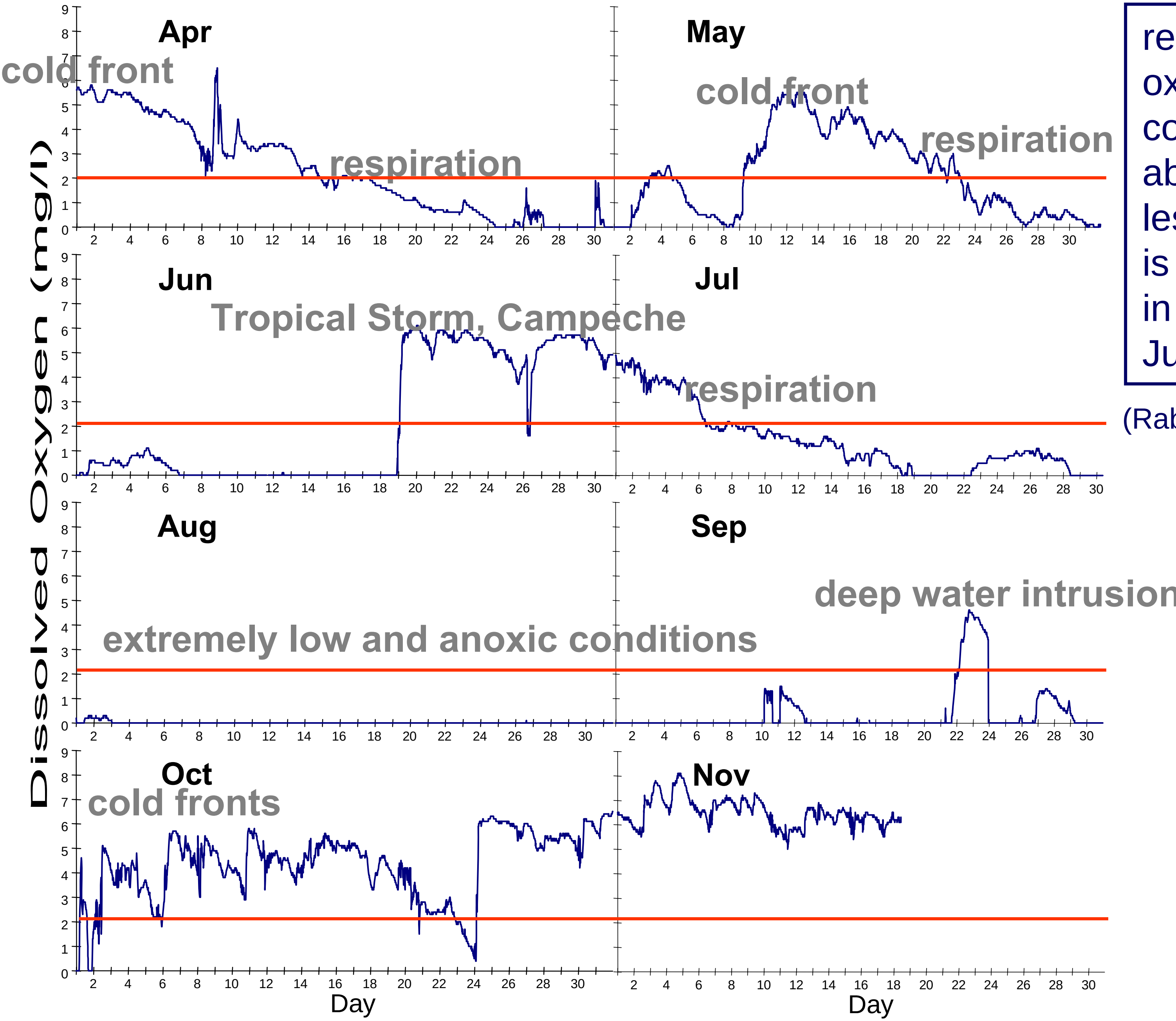

(Justić et al. 1997)

Prior and further analyses of timing and volume of discharge, timing and load of nutrients, particularly nitrate-N, timing and accumulation of carbon, and rates and temporal sequence of oxygen depletion are consistent with a seasonal cycle of nutrient-enhanced production, flux of organic matter and depletion of oxygen under persistent and strong water column stratification.




(Rabalais et al., in revision)

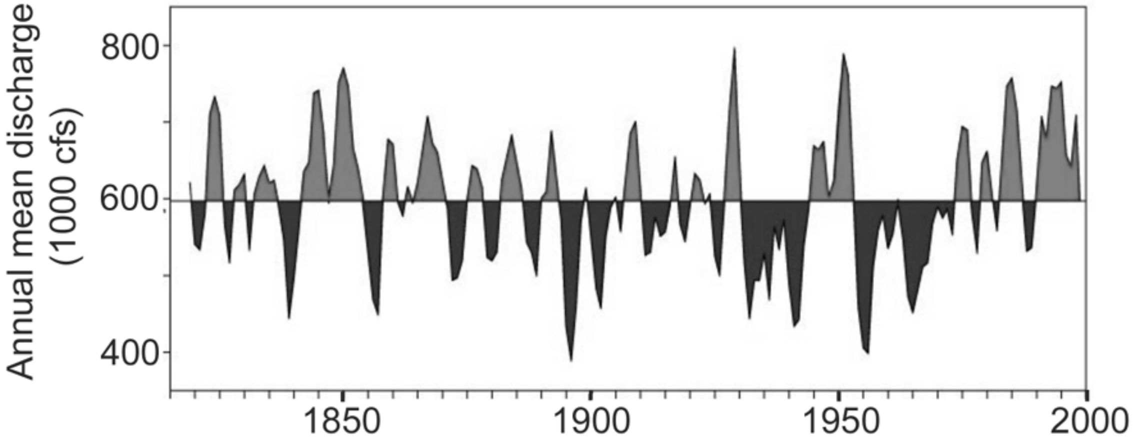
# Bottom Oxygen, 20 m water depth, 1993



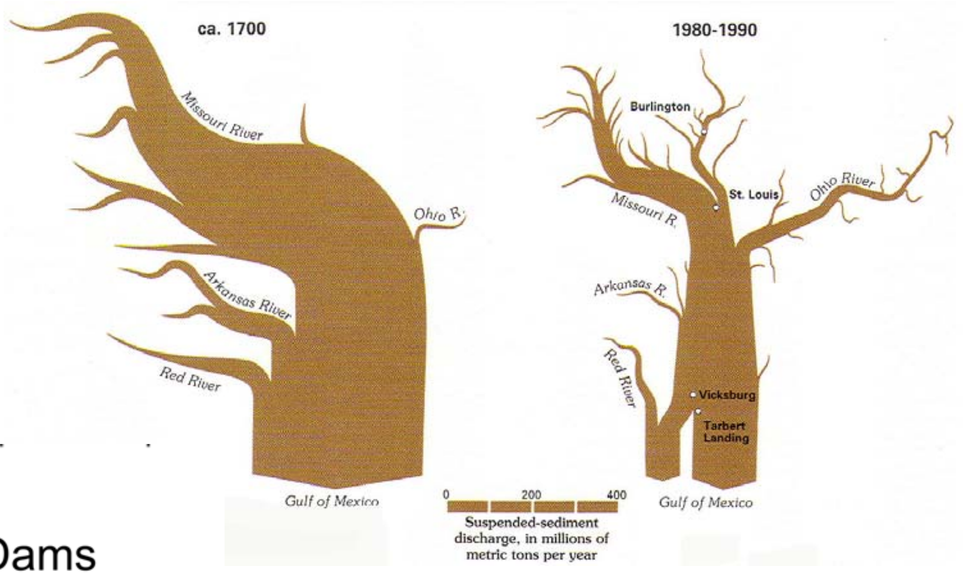

reduction of the oxygen concentration from about 6 mg $l^{-1}$ to less than 2 mg $l^{-1}$ is 18, 11 or 9 days, in April, May and July, respectively

(Rabalais et al., in revision)

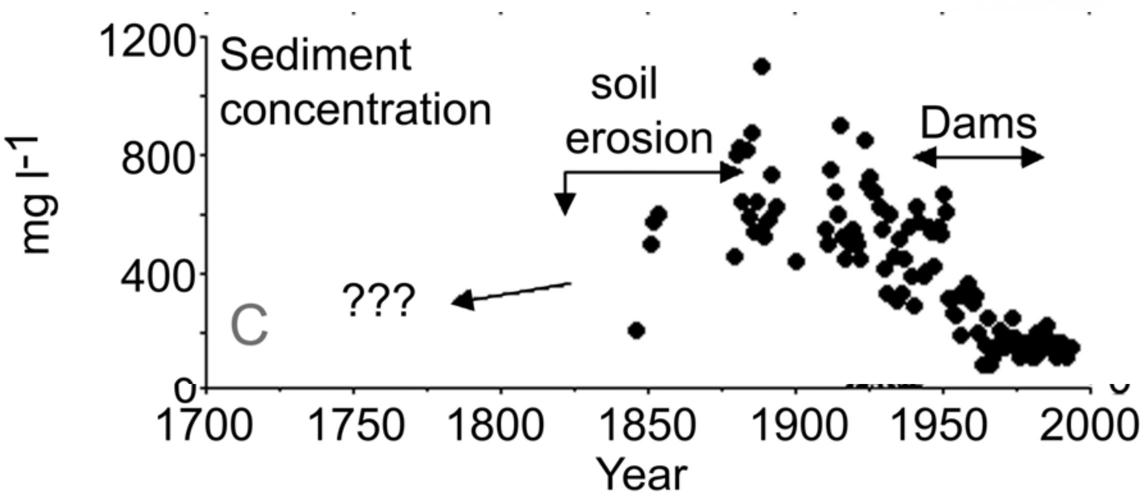
(Rabalais et al. 2002)



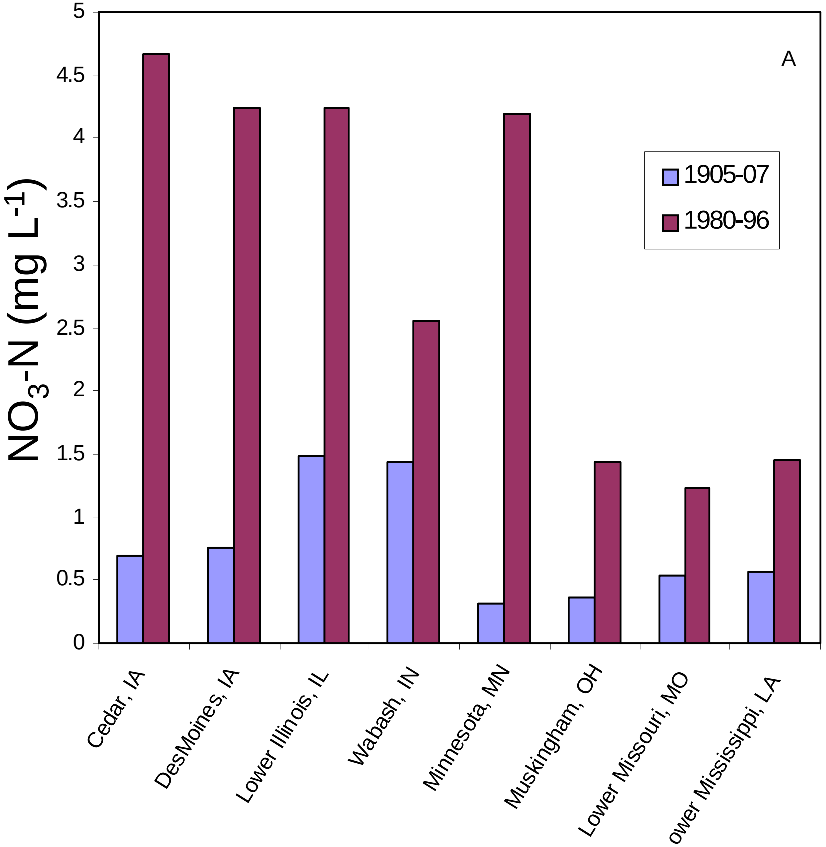

(Turner et al. submitted)




(Meade 1995)




(Turner and Rabalais 2003)

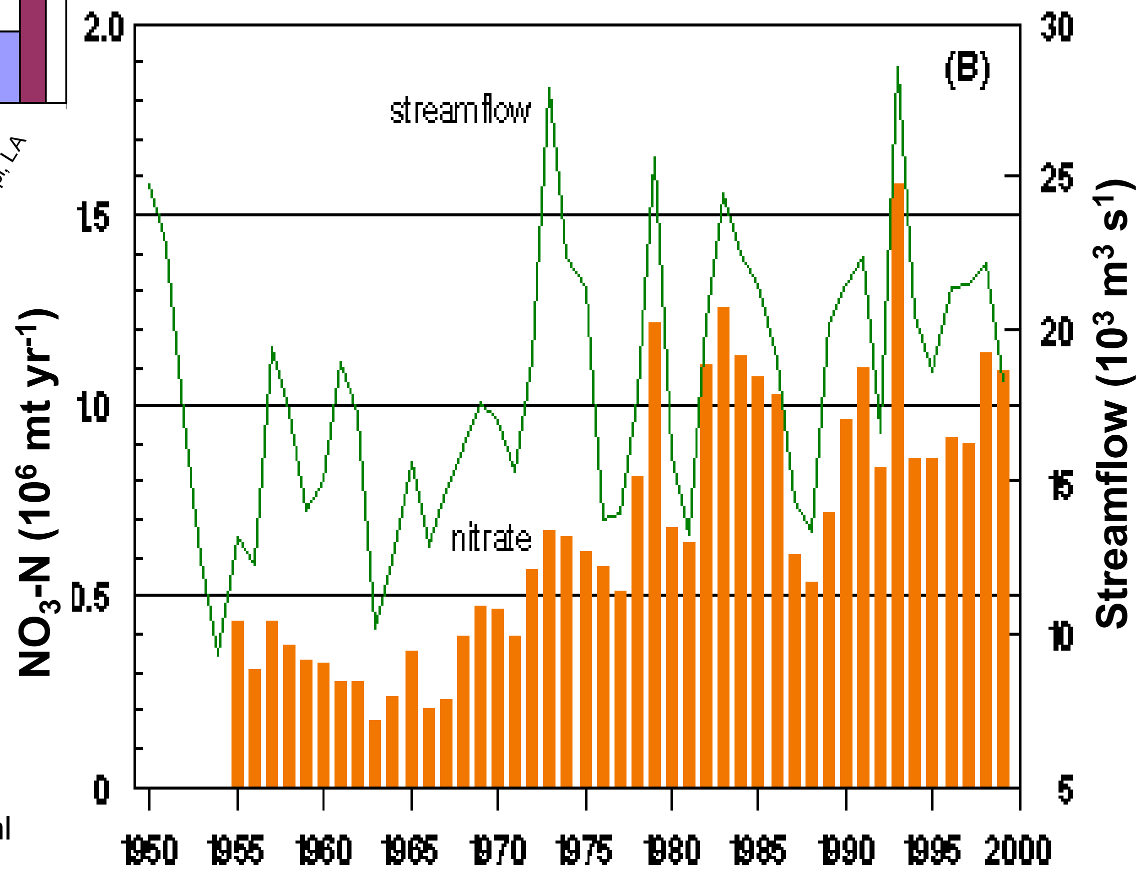



# 300% increase in N load

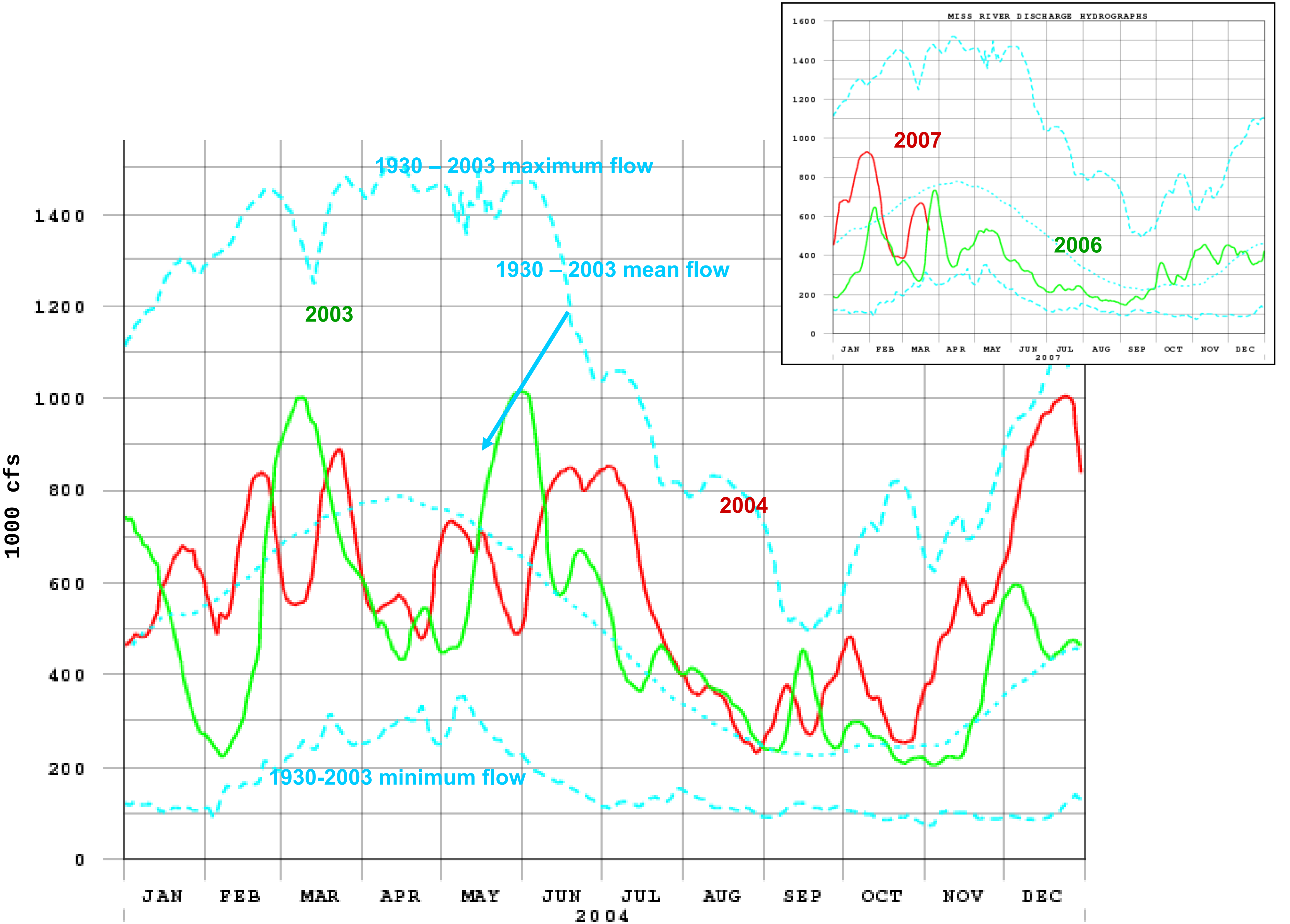
## 80% due to $NO_3^-$ concentration ↑

## 20% due to discharge ↑

(Donner et al. 2002, Justić  et al. 2003)

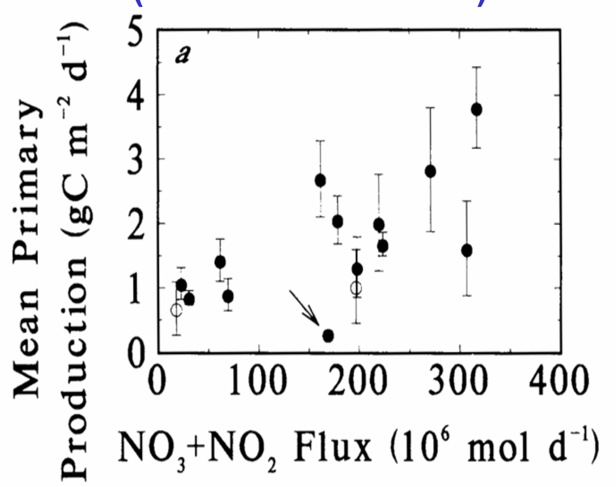


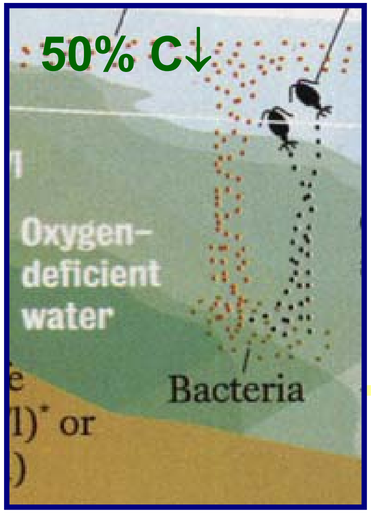

http://wwwrcolka.cr.usgs.gov/midconherb/hypoxia.html




http://www.mvn.usace.army.mil/eng/edhd/tar.gif

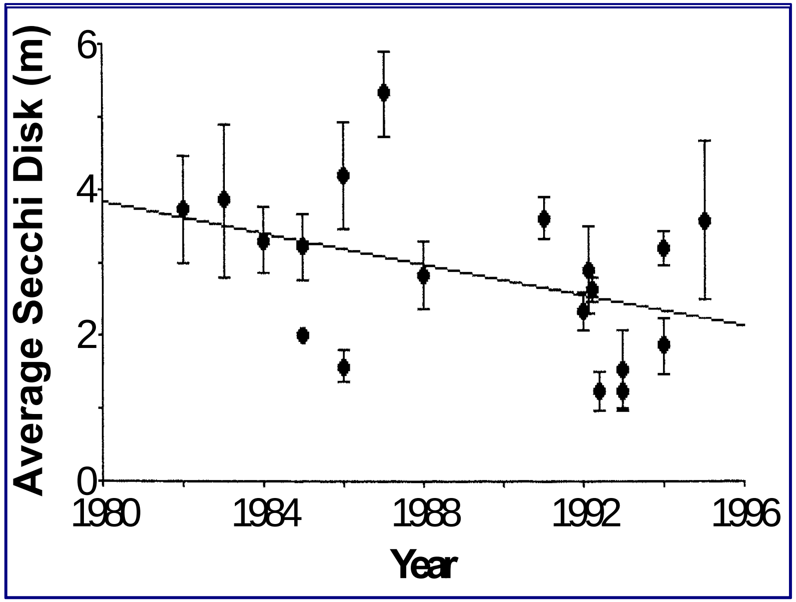
(Lohrenz et al. 1997)



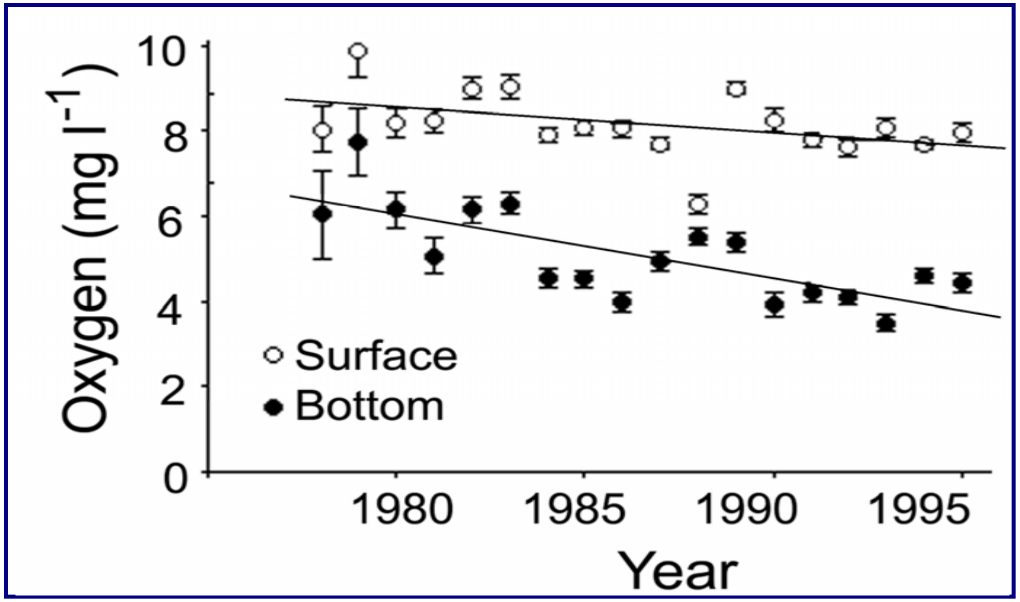

## More Nutrients, More Production, More Carbon Flux

## Decreased Water Clarity



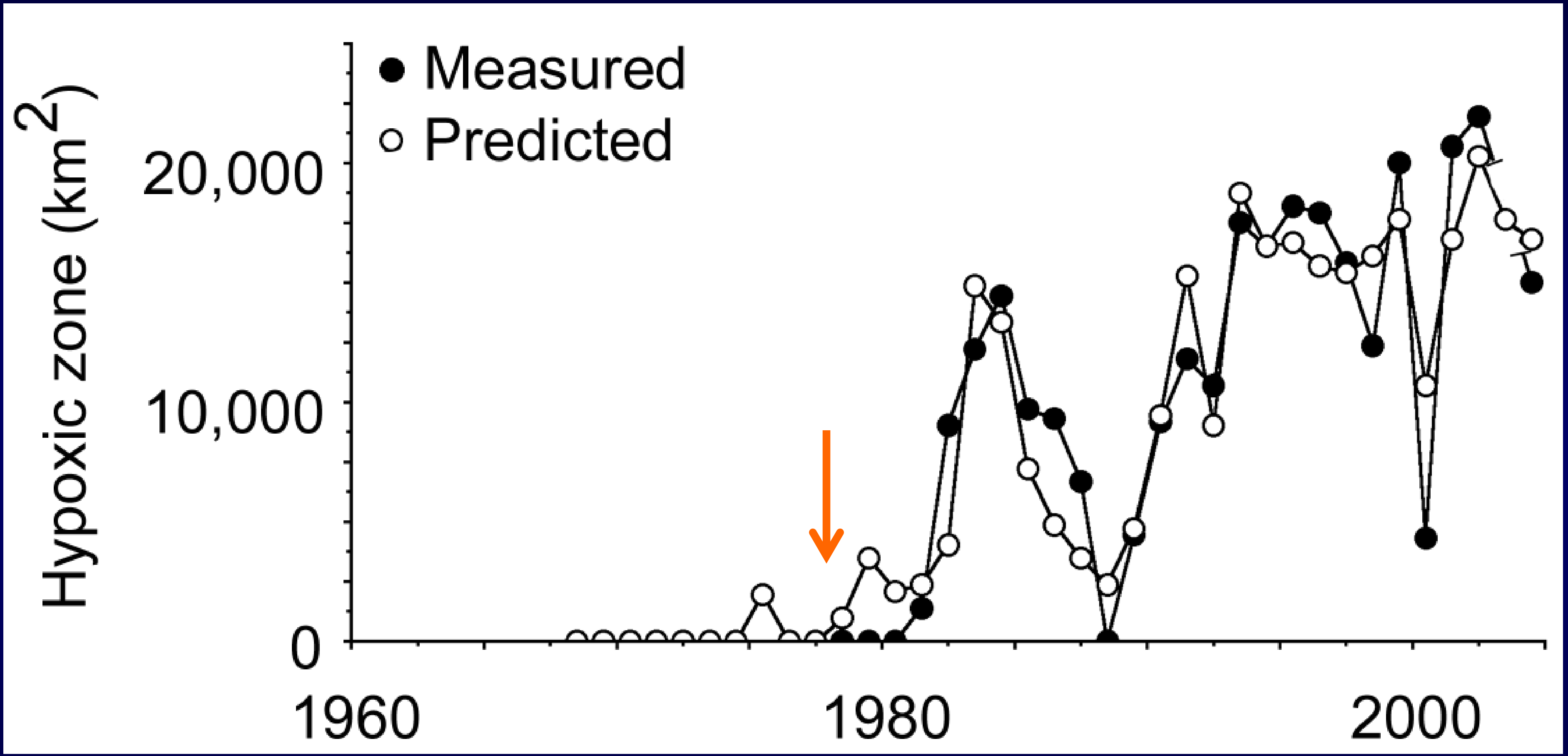

(Rabalais et al. 20021)

## Decreased Oxygen Concentration




(Turner et al. 2005)

# Predicting Hypoxia in summer (nitrate flux in the spring, Apr-Jun, year)

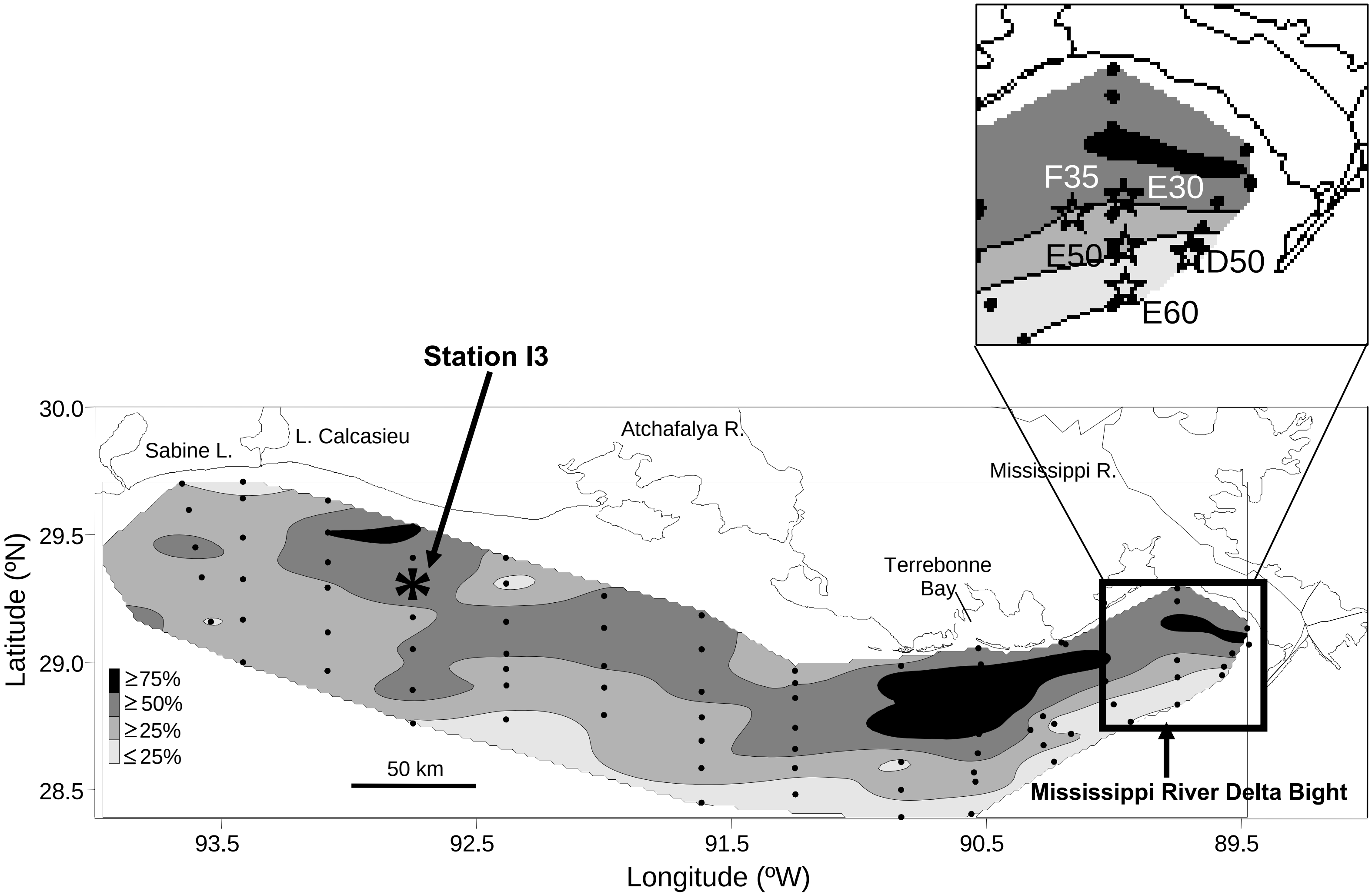



Similar analyses with PO4, TP, TN, Si, various Si:N:P ratios indicate that N, in the form of NO3+NO2, is the major driving factor influencing the size of hypoxia on the Louisiana shelf.

(Turner et al. 2006)

Photo removed.

Sediment cores taken from the Mississippi River bight where accumulation rates are between 0.5 and 2.5 cm $y^{-1}$.



## Fossil and chemical biomarkers from cores (in the last half of the 20th century):

- increased phytoplankton production
- Increased diatom biomass
- Increased diatoms that are less silicified as Si:N→1:1
- Increased phytoplankton pigments
- Increase in TOC
- Increase in hypoxia tolerant benthic foraminiferans
- Loss of hypoxia intolerant benthic foraminiferans
- Increase in pigments of anoxygenic phototrophic brown-pigmented green sulfur bacteria
- Worsening hypoxia stress
- Hypoxia has not always been present

## The long-term changes are consistent with

- the observational data on hypoxia and
- coincident with the well-documented increase in nitrate export from the Mississippi River.

| Important Factors for Hypoxia | Unimportant (or Minimal) Factors for Hypoxia |
|---|---|

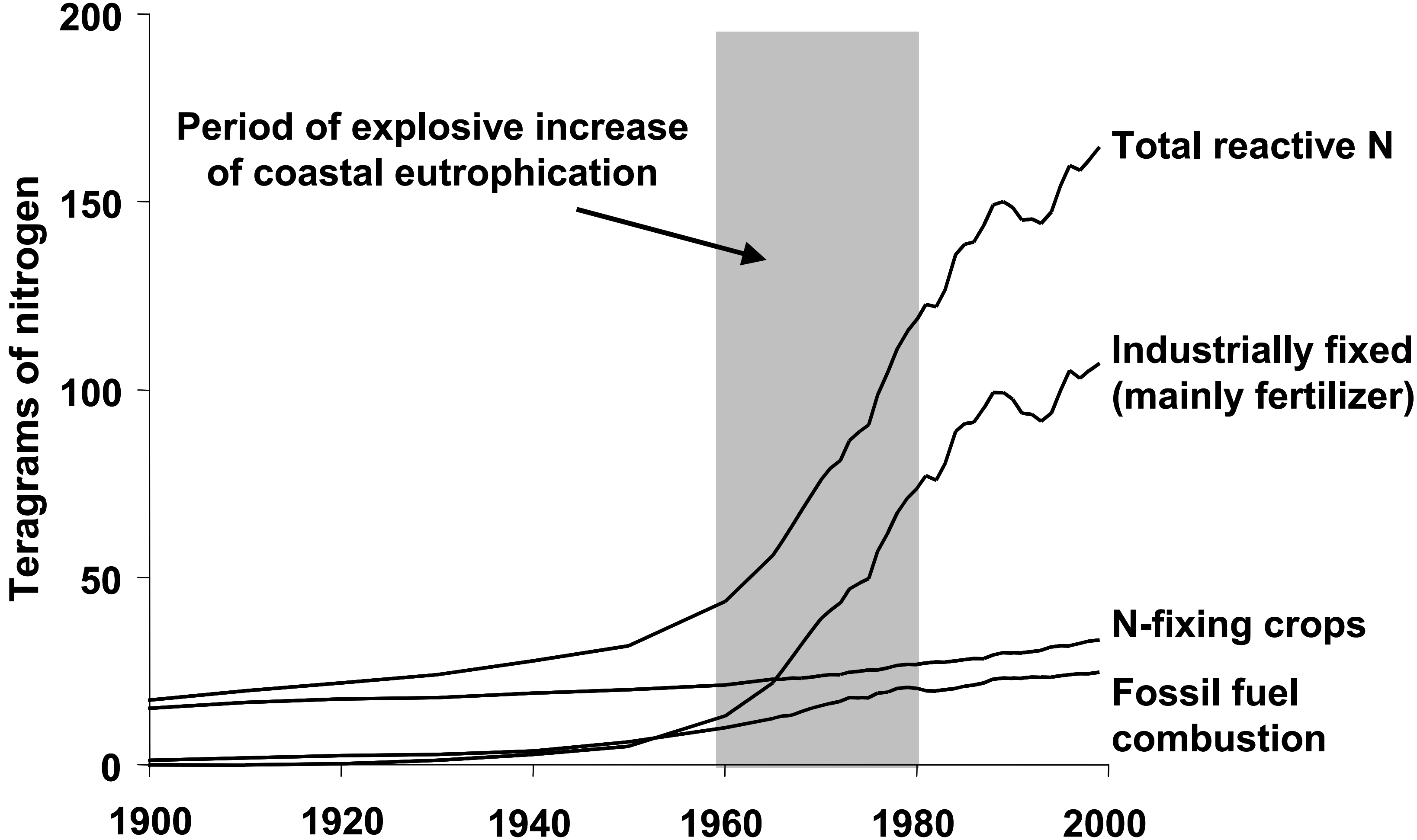
**Important Factors for Hypoxia**

- Stratification
- Currents
- Winds, waves
- Nutrient-enhanced primary production
- High flux of surface carbon to the seabed
- Oxygen consumption exceeds oxygen resupply
- Directly proportional to N load

**Unimportant (or Minimal) Factors for Hypoxia**

- Deep-water oxygen minimum layer
- Allochthonous river carbon
- Ground water
- Wetland erosion
- Estuarine nutrients
- Mississippi River mainstem and deltaic levees
- Reduced suspended sediments
- Upwelled nutrients
- Climate (not as yet)

(Source: N. N. Rabalais, LUMCON)




Period of the explosive increase in coastal eutrophication around the world in relation to global additions of anthropogenically fixed nitrogen (from Boesch 2002).