Patterns of Carbon, Oxygen, and Nutrient Cycling on the Louisiana Shelf

John Lehrter, US EPA Gulf Ecology Division

March 27, 2012

Workshop Questions

Q1) What are the biogeochemical pathways that process and recycle “new” nutrients and ultimately lead to generation and maintenance of hypoxia? How does the relative importance of these pathways vary temporally and spatially?

Q2) How much primary production and oxygen consumption results from each unit of N and P input onto the shelf? What is the stoichiometric relationship of N and P flux to hypoxic zone area? What are the repercussions for management nutrient reduction targets?

Q3) What are the research gaps that limit a more comprehensive understanding of biogeochemical processing?

A suggested rephrasing of this question:

Which syntheses can be done now to link river outflow to living resources?

Riley et al. (1937)
“… there is a zone of high productivity in the shallow water area near the mouth of the Mississippi, and since the effect of river outflow on ocean life is a phase of marine biology which has not yet received adequate attention, further investigation seemed desirable.”

Policy Issues

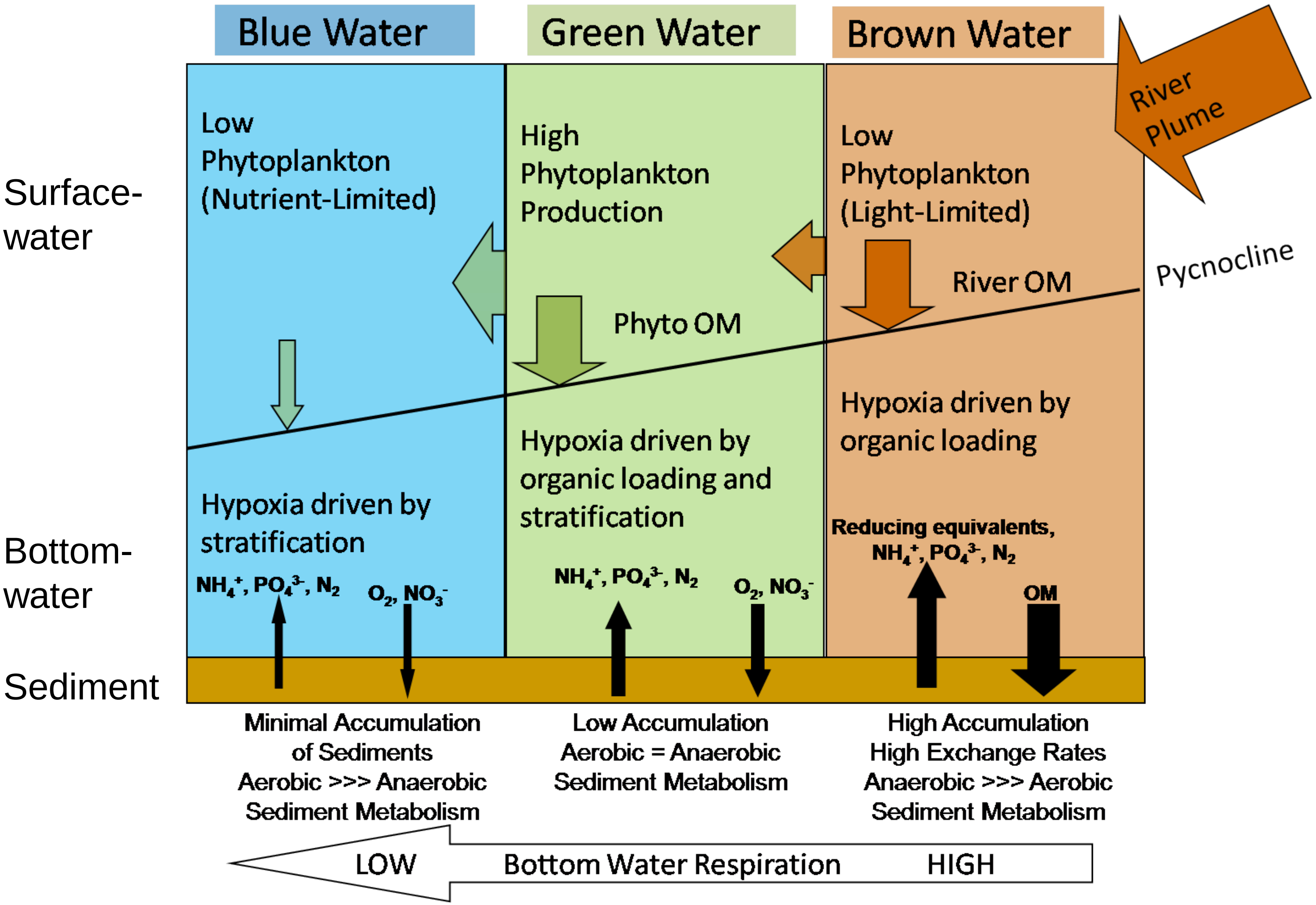
- The concentration of nitrogen (N) in the Mississippi River has nearly tripled since the 1950s (Turner and Rabalais 1991,Goolsby et al. 1999, CENR 2000, Greene et al. 2009).
- The goal set by the Hypoxia Task Force is to achieve a 5-year running mean of 5,000 km^2 by 2015.
  - Previous work suggests 40-45% reductions in N&P will be required to achieve the goal (Scavia et al.2003, Donner and Scavia 2007, Scavia and Donnelly 2007, Greene et al. 2009).
  - What are the impacts on living resources?
- States in the basin require a loading target at the mouth of the Mississippi River to establish N&P criteria protective of downstream impacts.
- Identified need by Louisiana to investigate stratified O_2 criteria for coastal waters
  - Issue of contiguity with shelf hypoxia
- Economists and other analysts require realistic simulation tools to evaluate policy scenarios
  - Response surface modeling
  - Developing “intuition” about how a system works

Questions Addressed

- What are the patterns of primary production across the area of the Louisiana shelf where hypoxia occurs?
  - Previous work in subsections of the shelf (Lohrenz et al. 1990; 1997; Chen et al. 2000)
- What are the patterns of water-column respiration?
  - Plume and the eastern shelf (Turner and Allen 1982; Dortch et al. 1994; Turner et al. 1994)
- What are the patterns of sediment-water exchanges of C, O, N, and P
  - Plume and eastern shelf (Rowe et al. 2002)
- What are the patterns of sediment diagenetic processes?
  - Plume (Morse and Rowe 1999)
- What are the mechanisms underlying observed patterns?

Hypothesized Process Patterns

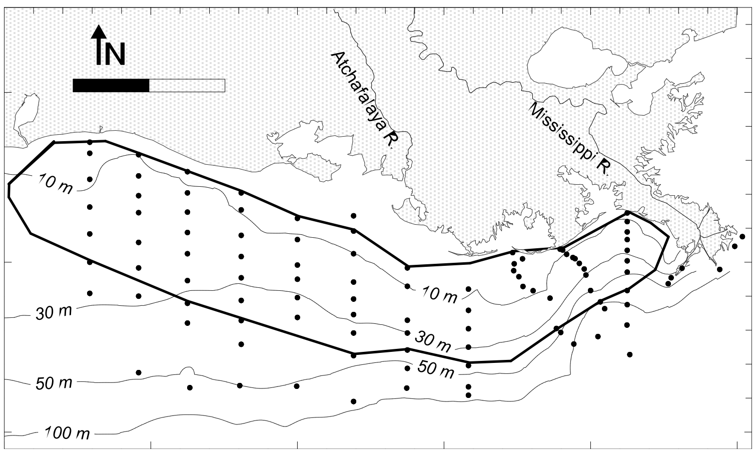
modified from Rowe and Chapman (2002)



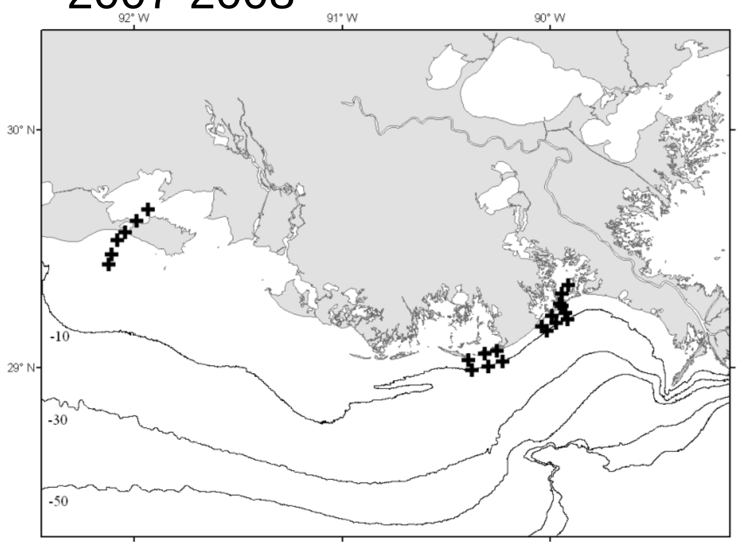
Survey Designs

Water-column

2002-2007

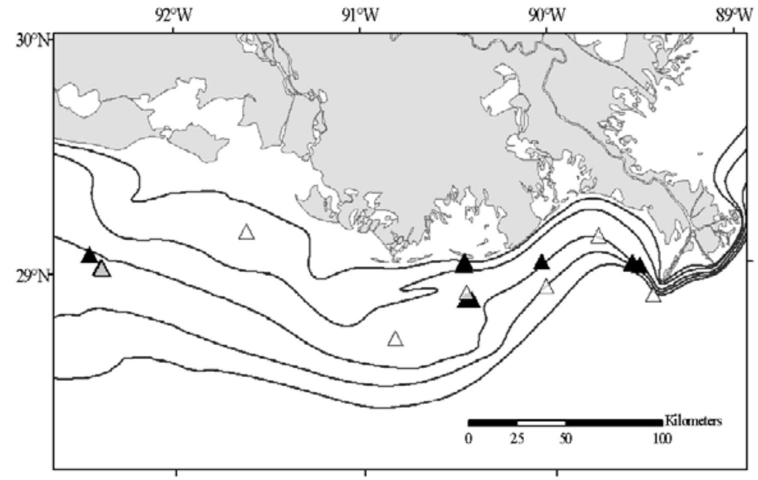


2007-2008

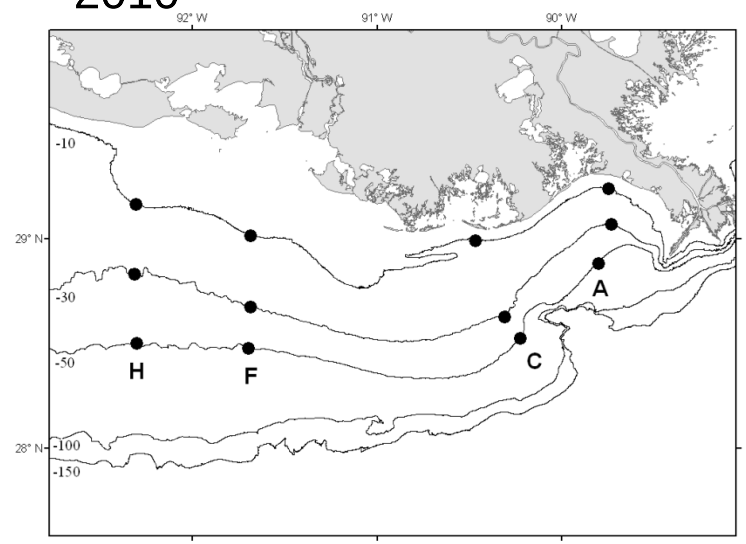


Sediment

2003-2007



2010



Measurements

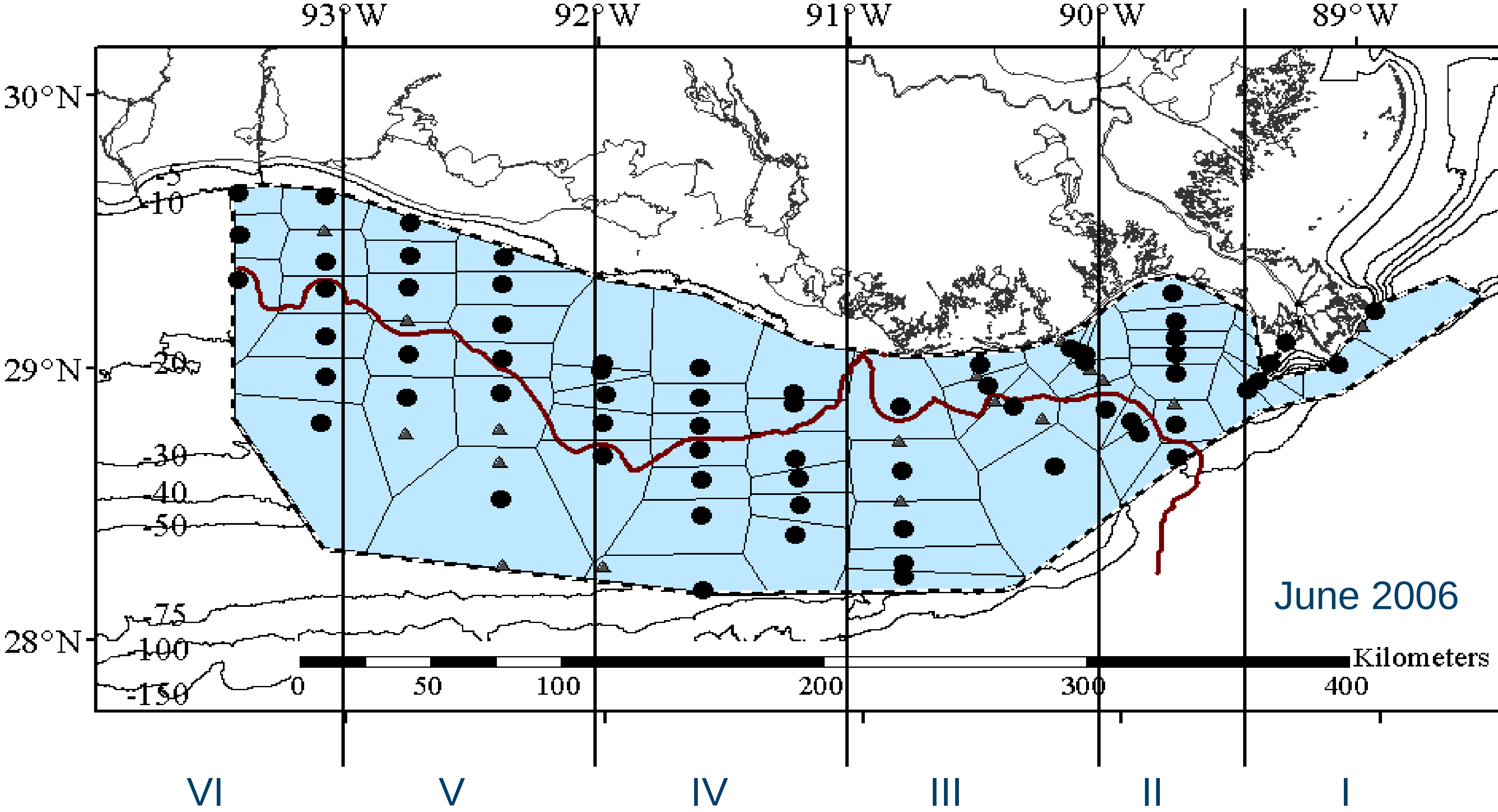
Surveys	# of stations CTD	Water	Sediment
Dec 2-15, 2002	36	19	0
March 17-31, 2003	65	36	6
June 9-23, 2003	51	25	7
Nov 5-19, 2003	70	42	9
April 2-7, 2004	22	22	4
March 21-31, 2005	66	42	10
Sept 26-Oct 9, 2005	65	50	0
March 23-April 6, 2006	131	98	3
June 6-22, 2006	125	95	3
Sept 5-19, 2006	125	95	3
April 24 – May 8, 2007	125	95	3
Aug 18 - Sept 1, 2007	125	95	3
Sept 25 - Oct 9, 2010	12	12	12
Total			
13	***1018***	***726***	***63***

Dissolved Inorganic – NO_x, PO_4, NH_4, Si	X	
Particulate C, N, P	X	X
Total Dissolved N, P, Total N, P	X	
Dissolved organic carbon	X	
Total Suspended solids	X	
Biogenic silica	X	
Chlorophyll a	X	X
PAR, secchi depth, attenuation	X	
Dissolved oxygen	X	
T, S, turbidity, in vivo fluorescence	X	
Phytoplankton species compostion	X	
Primary productivity rates (^{14}C & FRRF)	X	
Respiration rates (change in O_2)	X	
Bacterial productivity rates (^{3}H-Leucine)	X	
O_2, DIC, and nutrient flux rates		X
Denitrification rates		X
Grain size, Bulk density, porosity, % water		X
Pore water Fe, Mn, SO_4, NH_4, DIC, TN, TP		X
Solid phase Fe, C, N, P		X
Stable Isotope $\delta^{13}C$, $\delta^{15}N$		X
Sulfate, Fe, Mn reduction rates		X

Hydrography data archived with NODC

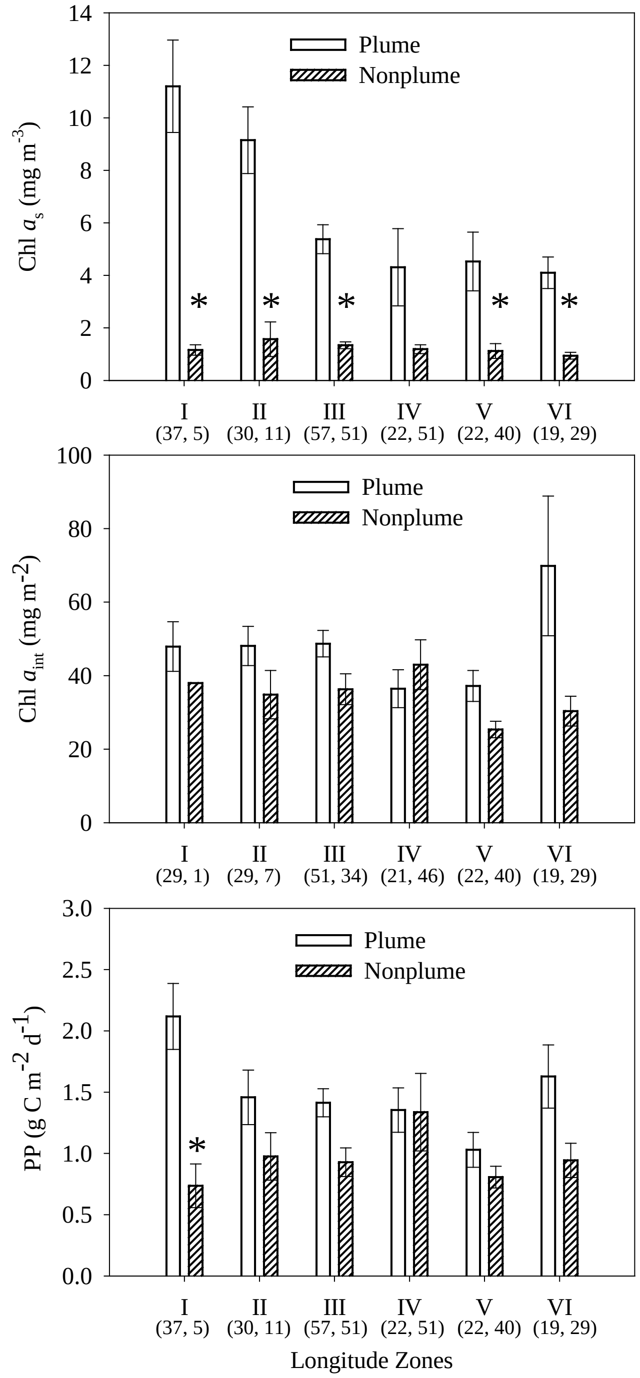
Primary Production Stations

Regional and domain estimation of primary production



Lehrter et al. (2009)

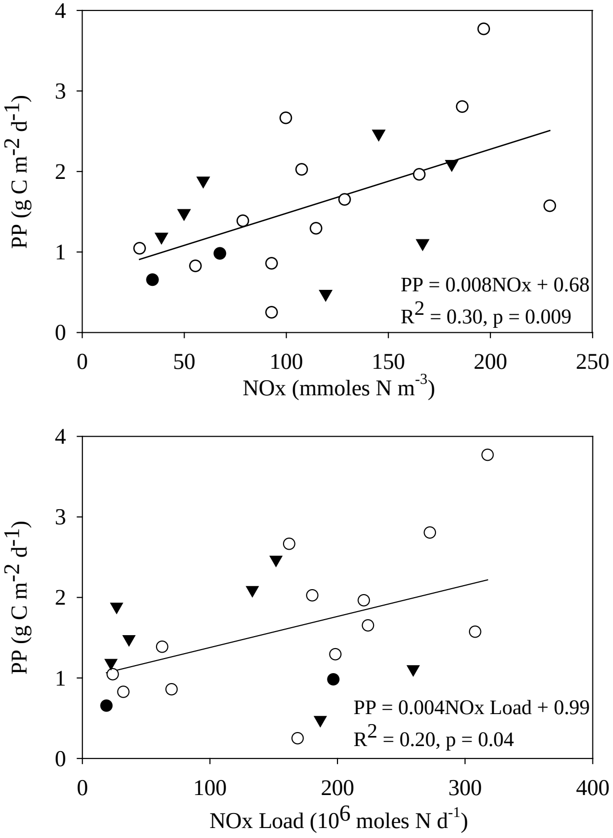
Spatial patterns



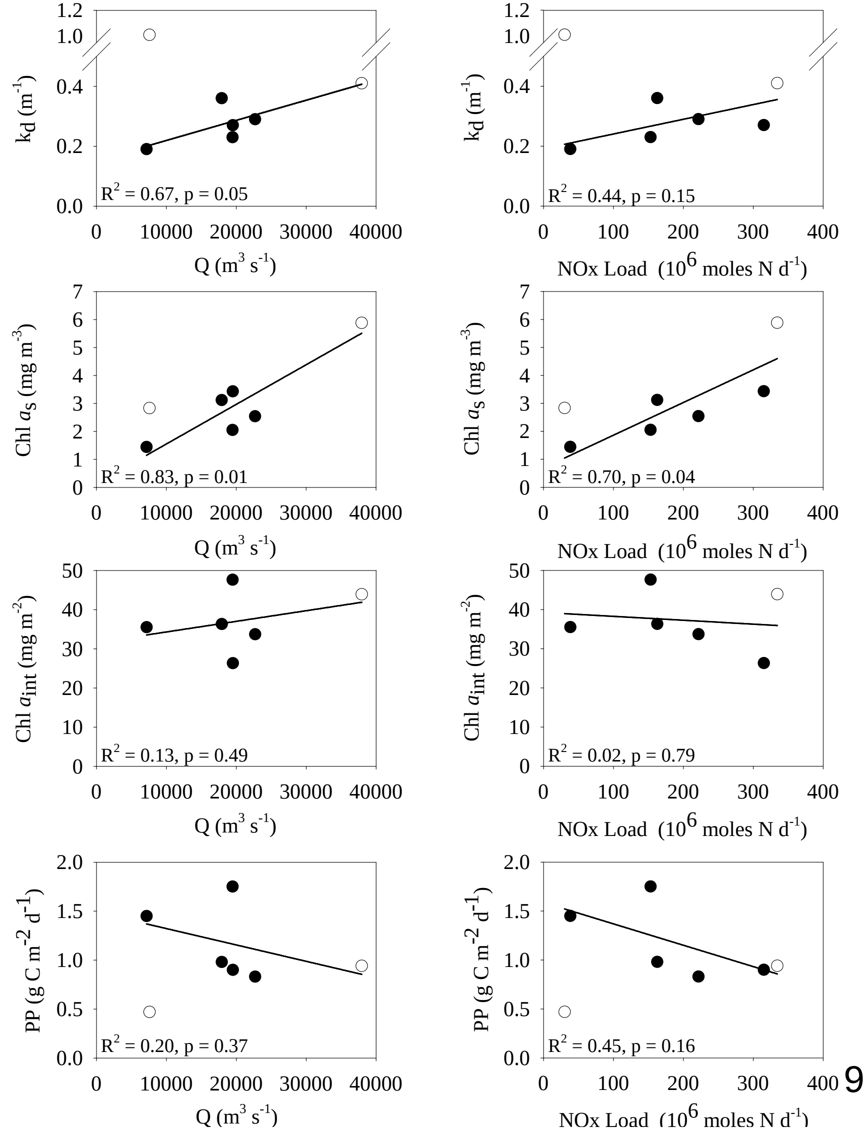
- Average spring/summer PP = 1.05 g C m^{-2} d^{-1}

Observed relationships with river inputs

Plume region averages adjacent to the birdsfoot delta

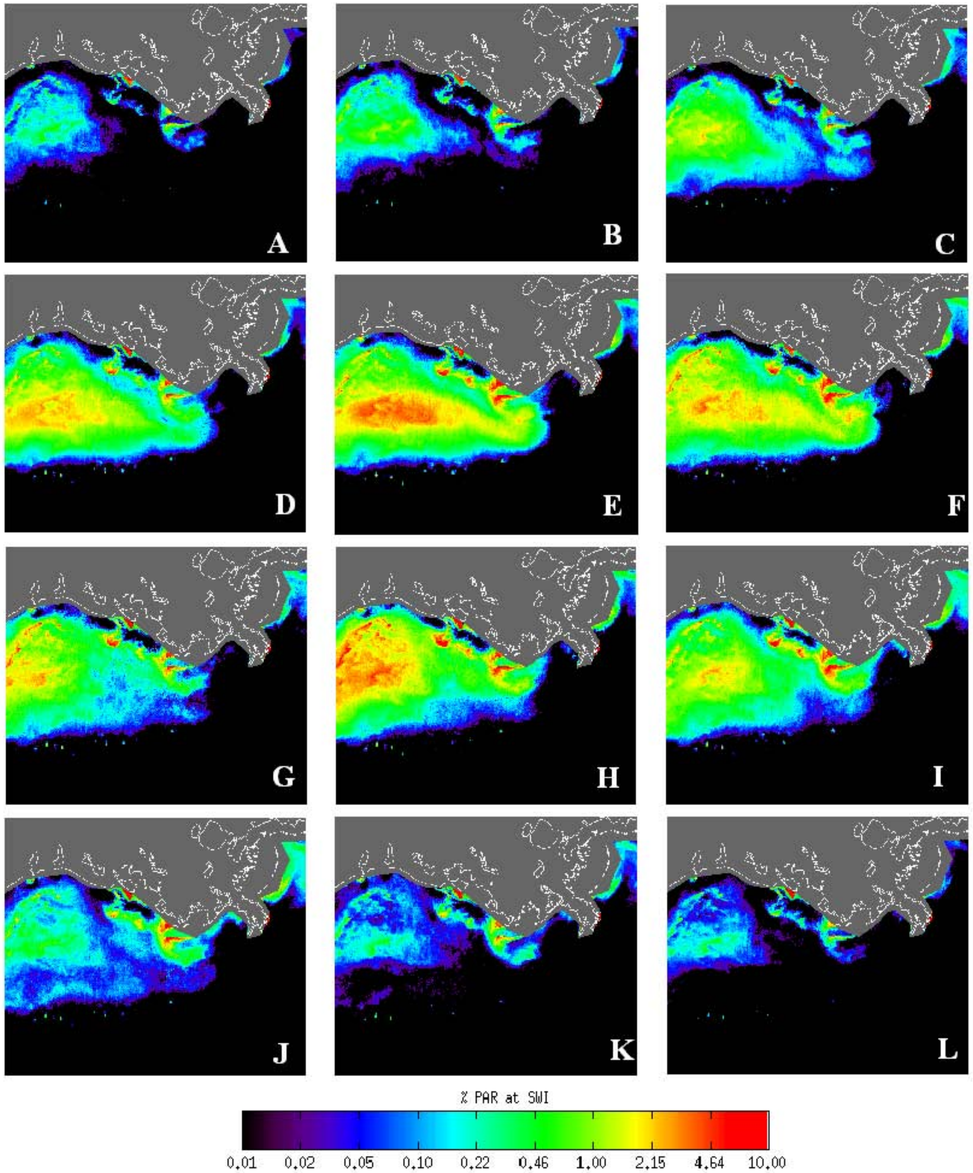


Shelf averages



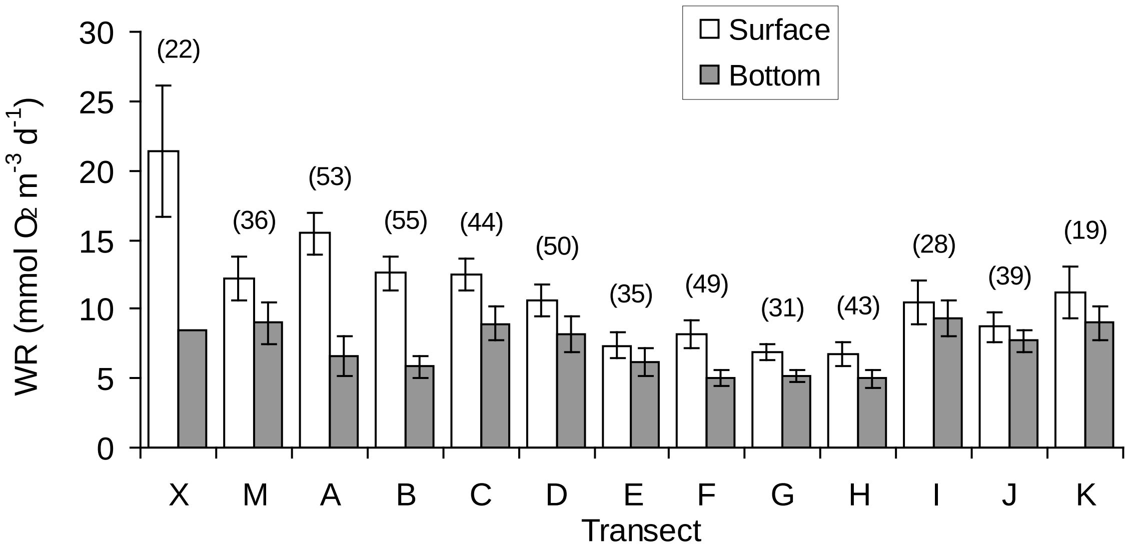
PAR at the seafloor

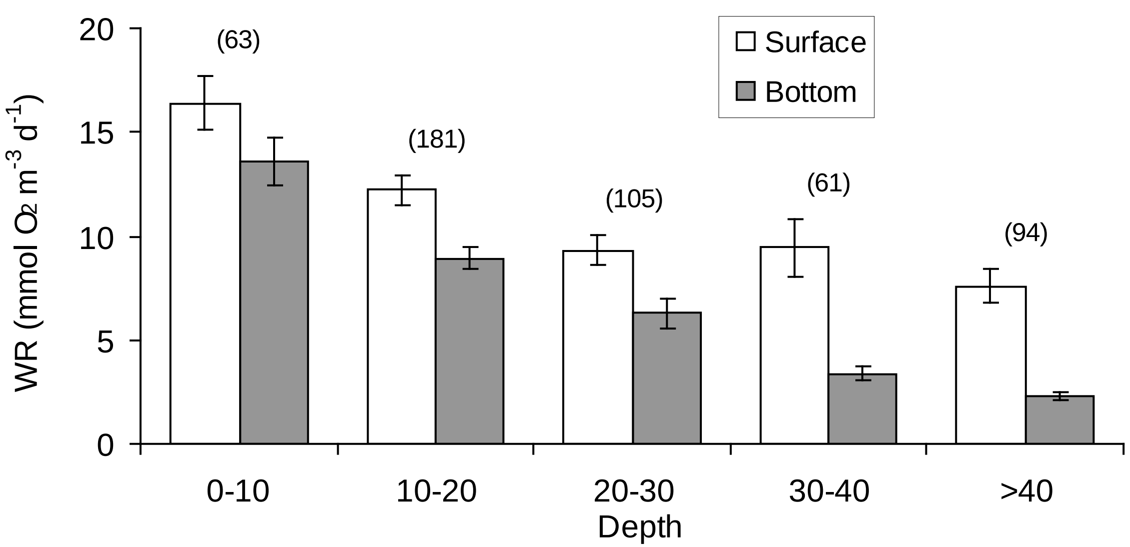
- Light attenuation was correlated with wind, discharge, and nutrients
- Estimated euphotic depths were often greater than the bottom depth
- Light may be a significant factor regulating bottom-water O_2 in this system



Schaeffer et al. (2011)

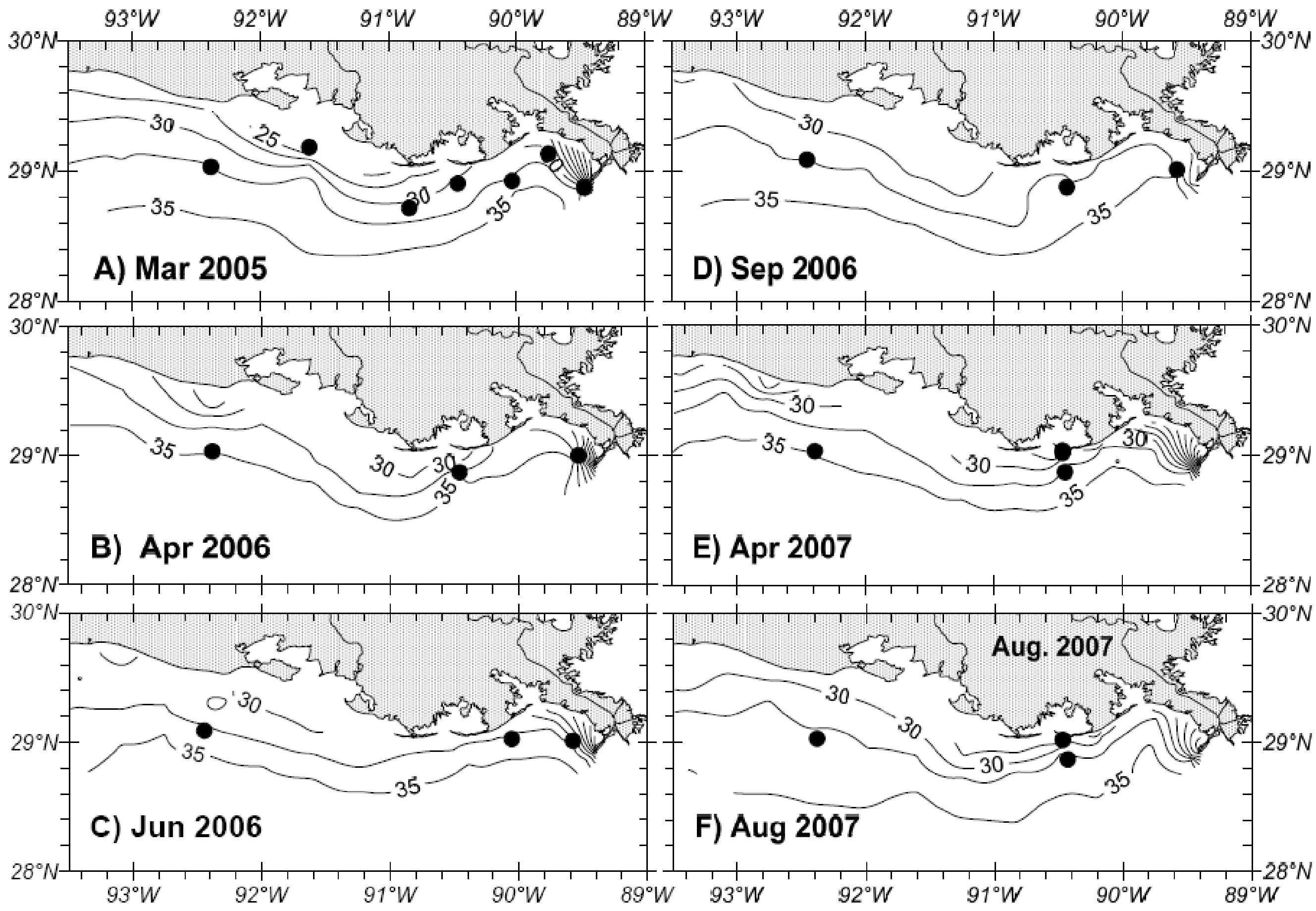
Respiration Patterns





Murrell et al. (in review)

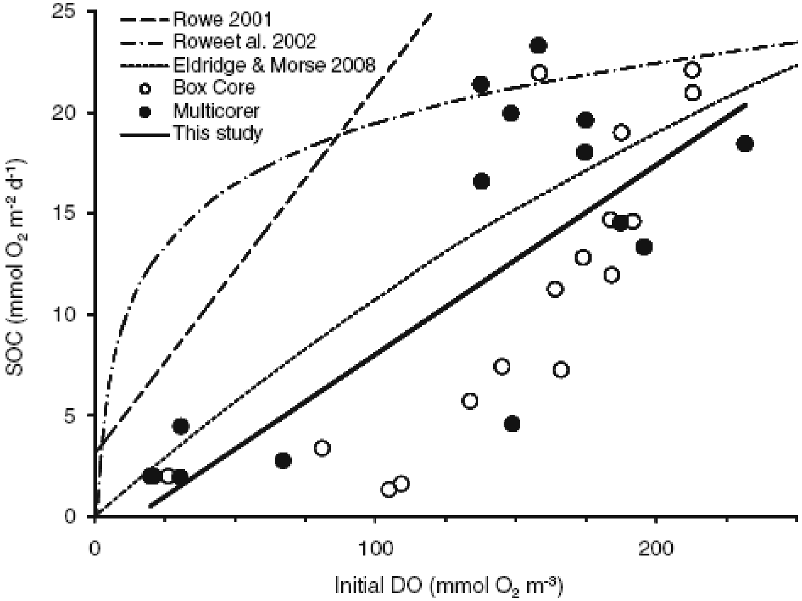
Sediment Stations

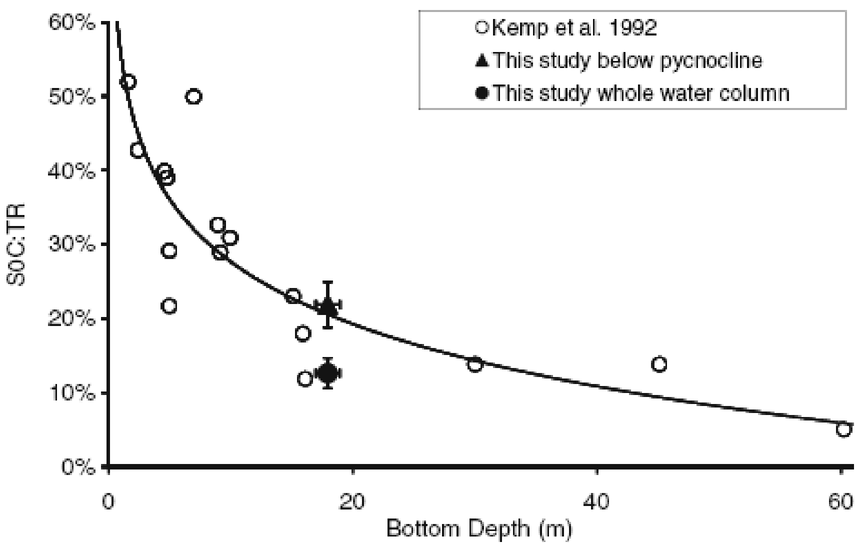


Sediment oxygen consumption

SOC rates typical of other estuarine and coastal systems and vary primarily as a function of bottom-water O2

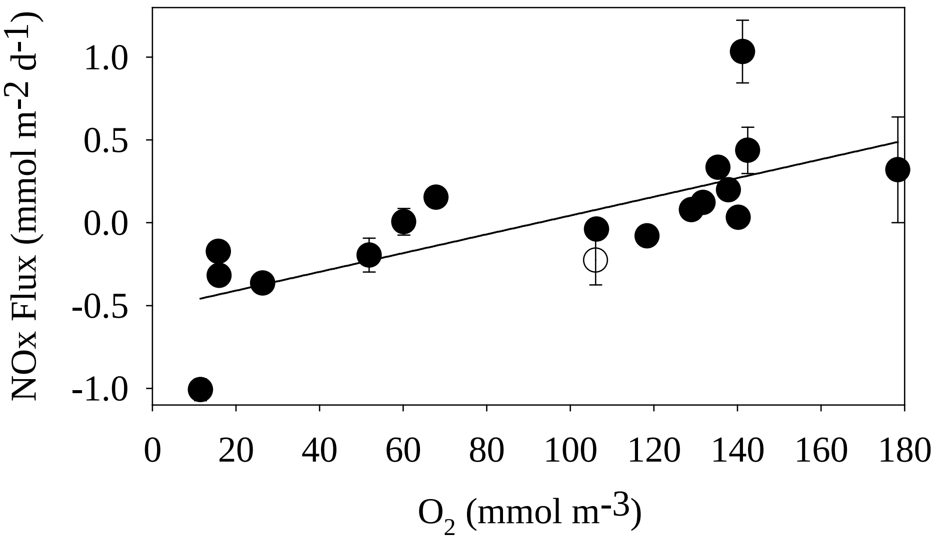
On average, SOC accounted for 20% of sub-pycnocline respiration





Murrell and Lehrter (2011)

Relationship between O_2 and sediment-water NO_3^- exchange

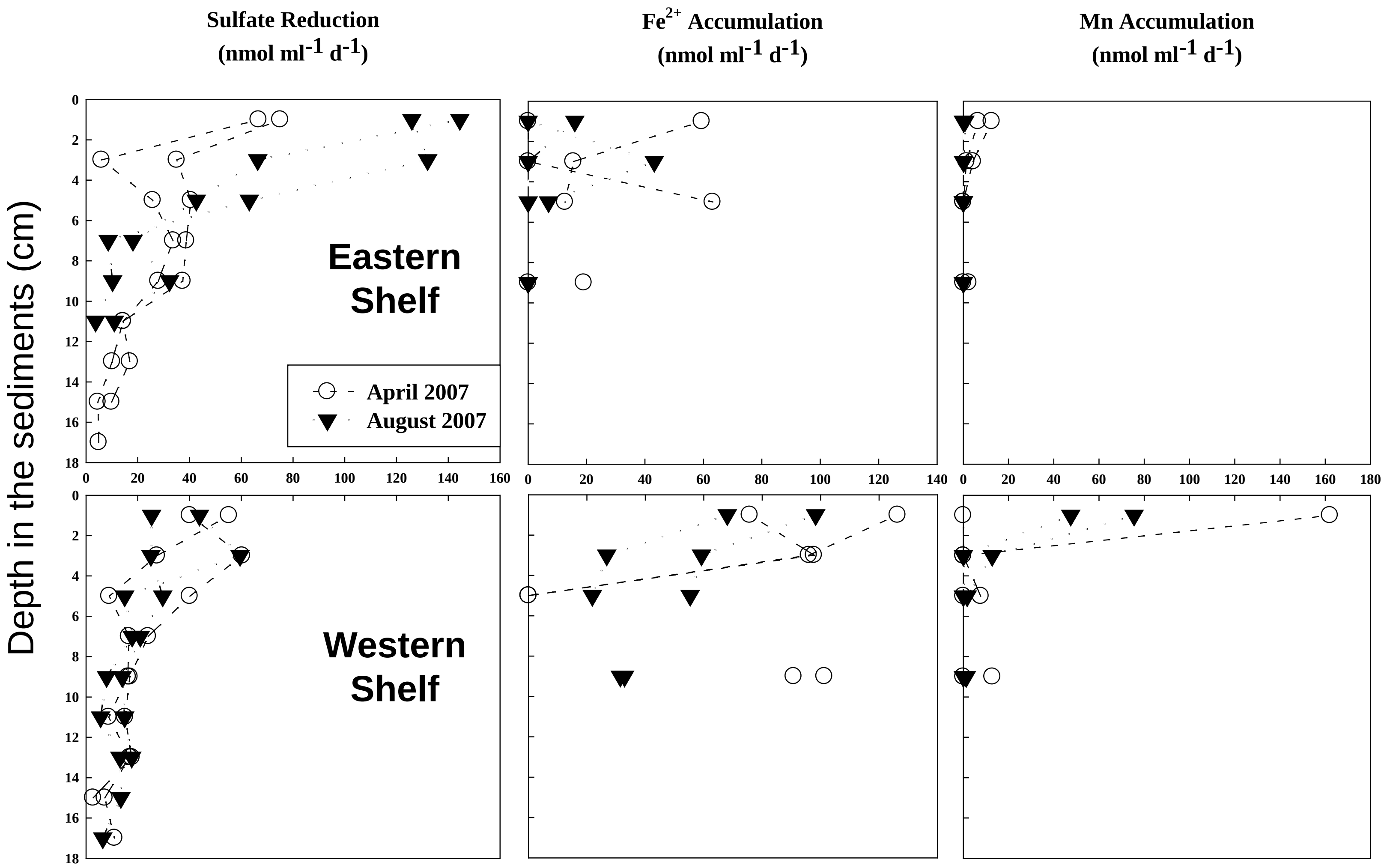


Other Findings

- Sediment nutrient fluxes could supply only a minor fraction of water-column N&P demand by phytoplankton
    - Fluxes were potentially a more significant source beneath the pycnocline
- Denitrification occurred primarily through coupled nitrification-denitrification
- Avg rate = 1.4 mmol N m^{-2} d^{-1}
- Extrapolated to the area of the shelf (to the 200-m contour), this N sink represents 39% of the River TN load

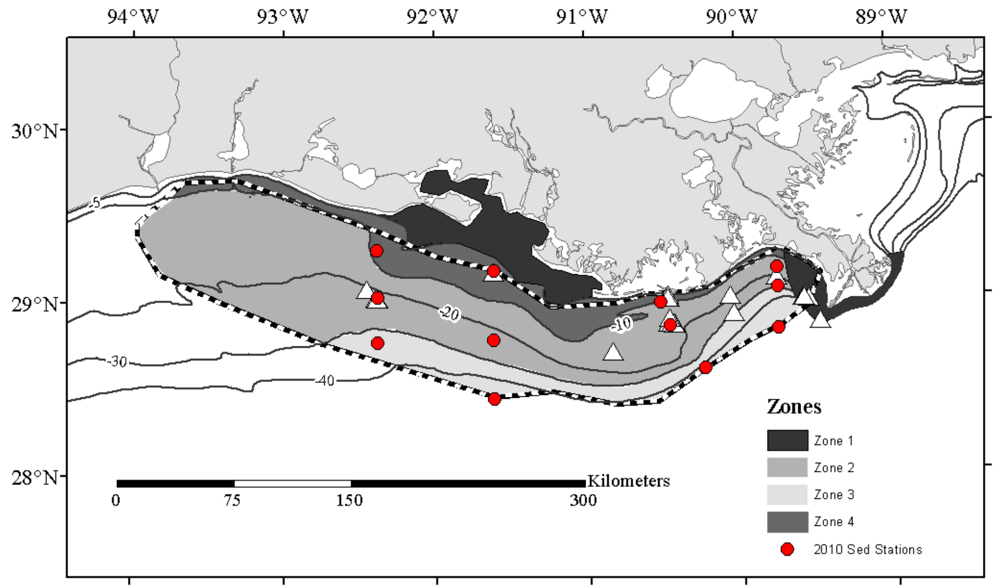
Lehrter et al. (2011)

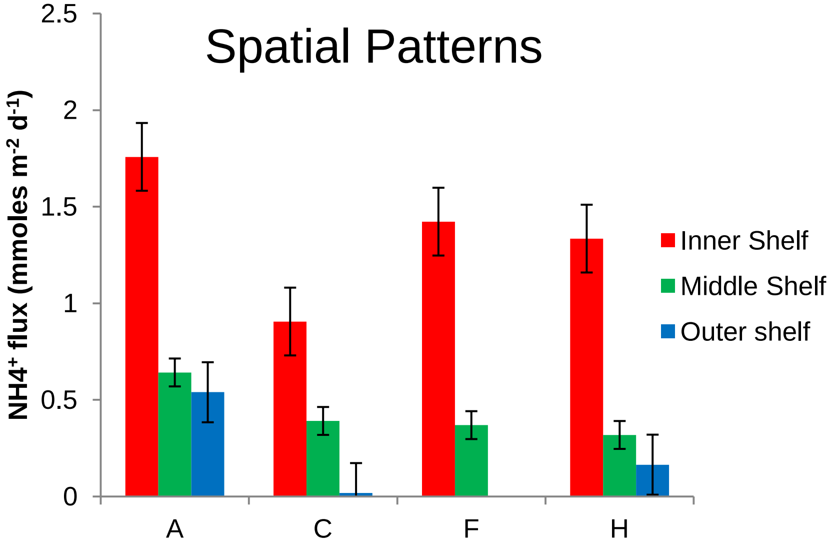
Oxygen feedback on other important biogeochemical processes



Devereux et al. in review

Sept. 2010 cruise was undertaken to assess hypothesized inshore to offshore dominant gradient





In prep

- Rates of sediment-water exchange and diagenesis process rates were generally oriented from inshore to offshore
- Sediment-water exchange patterns were modified by bottom-water O_2 concentrations

Summary

- Largest spatial gradients in rates occur in an inshore-offshore direction
- Patterns in light attenuation indicate the water-column and sediments are euphotic for large regions of the shelf
- SOC and some nutrient fluxes were strongly coupled to O_2 concentrations
  - SOC was observed to be a minor component of water-column respiration
- Denitrification rates were sufficient to remove an estimated 39% of the TN load to the shelf
- Availability of Fe and Mn as electron acceptors limits sulfate reduction to sulfide

Next Steps

- Analyses and syntheses to develop shelf oxygen, carbon, and nutrient budgets
- Tools for evaluating the “effects of river outflow on ocean life” .

The Gulf Ecology Division Hypoxia Research Team