Spatial and Temporal Patterns in Carbon, Oxygen, and Nutrient Cycling in the northern Gulf of Mexico hypoxic zone

Brian J. Roberts[1], Wendy Morrison[1], Nancy N. Rabalais[1], and R. Eugene Turner[2]

[1]Louisiana Universities Marine Consortium (LUMCON), Chauvin, LA
[2]Coastal Ecology Institute & DOCS, LSU-Baton Rouge

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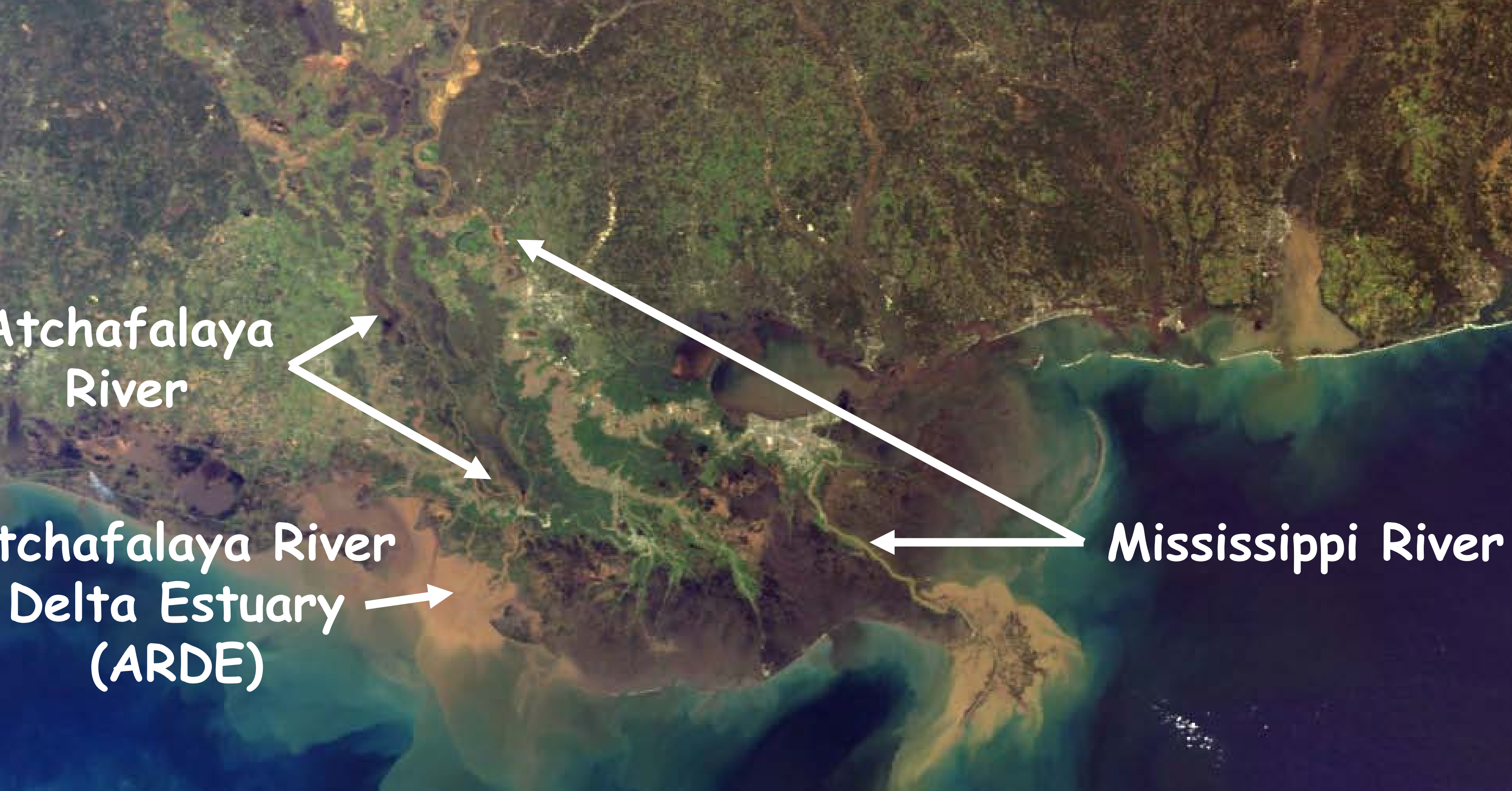
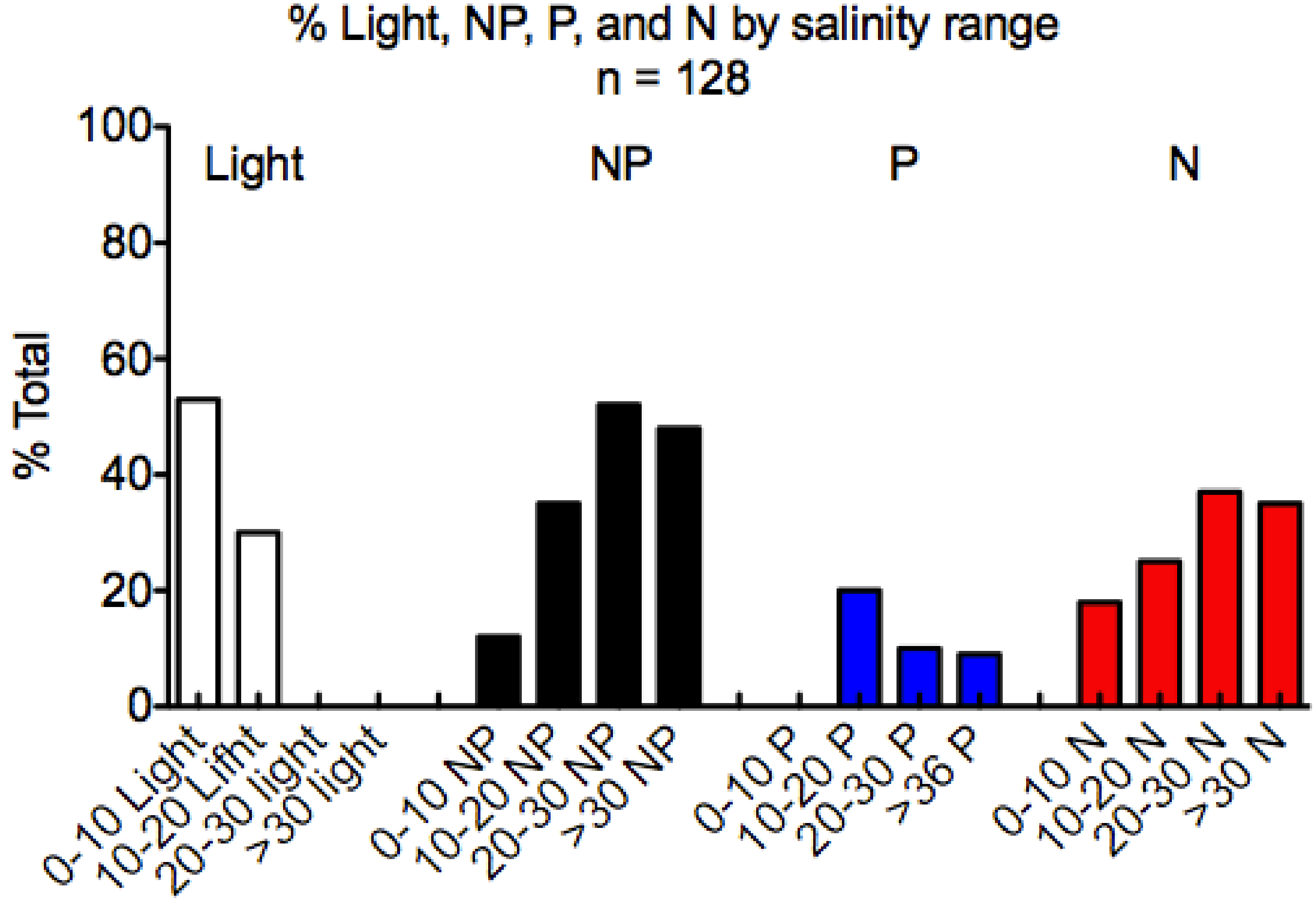


- Most research has focused on the main stem MR and its plume
- However, only ~50% of annual discharge via Southwest Pass goes west to the area of shelf suffering from hypoxia
    - 50% of 70% of total flow = 35% --not much different from 30% of AR
- MR discharges into deep water compared to AR which discharges into shallow ARDE (< 3m) then a shallow broad, low-gradient shelf (10m isobath > 40km offshore)—much greater potential for biogeochemical transformations in ARDE system

What Limits Phytoplankton Growth?

- 158 Bioassay experiments using surface samples collected from Louisiana shelf
- April – November
- July hypoxia cruises in 1984, 1994, 2005, 2010, 2011
- 81 between 1981 and 2009, 62 in 2010, and 15 in 2011



Turner and Rabalais (In review)

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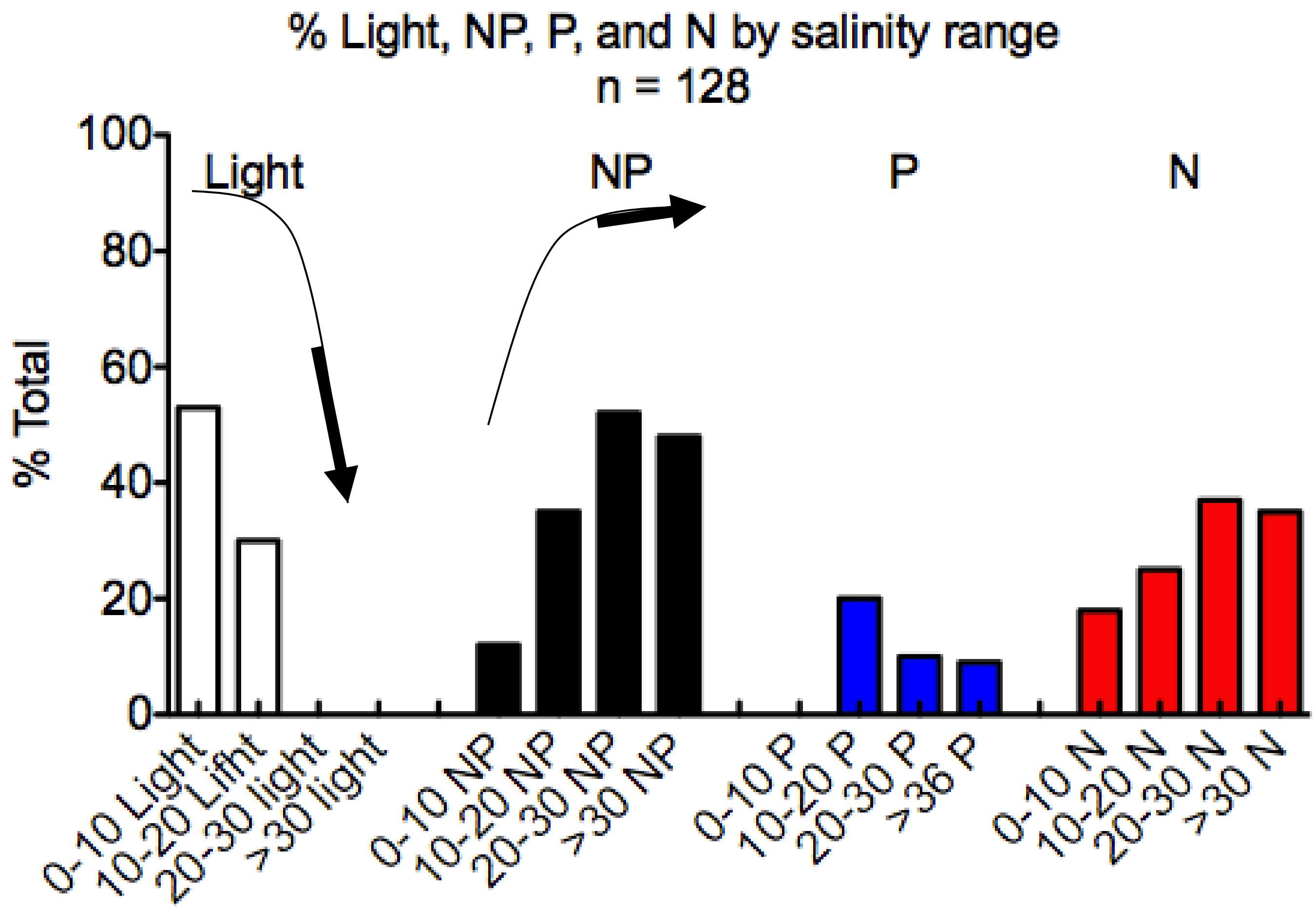

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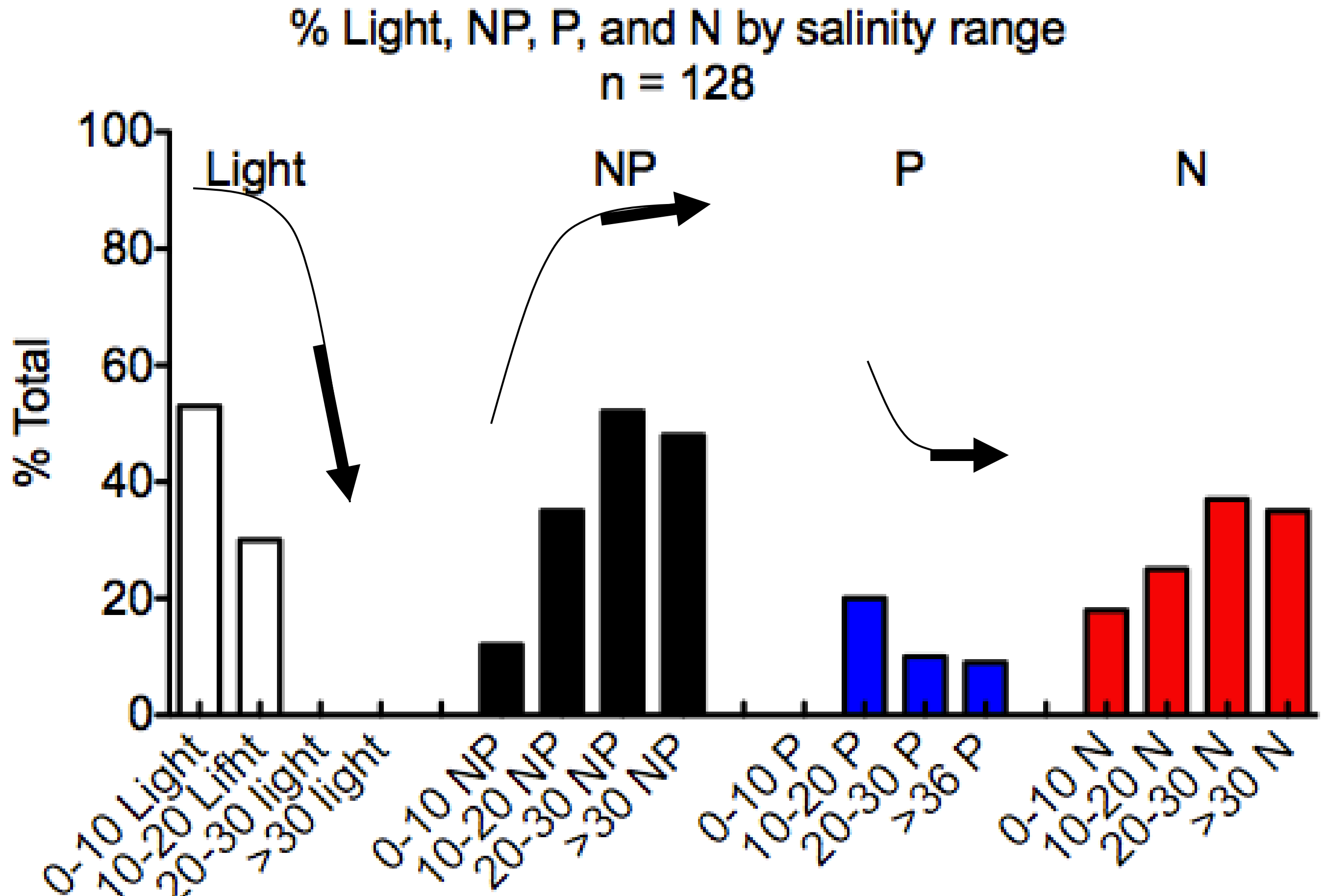

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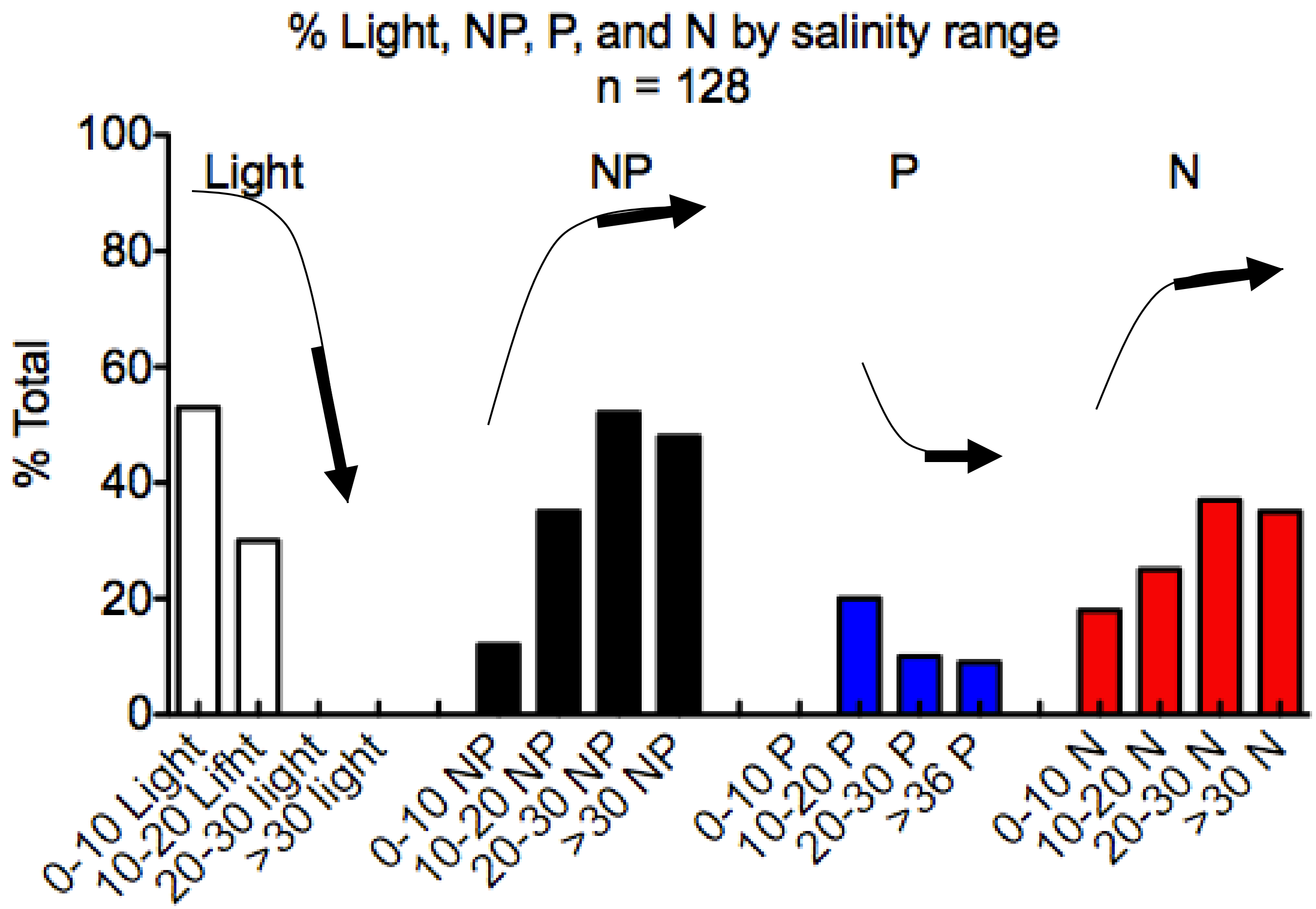


Turner and Rabalais (In review)

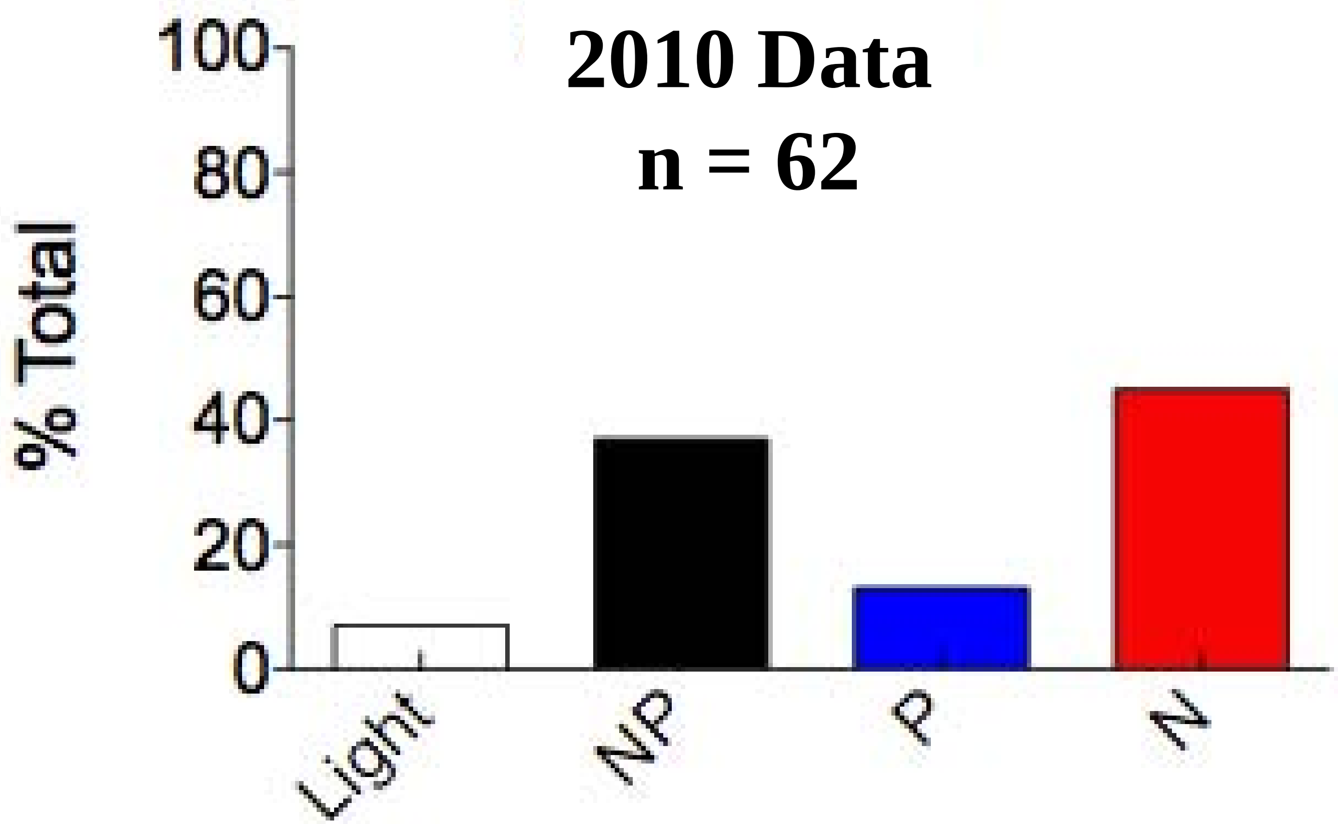
What is the relative significance of N and P on phytoplankton growth limitation?

Seasonal: no obvious changes among years

Annual: no obvious changes among years

Shelfwide: N and NP are the dominant limiting factor;
P of lesser importance (10%?);
Light limitation < 15 psu

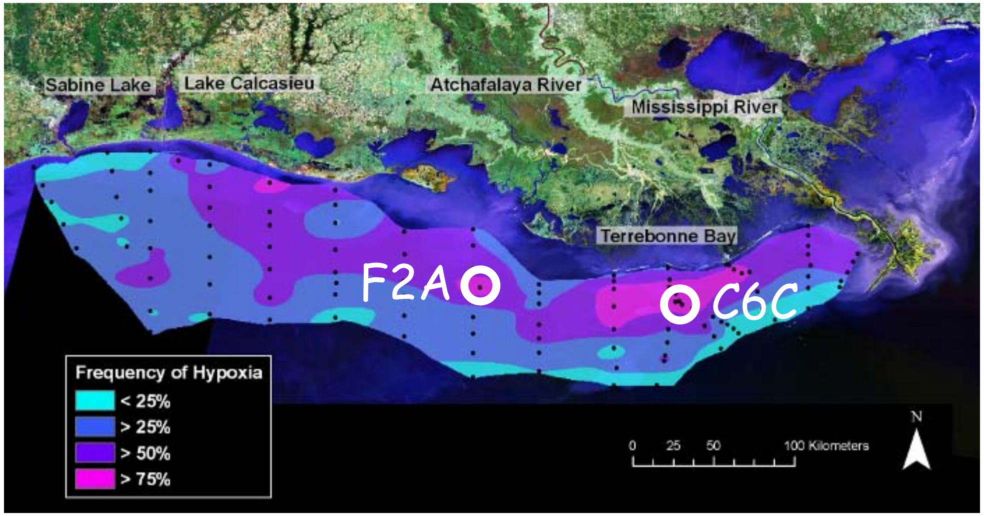
Salinity gradient: transition from light limitation (turbidity), to N with some P (relatively nutrient rich), and then to mostly NP (most dilute) that may be synergistic



- N and NP co-limitation most common (~ 85%)
- P limitation (~ 10%)
- Light limitation (~ 5%)

Turner and Rabalais (In review)

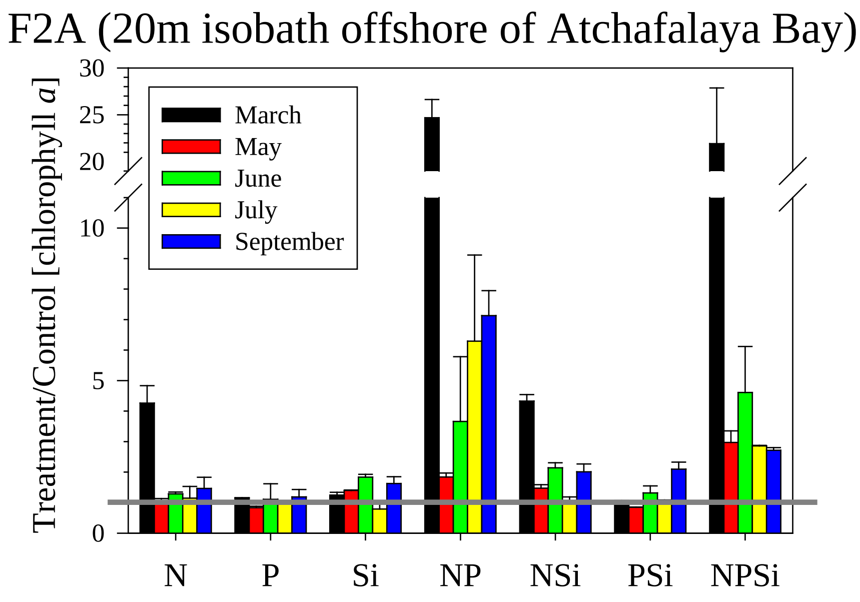
Carbon production and cycling dynamics
(A new spin on nutrient limitation experiments)

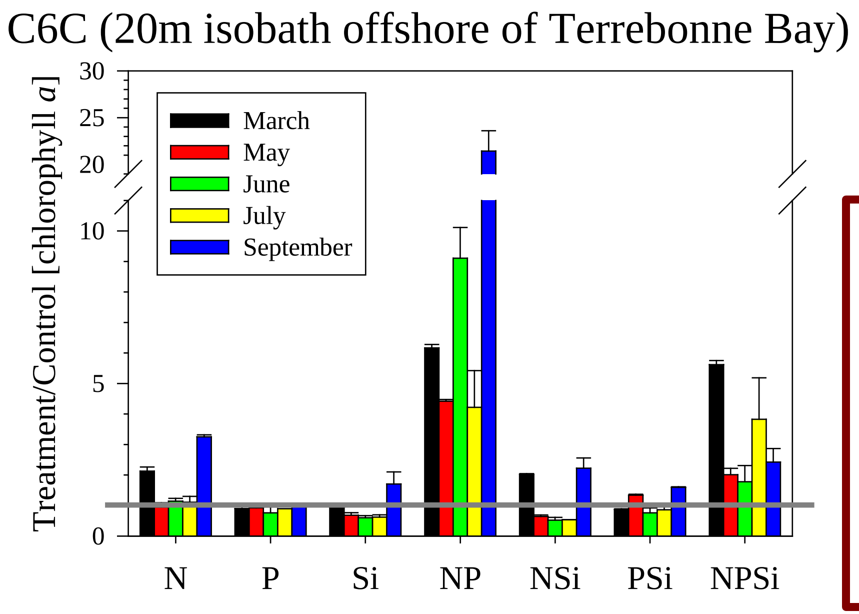


5 Experiments
(March, May, June, July, Sept 2010)

- *Water Collected from C6C & F2A*
- *Replicated Nutrient Treatments:*
  (Control, +N, +P, +Si, +NP, +NSi, +PSi, +NPSi)
- *Examination of Fe limitation*
  Fe spikes to BOD bottles on day 2
- *Parameters monitored:*
  inorganic nutrients, chlorophyll *a*, POC/PN/PP, DOC/DON, size-fractionated chlorophyll and POC/PN, phytoplankton, HPLC, bacteria, zooplankton

Carbon production and cycling dynamics



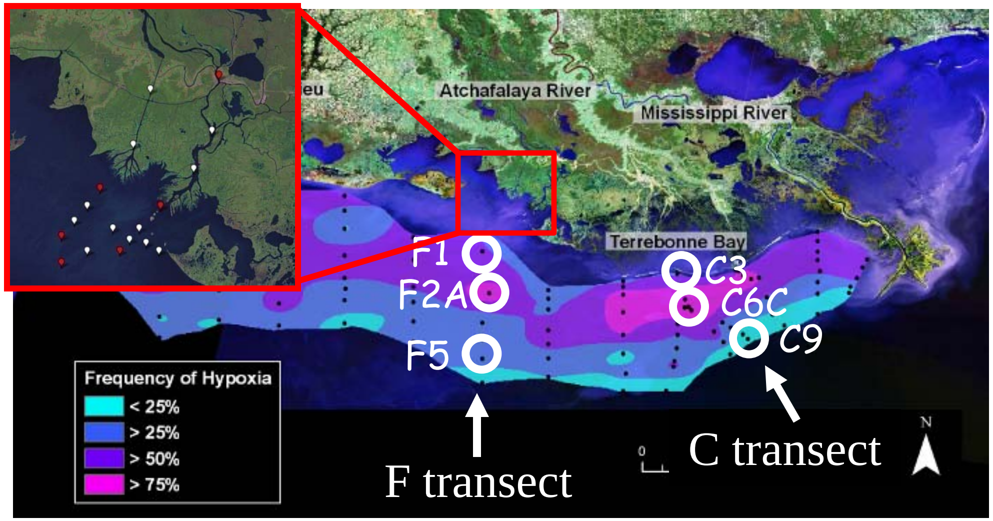


- N and P co-limitation most common
- N alone in some cases
- No evidence of P limitation
- +NPSi often yielded lower stimulation in chlorophyll

Need to go beyond looking at bulk chlorophyll and primary production to understand importance to hypoxia development

Water Column Respiration and Nutrient Cycling

(Apr, Jun, Aug, Oct 2010 and Apr, Jun, Jul, Aug 2011)



2 sets of paired experiments

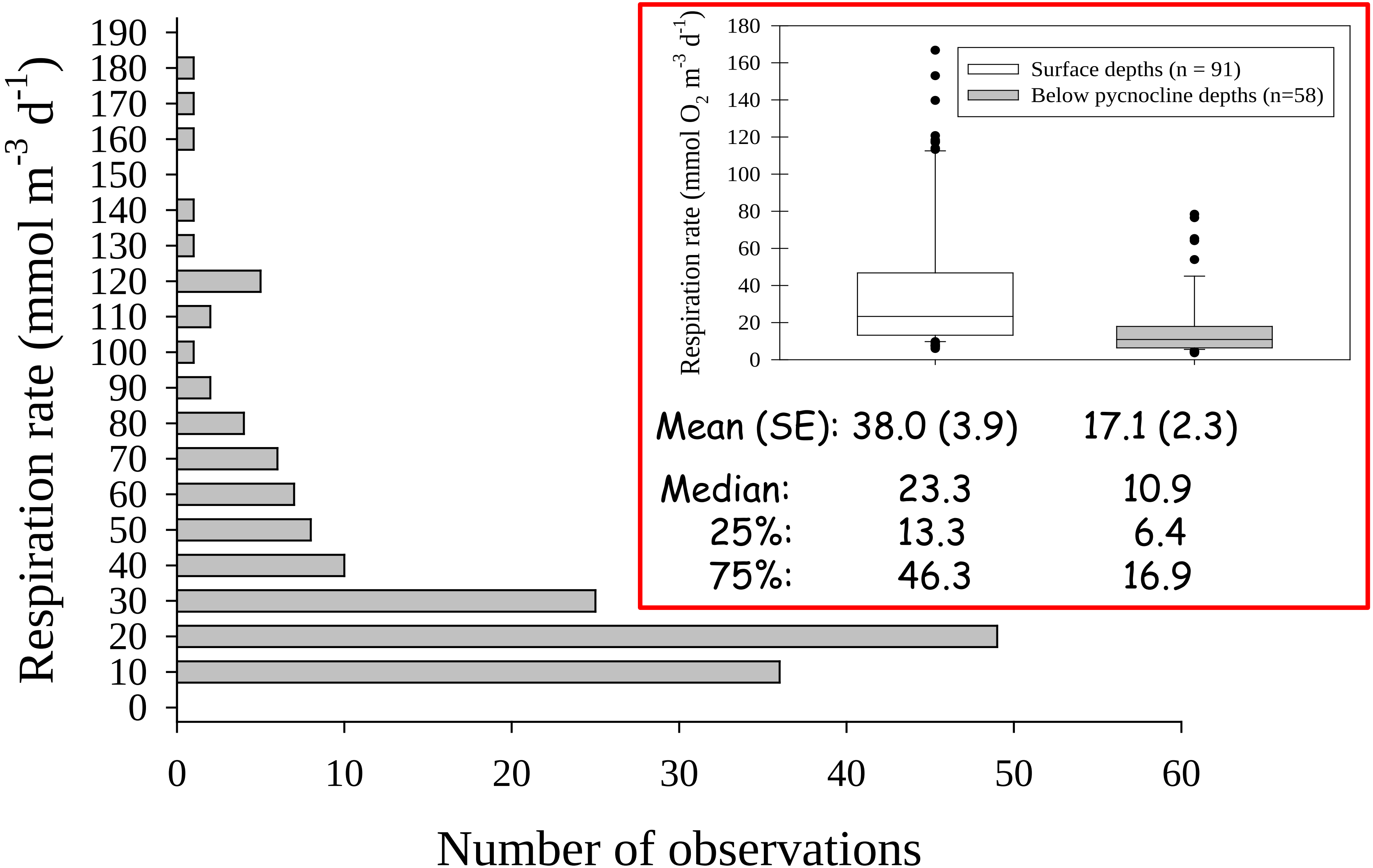
- 3 stations (4 in 2011) each on C & F transects (5-7 depths per station)
- 6 stations in lower AR & ARDE (surface and bottom waters only)

Rate Measurements

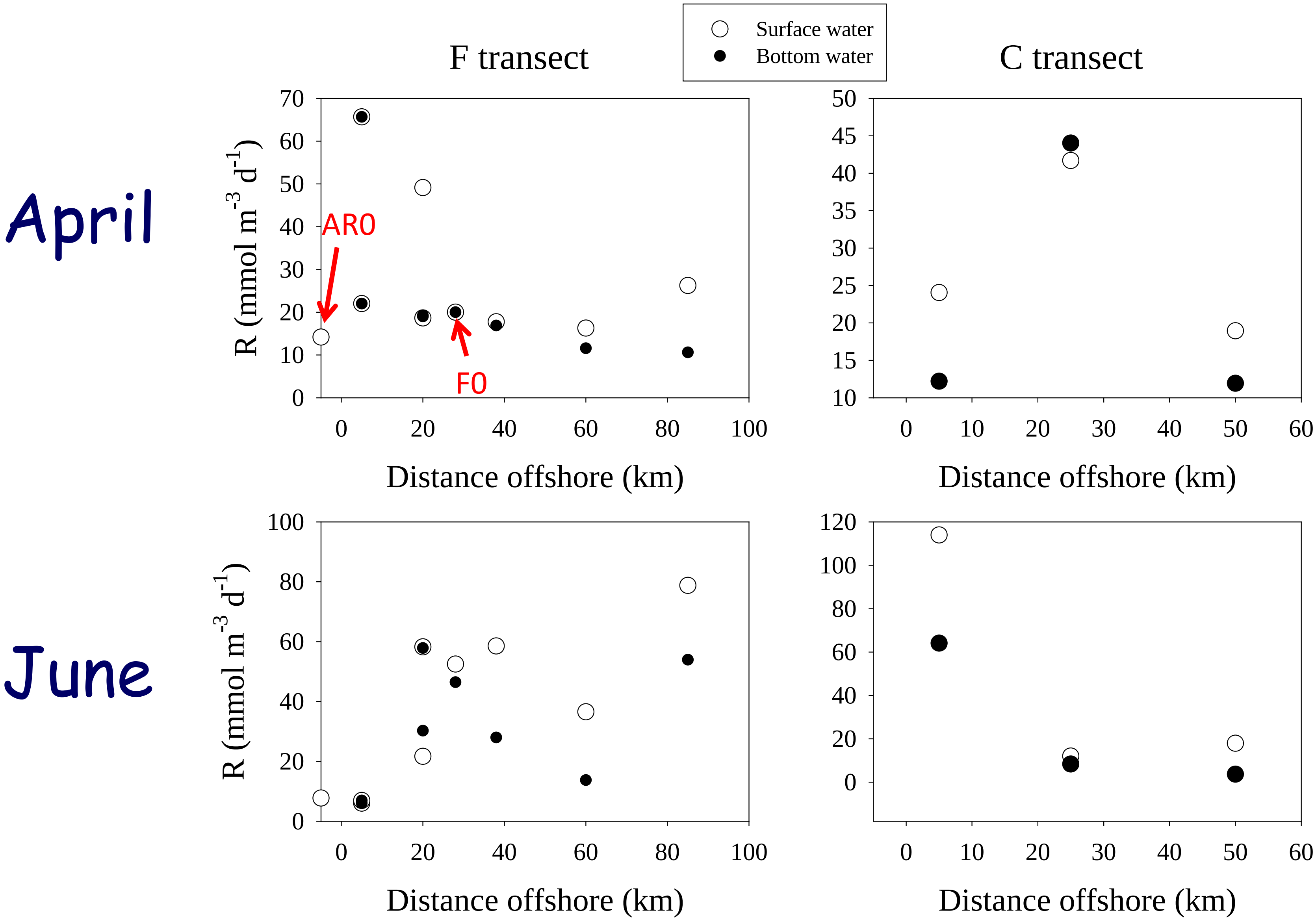
- Inshore-offshore and vertical patterns water column R rates
- Inshore-offshore & vertical patterns in net C & nutrient uptake rates
- In August, measured net N_2 fluxes for all 6 C & F station incubations

- Inshore-offshore & vertical patterns in CO_2, CH_4, N_2O concentrations in August 2010 and N_2/Ar ratios since August 2010 cruise

Water column R rates spans wide range: 3.7 – 176.8 mmol O_2 m^{-3} d^{-1}



Water column R rates vary seasonally & with distance offshore



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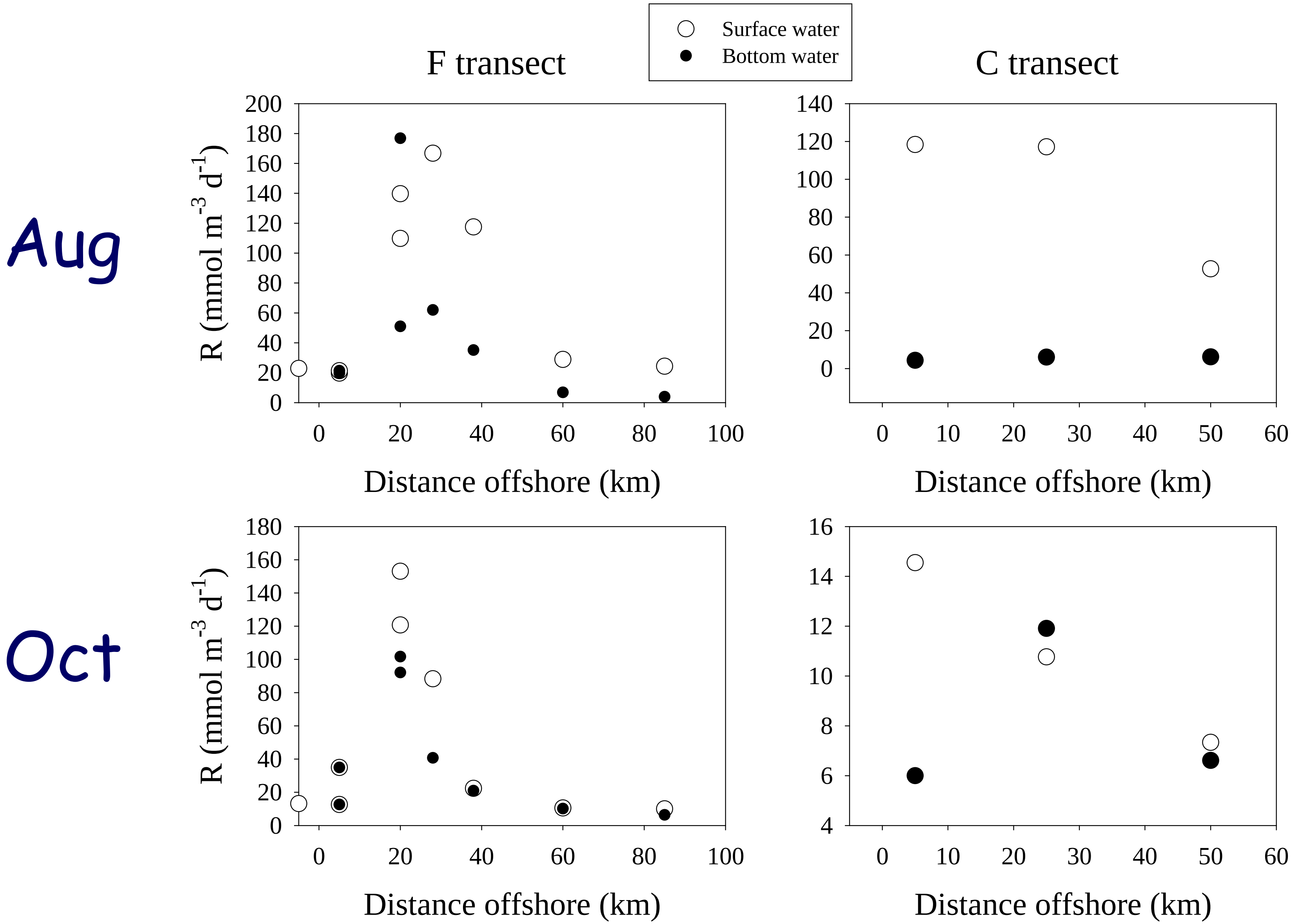
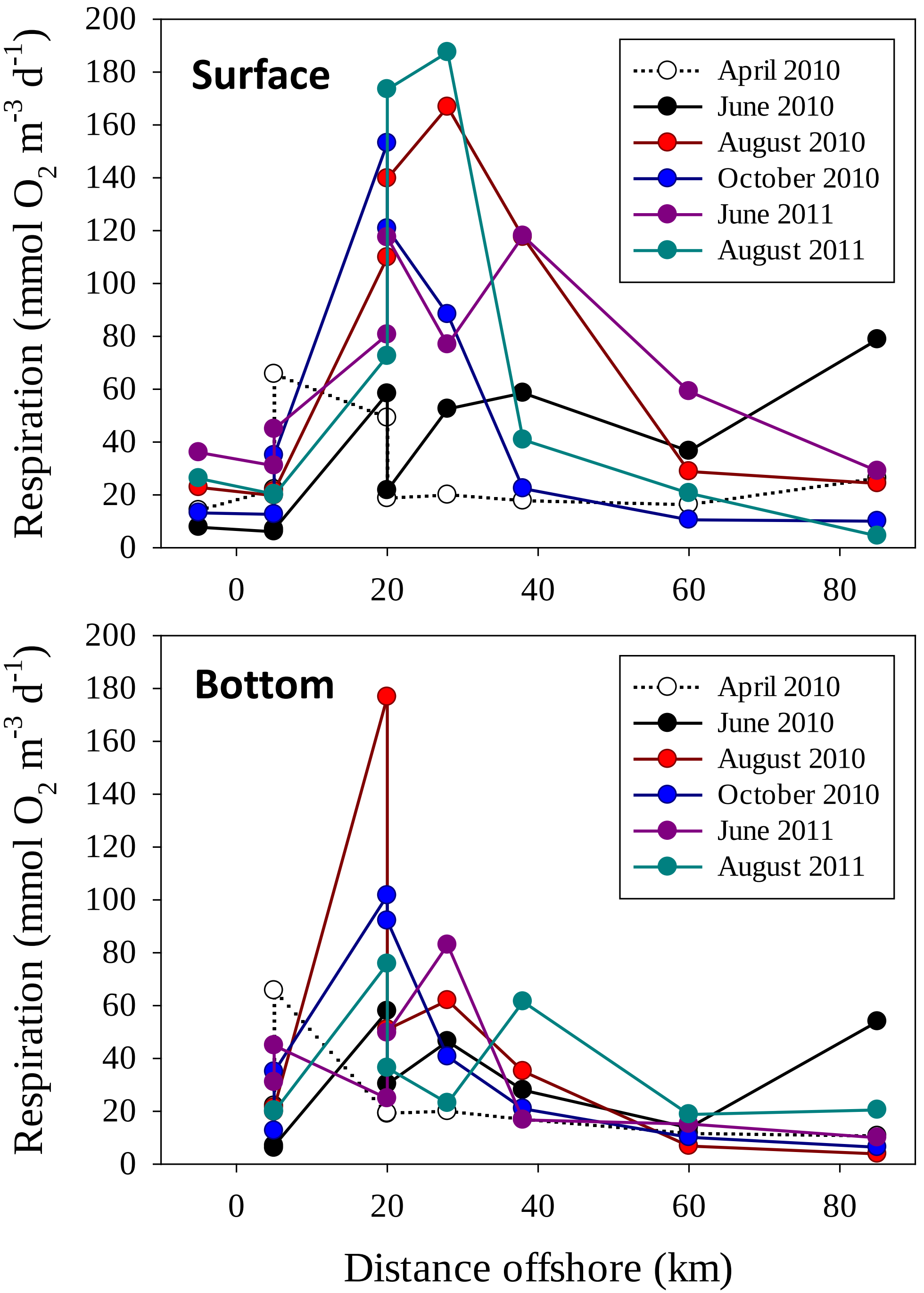
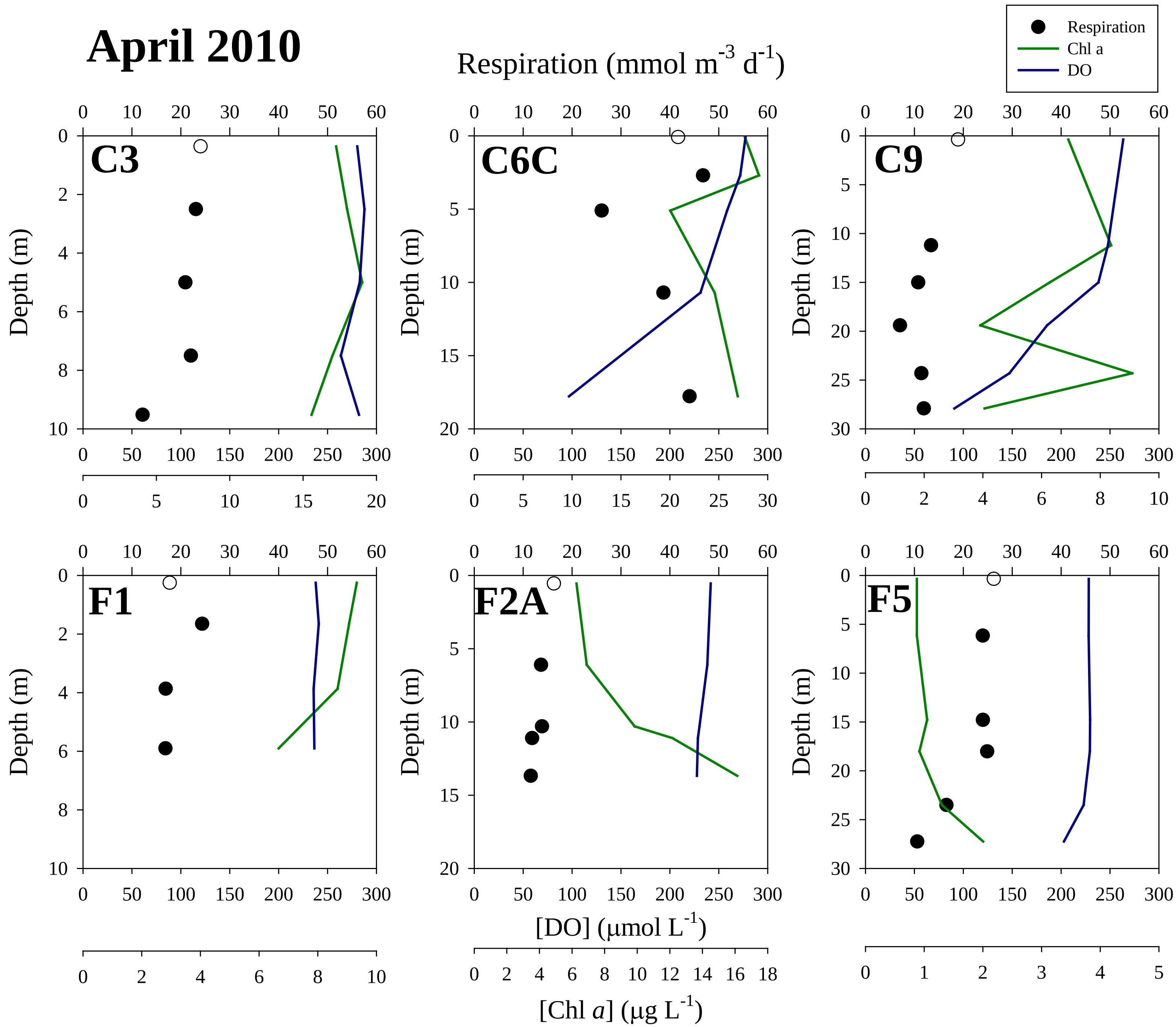


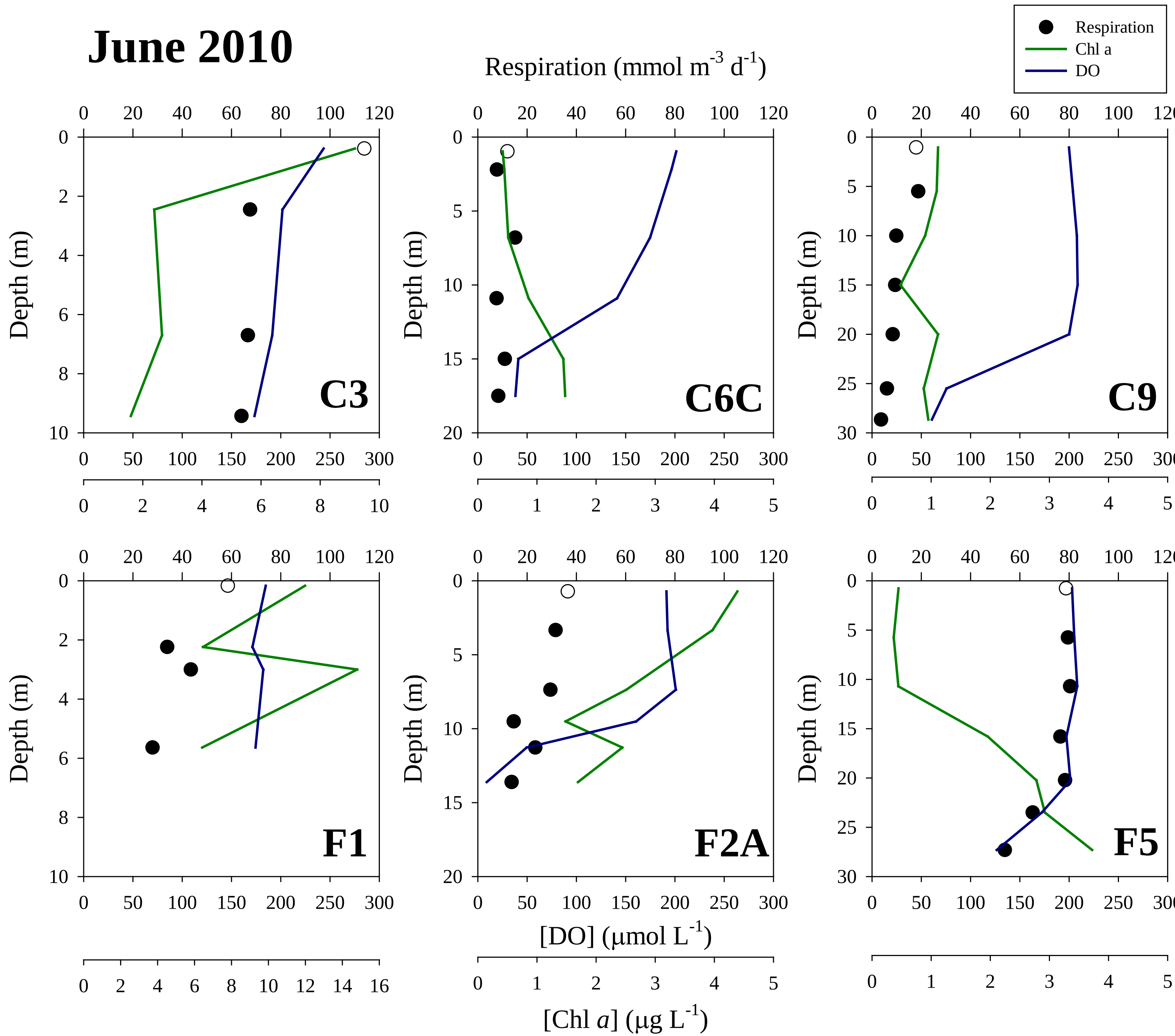
High variability in Respiration with distance offshore over time in surface waters and bottom waters

- Displaying 6 of 9 complete transects sampled off of Atchafalaya River

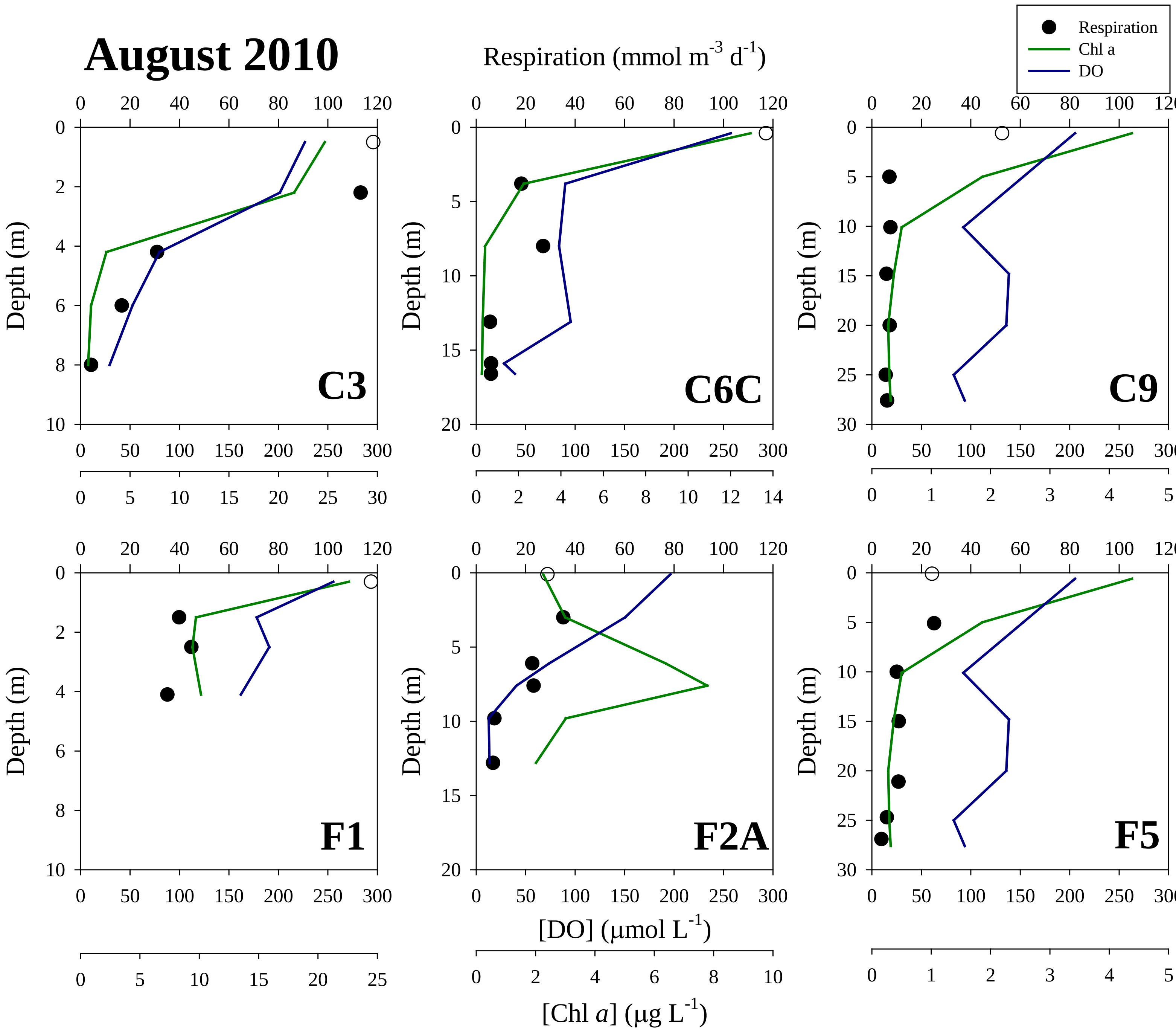




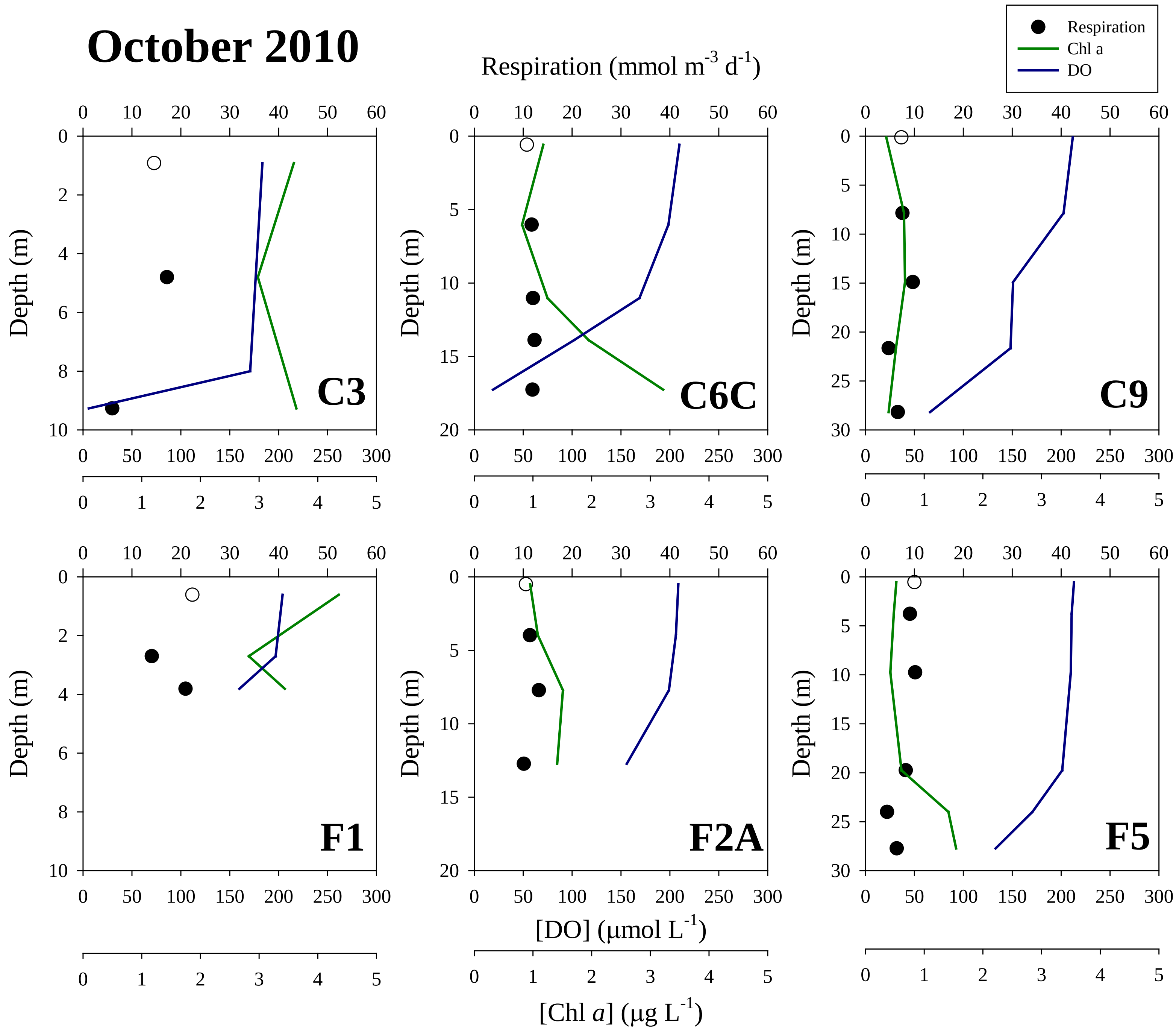
April 2010
Respiration (mmol m-3 d-1)
Respiration
Chl a
DO
C3
C6C
C9
F1
F2A
F5
Depth (m)
[DO] (µmol L-1)
[Chl a] (µg L-1)



June 2010
Respiration (mmol m-3 d-1)
Respiration
Chl a
DO
Depth (m)
C3
C6C
C9
F1
F2A
F5
[DO] (μmol L-1)
[Chl a] (μg L-1)



August 2010
Respiration (mmol m-3 d-1)
Respiration
Chl a
DO
C3
C6C
C9
F1
F2A
F5
Depth (m)
[DO] (μmol L-1)
[Chl a] (μg L-1)

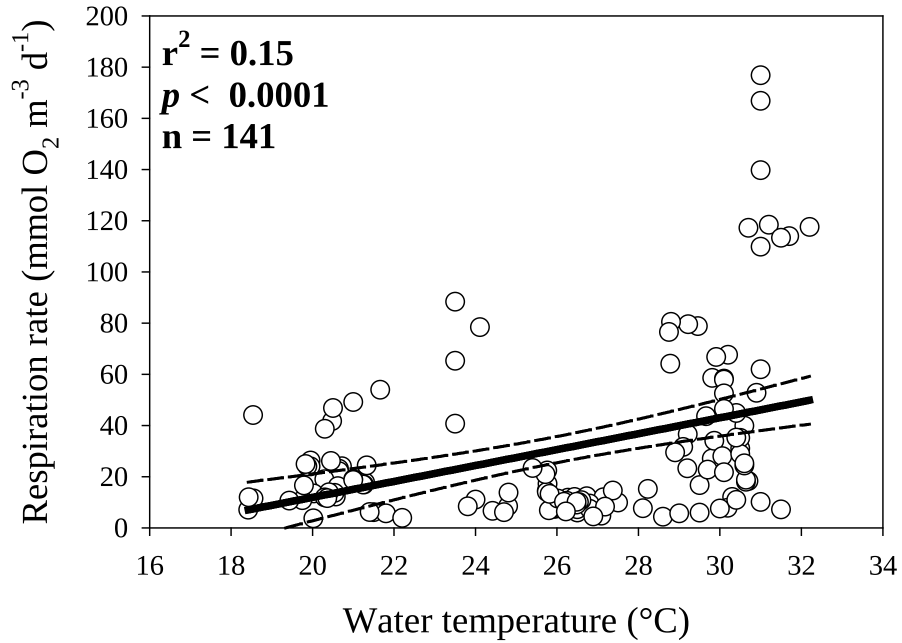


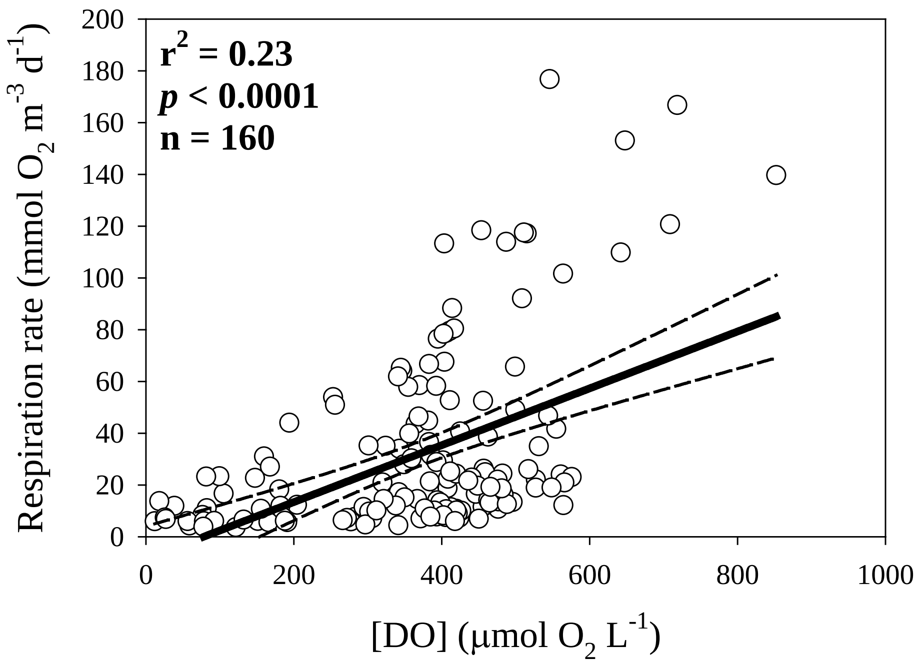
October 2010
Respiration
Chl a
DO
Respiration (mmol m-3 d-1)
Depth (m)
C3
C6C
C9
F1
F2A
F5
[DO] (µmol L-1)
[Chl a] (µg L-1)

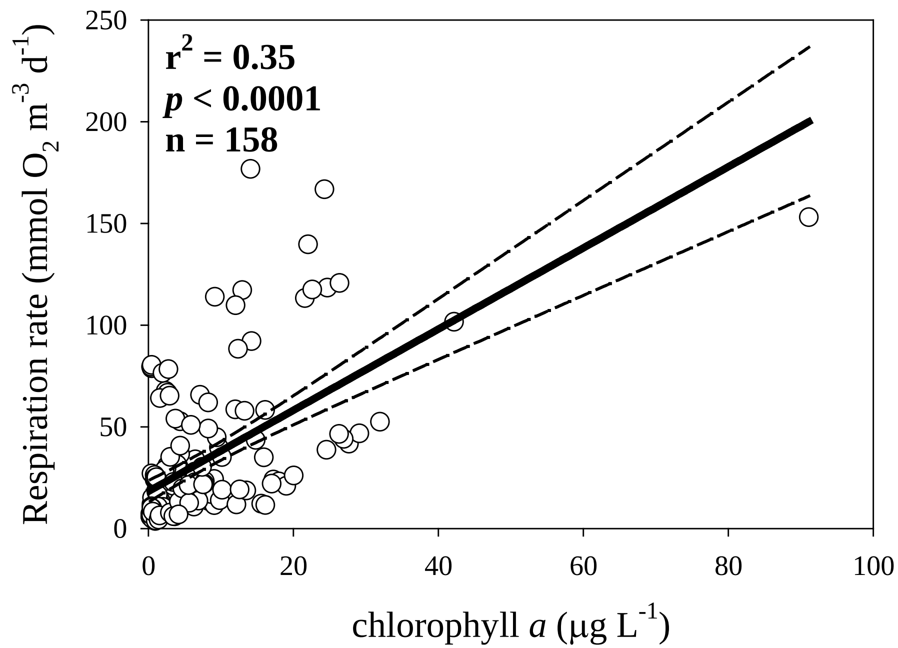
Much more detailed analyses are still needed, but a few things that show significant relationships with water column R rates include:

- Temperature
- Dissolved O_2
- Chlorophyll *a*

Note: inorganic N & P do not correlate with R

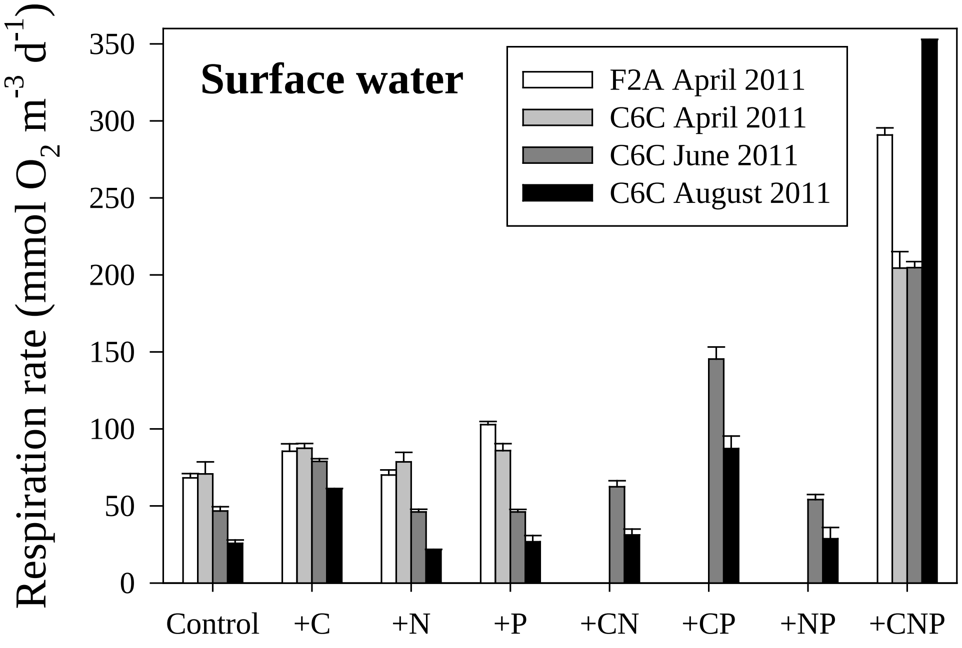


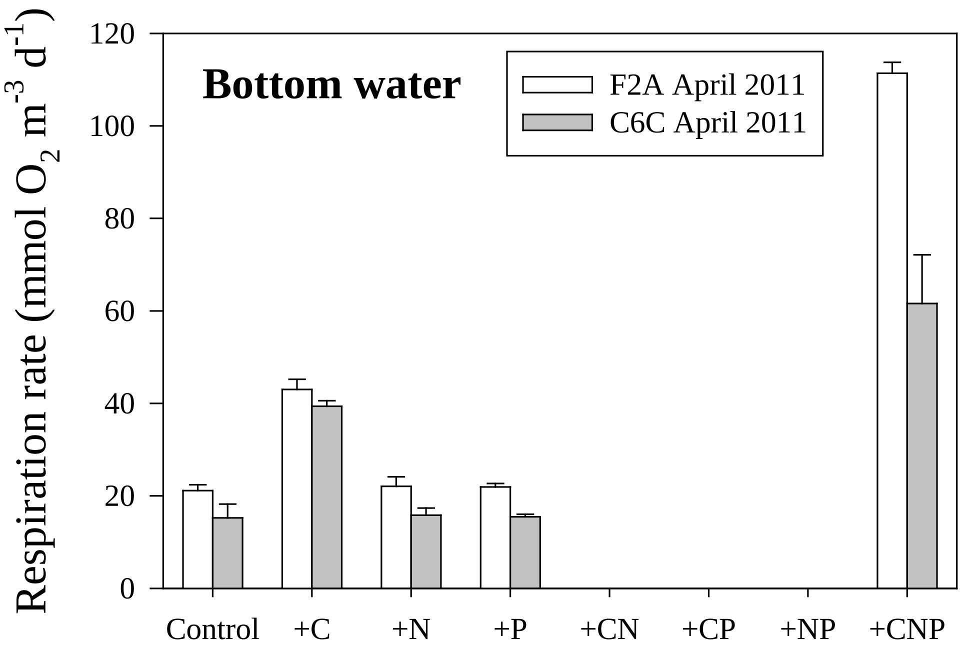




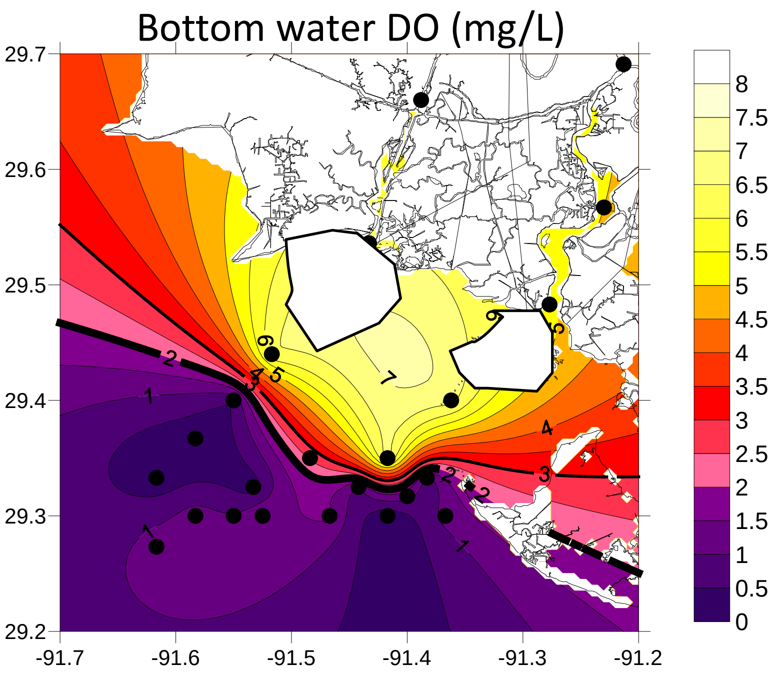
Water column Respiration Limitation Experiments

- C additions stimulate water column rates especially in bottom waters
- Greatest stimulation occurred when C, P, and N were added in combination
    - N only showed stimulation when added with both C and P





16 July 2009

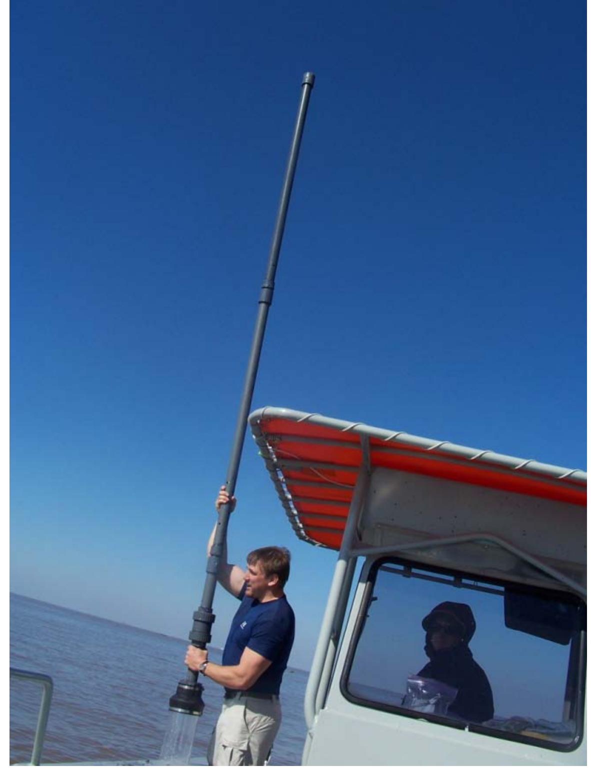


Bottom water hypoxia observed in summer/fall during every year of study (2008 – 2011) despite shallow depths throughout ARDE (2 – 4 m)

- Strong hypoxia with bottom water DO concentrations as low as 0.1 mg/L and extending to up to 1.0 – 1.5 m off the bottom were observed in 2009, 2010, and 2011
- 2010 extended mapping westward to demonstrate hypoxia present extended to Marsh Island
- Hypoxia has been documented in the southwestern portion of ARDE as late as October in 2009 and 2010

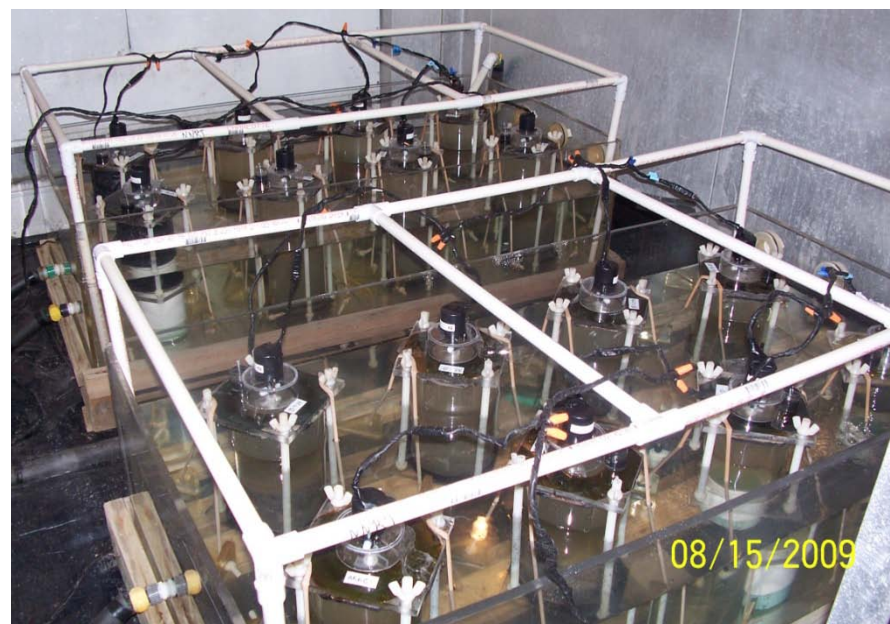
Benthic Metabolism and Nutrient Cycling

Incubations conducted 6 times over 2009 and 2010 at 4 sites (near two deltas and 15 km further offshore of each) in Atchafalaya River Delta Estuary

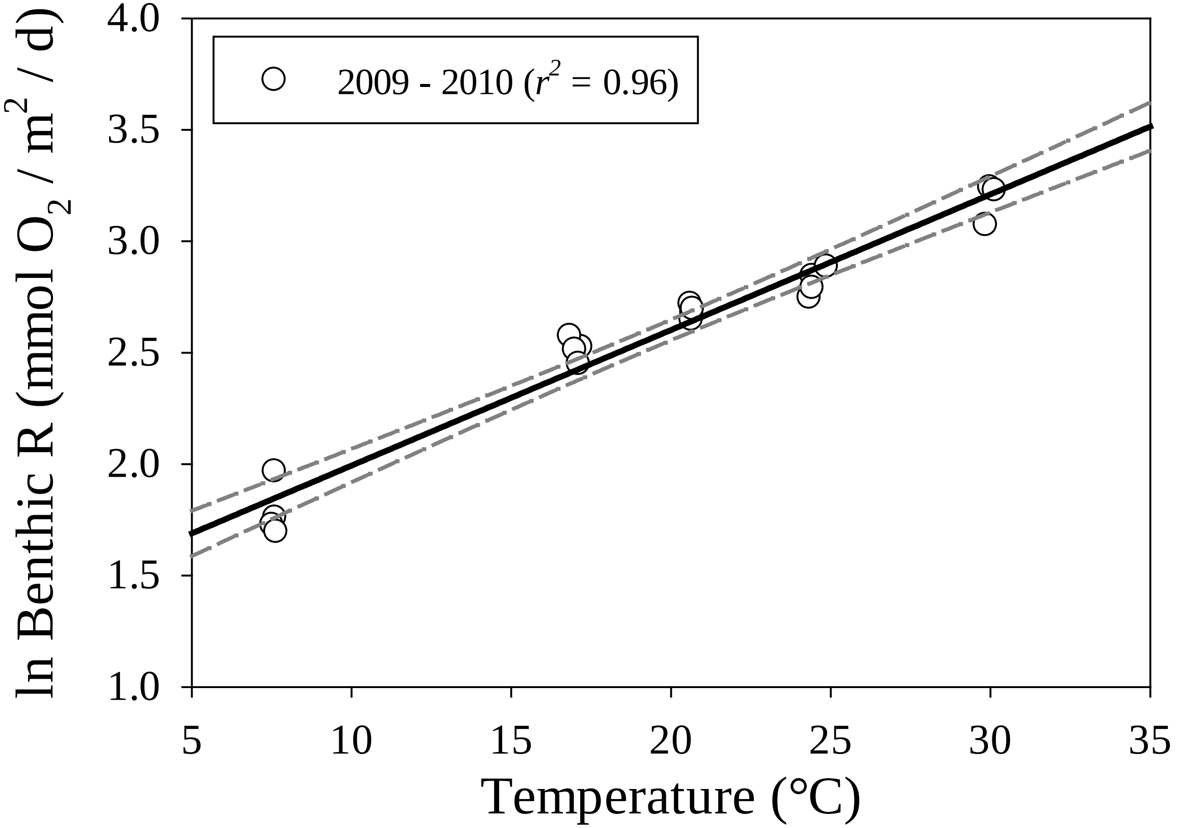


Triplicate sediment cores and “short” bottom-water cores incubated in dark (light doesn’t reach sediments) at ambient temperatures

- Respiration rates
- Net nutrient uptake rates



Temperature is a very strong predictor of benthic respiration rates in ARDE



Surprisingly little site to site variability in benthic R

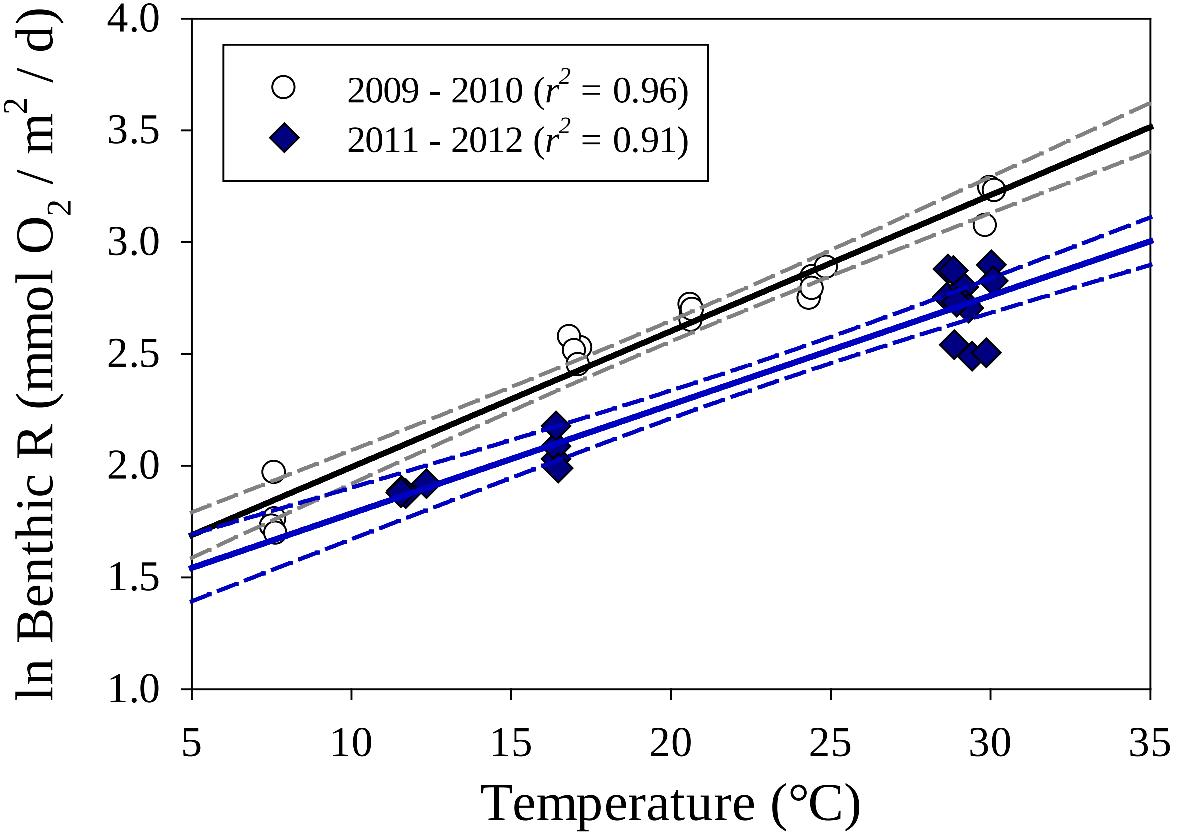
(Hypothesized higher rates "offshore"—substrate anticipated to be more stable)

ARDE sites only 0.5 - 2% C content (usually at low end of range)

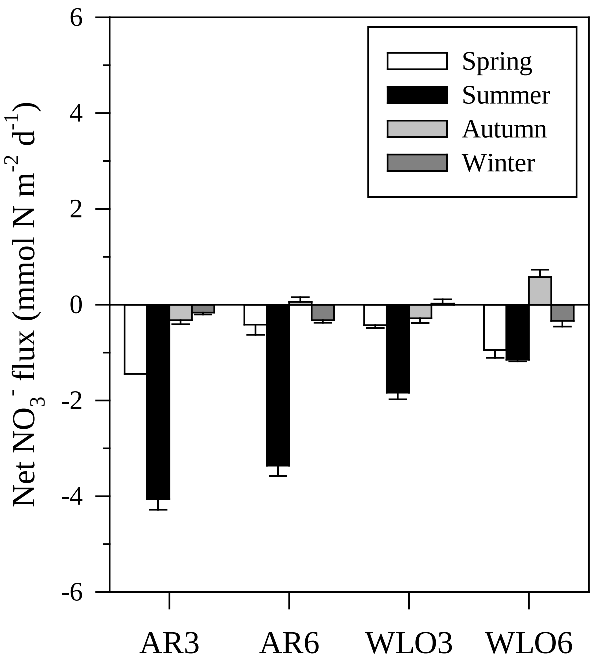
Sites often > 50% sand even at 20km offshore

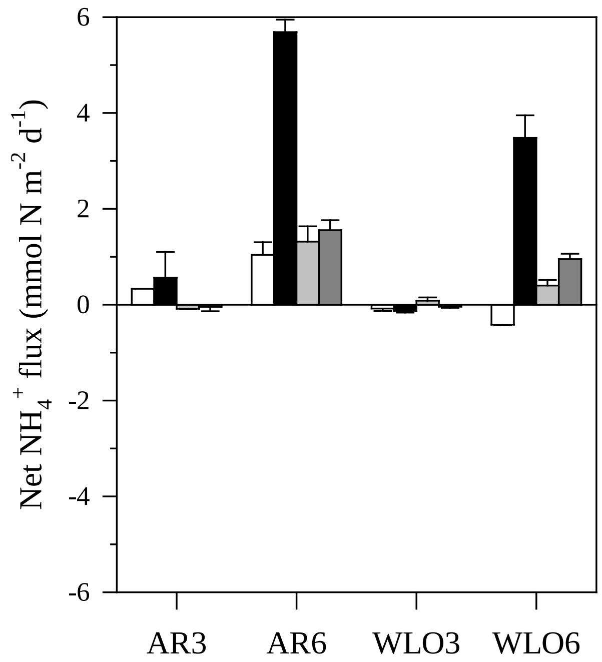
Benthic R rates lower in 2011 than in previous years

Suppressed rates sustained through winter 2012 sampling

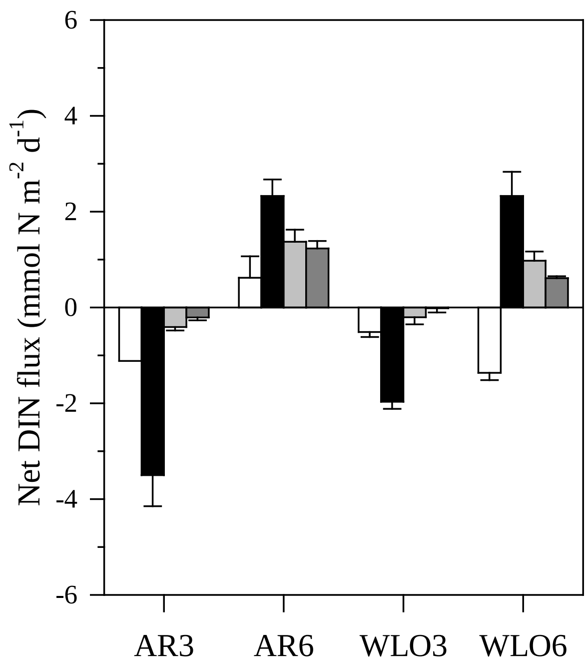


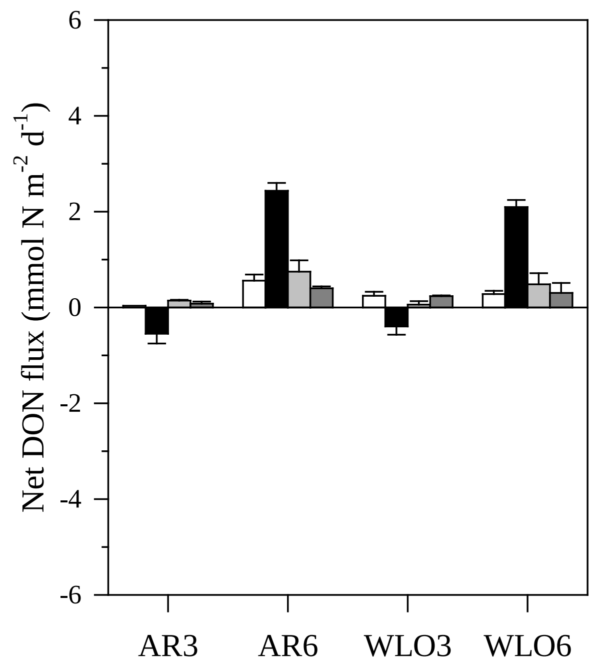
- Net nitrate uptake observed at all sites
    - higher rates offshore of AR than WLO but for both higher rates near delta than offshore
- Net NH_4^+ release at all sites except WLO3
    - higher rates offshore





- Delta sites are net sinks for DIN
- Offshore sites are net sources of DIN
- DON behaves similarly to NH_4^+ with highest release rates offshore

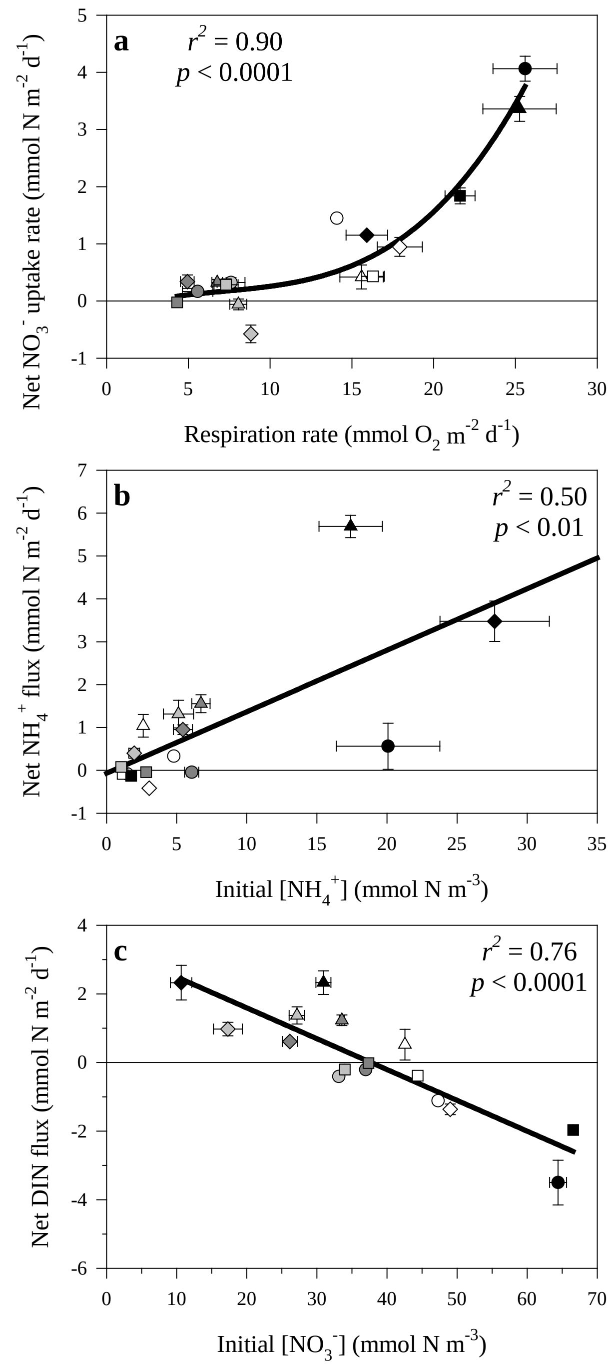




Benthic respiration explained 90% of the variance in net NO_3^- uptake rates, consistent with assimilatory uptake

Net NH_4^+ fluxes were correlated with initial NH_4^+ concentrations, consistent with extended exposure to O_2-depleted conditions resulting in higher NH_4^+ fluxes.

Net DIN fluxes were most strongly correlated with initial NO_3^- concentrations.



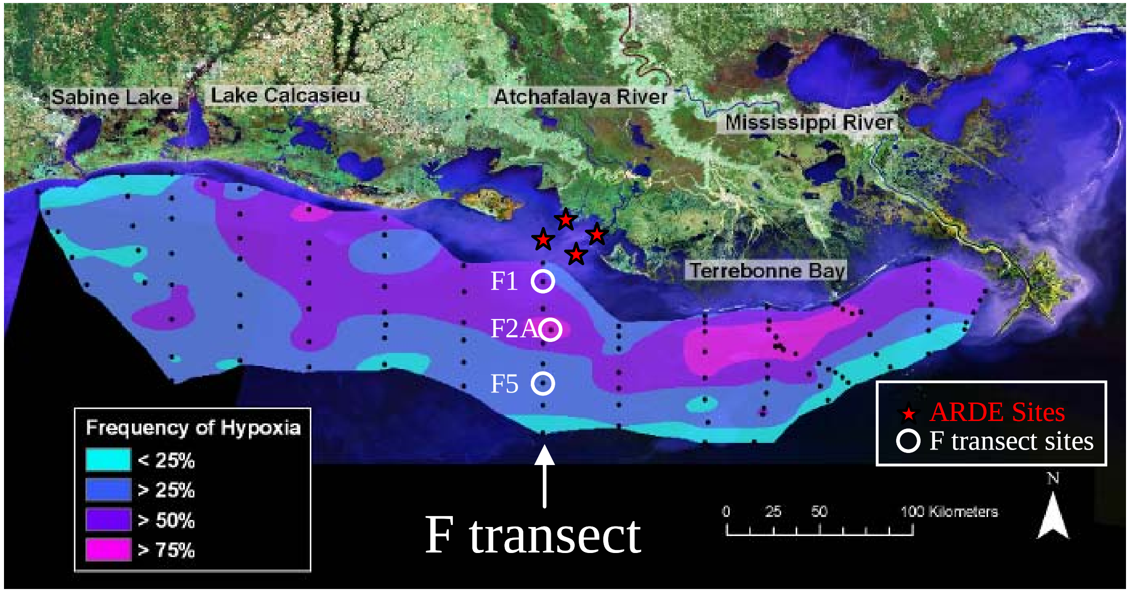
Benthic Metabolism and Nutrient Cycling

Core incubation experiments in April and August 2010

2 sets of paired experiments

1) 3 F transect sites (Light & Dark cores)

2) 4 ARDE sites



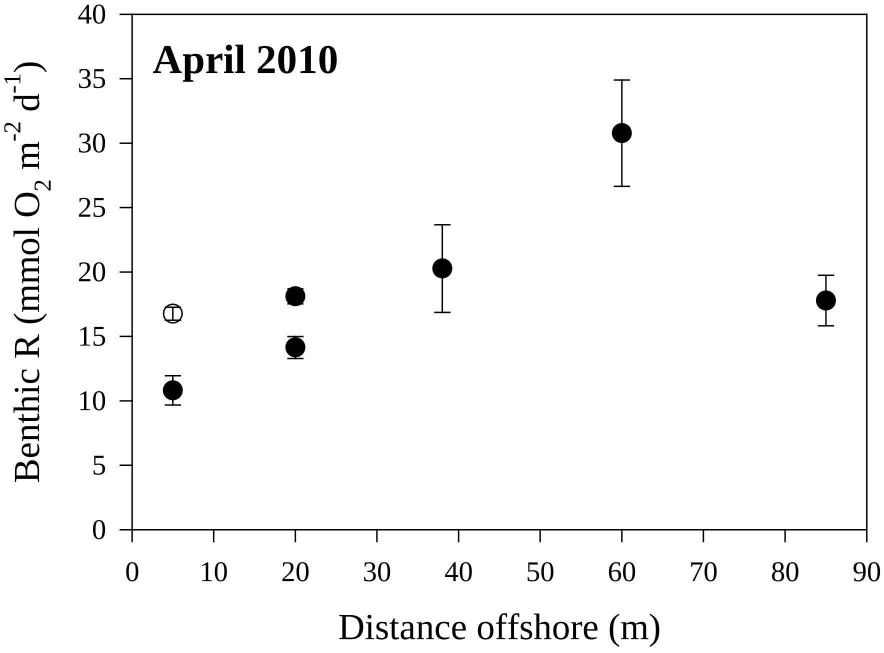
Rate Measurements

- Core and bottom water metabolism
- Net benthic fluxes of NO_3^-, NH_4^+, DON, PO_4^{3-}, SiO_2
- For F transect sites in August, measured net CO_2, CH_4, and N_2O fluxes as well as N_2/Ar ratios
- Pilot ^{15}N Isotope Pairing Technique Study with cores from F2A (August 2010)

Incubators shaded to match light reaching sediment surface at each site

In April, Benthic R peaks near 20 m isobath

~60 km offshore!



Benthic Primary Production rarely detectable despite light availability > field conditions

C Transect Benthic R

Stations C4 and C6B (17 total experiments)

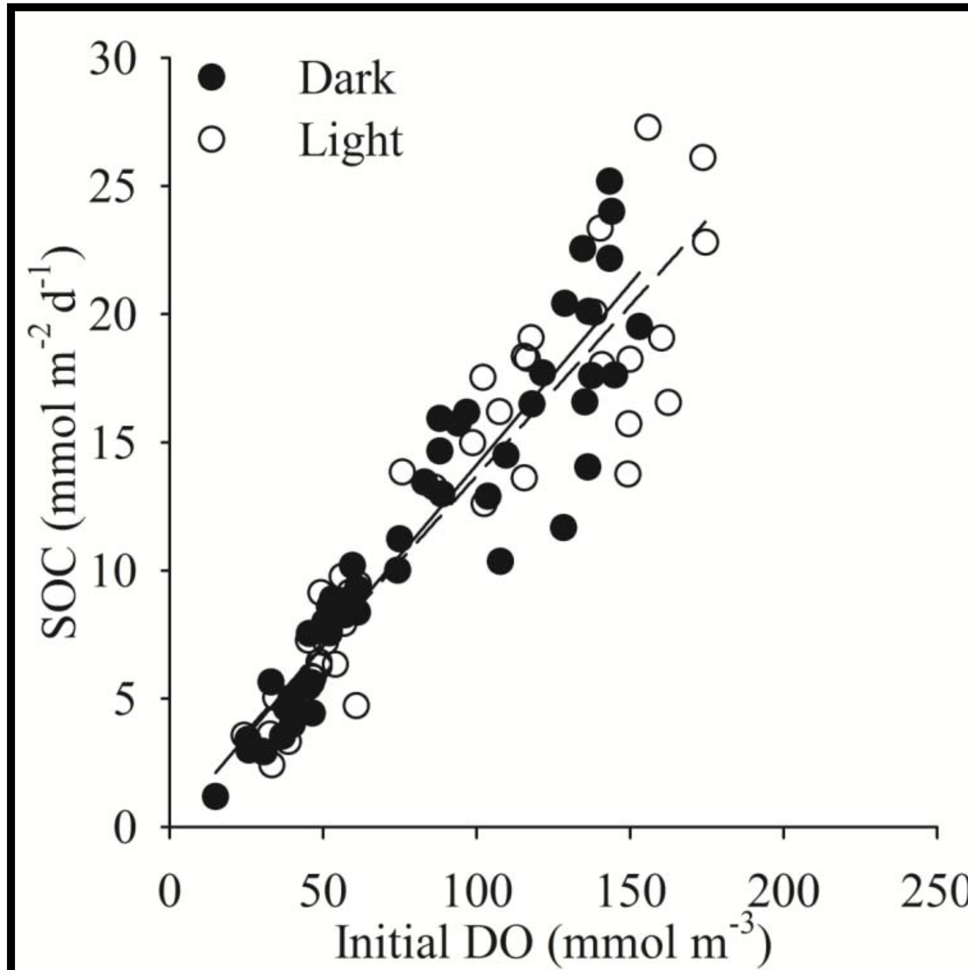
- 2007: Jun, Jul, Aug, Sep and 2008: Apr, May, Jun, Jul, Aug

No differences in net DO changes between Light and Dark Cores → Benthic GPP minimal

- SOC depended on DO
- Test differences by using the slopes of Light and Dark cores

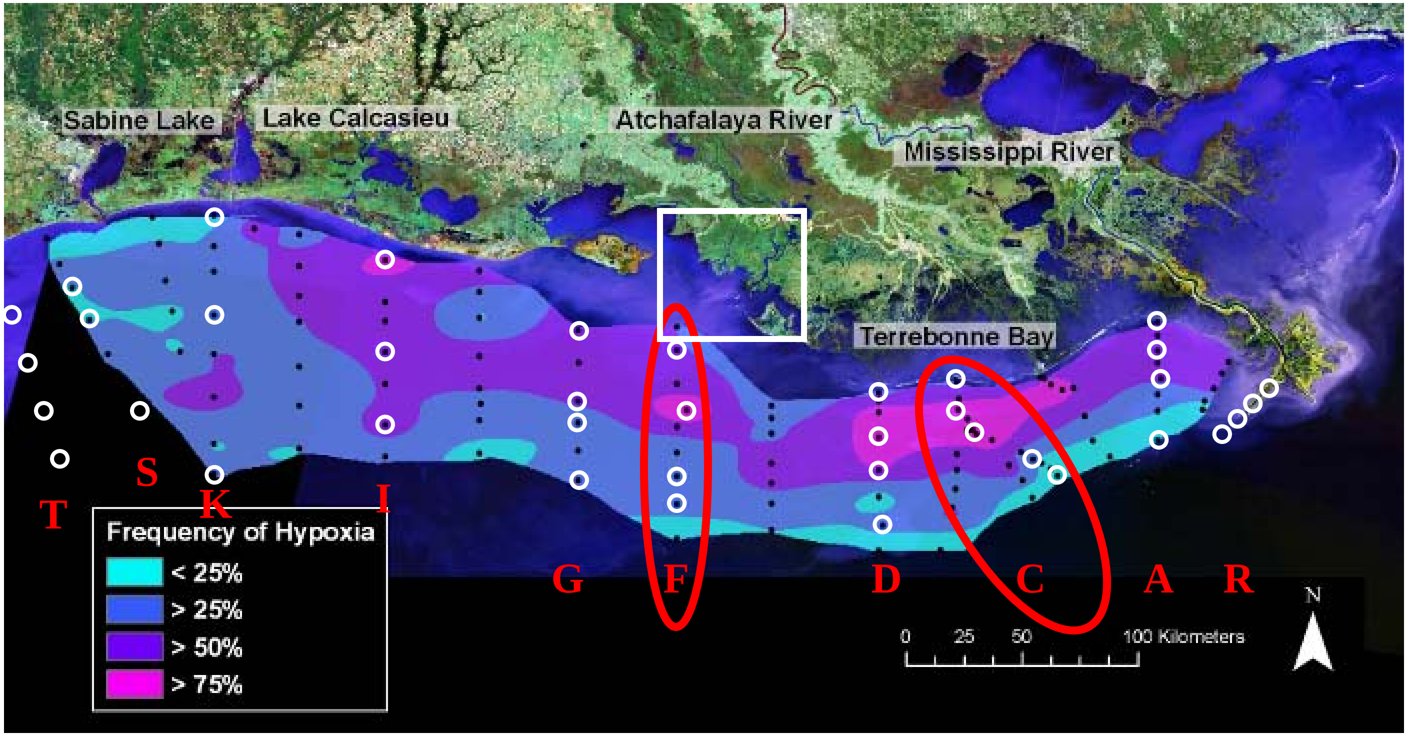
  (ANCOVA, do*treatment)

  - Stations and years ($p > 0.05$)
  - Stations with years pooled ($p > 0.05$)
  - Years separate for each station ($p > 0.05$)
  - PAR treatment categories ($p > 0.05$)
  - Only day light data for light cores ($p = 0.73$)
  - C4 vs. C6B ($p = 0.30$)



(Baustian et al. In review)

Spatial and temporal patterns of water column N_2/Ar ratios as indication of denitrification



Spatial (July 2011 shelfwide cruise)

- Sampling of surface & bottom waters at ~45 stations across LA-TX shelf

Temporal (Aug & Oct 2010 and Apr, Jun, Jul & Aug 2011)

- Sampling of surface & bottom waters at all stations on both C & F transects
  - -sampling at 5–8 depths at 4 stations on C & F
  - -since June 2011, sampling has included WLO transect in ARDE

Observations and remaining research gaps

- **Water column Primary Production most often limited by N alone or N and P**
  - However, Si may be important because of importance of diatoms to hypoxia formation
  - Need more focus on C instead of chlorophyll and also on size-structure of phytoplankton community
- **Water column Respiration rates span wide (50-fold) range**
  - High spatial variability across shelf and over time
  - High variability within vertical profiles –suggests need for better resolution in future studies
  - More work needed to understand controls on surface and bottom water rates
    - Limitation assays suggest primary limitation by C; greatest stimulation when CNP added but only N response when both C and P also added

Observations and remaining research gaps

- **Atchafalaya River and ARDE play important role in influencing processes on shelf**—alterations to these systems likely important to shelf hypoxia development in the future
- **Current state of knowledge of benthic respiration and nutrient cycling in hypoxic area is still lacking**
  - Temperature is a very strong predictor of benthic respiration rates in ARDE
  - High variability (> 3-fold) in benthic R with distance offshore. Hot spot at ~60km offshore of AR—highest frequency of hypoxia observance on shelfwide cruises
  - Sediments important site of N transformations and fluxes
    - Site where ARDE shifts from net DIN sink to source to overlying waters varies over time
  - No evidence Benthic PP important on either C or F transect
  - Just beginning to determine hot spots for denitrification

Thanks!

Image Credit: US Army Corps of Engineers Image (http://commons.wikimedia.org/wiki/File:Atchafalaya_River_delta.jpg)