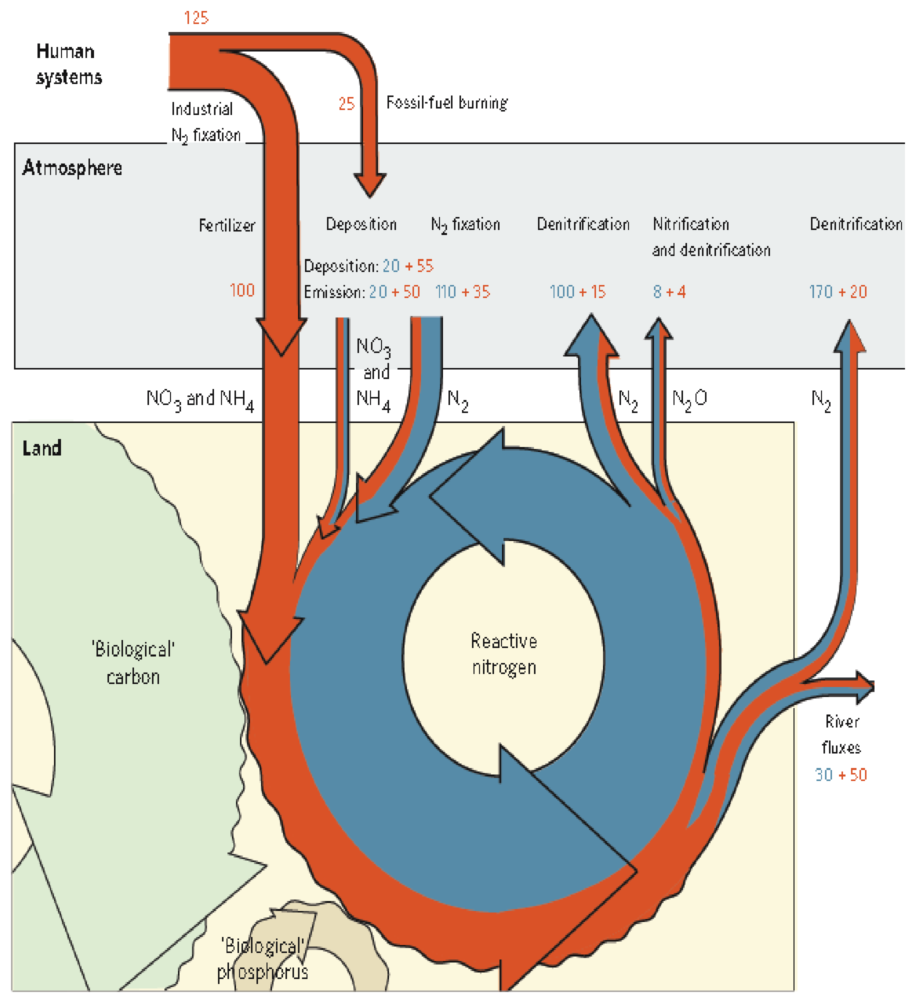
Diel Phosphorus Variation and the Stoichiometry of Ecosystem Metabolism in a Spring-Fed River

Matt Cohen, Marie Kurz, Jon Martin,
Rachel Douglass, Ray Thomas
University of Florida

Jim Heffernan
Duke University

Coupling of Elements: From Cells to the Biosphere

- Elements can constrain metabolism.
  - Increasing availability can lead to excess C fixation
  - Organism stoichiometry differs from supply
- Metabolic activity couples element cycles across scales
  - Ecosystem scale is of particular interest
- Coupling is direct + indirect
  - Direct autotroph assimilation
  - Indirect effects on redox, pH, heterotrophs

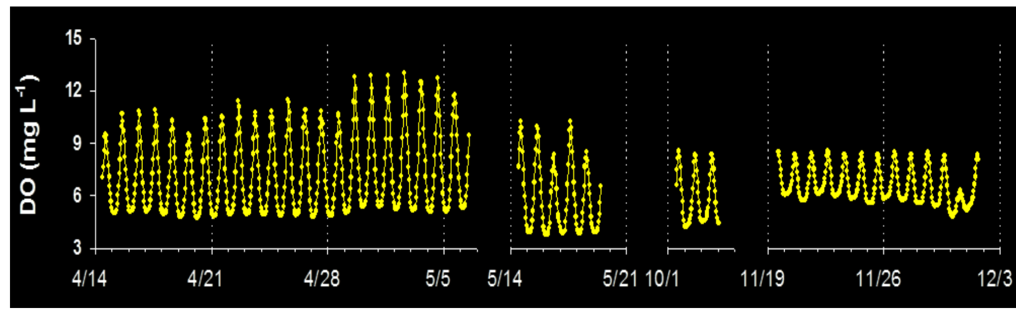


Gruber and Galloway 2008

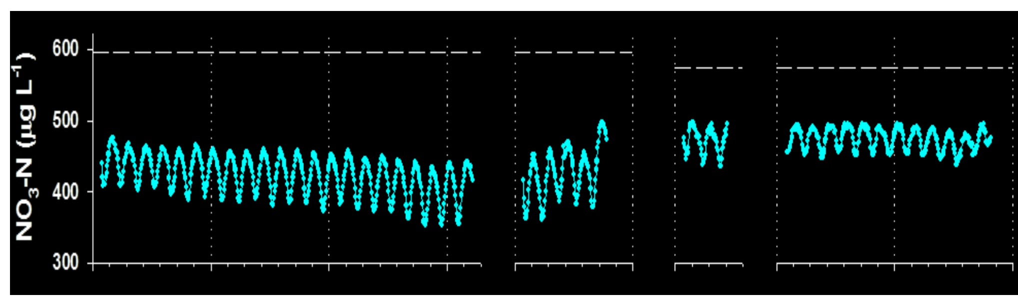
"Ecology **in** Streams"
Streams as Model Ecosystems

- Flow creates coherent (diel) downstream signals from ecosystem metabolic processes

- **Carbon**: Diel O_2 for riverine GPP, R (Odum 1956)



- **Nitrogen**: Diel NO_3 for autotrophic N demand (Heffernan and Cohen 2010)



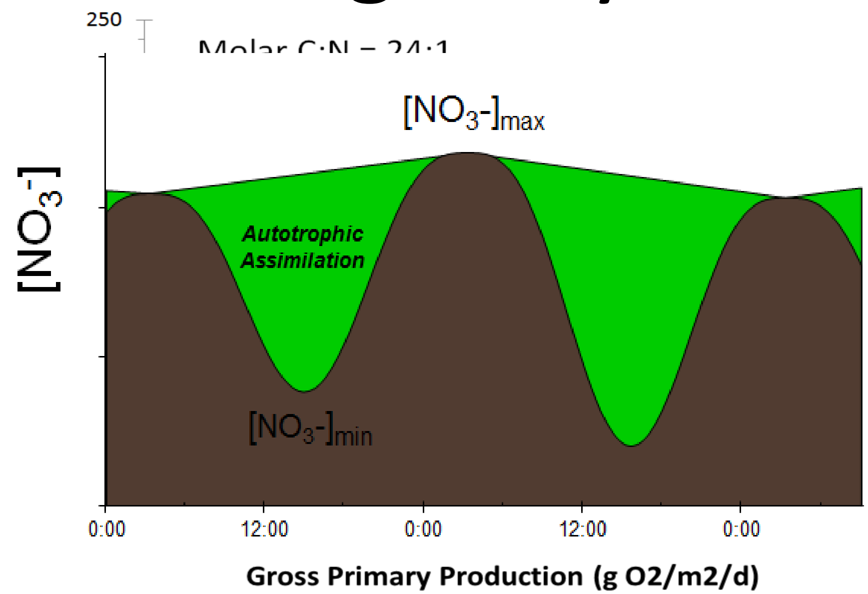
North Florida's Springs as Model Rivers

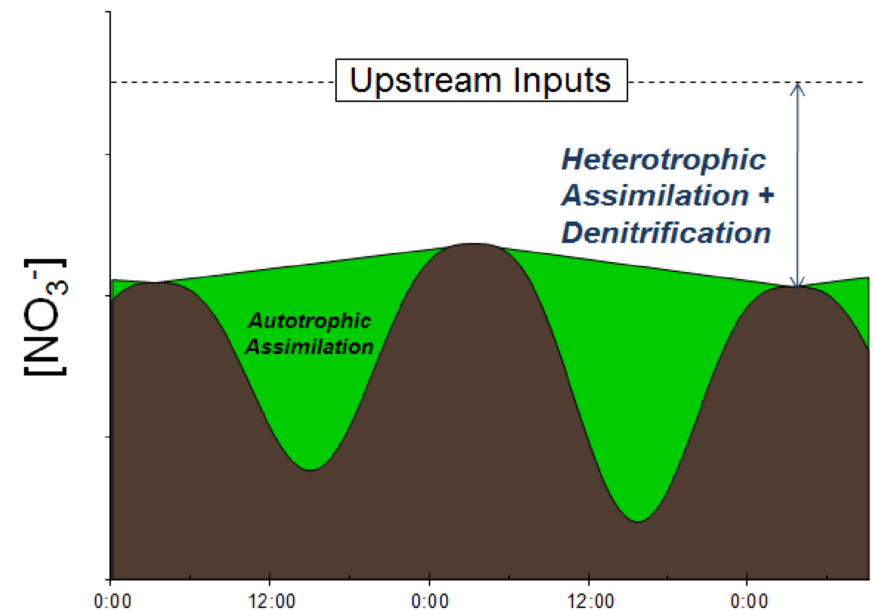
- High GPP (clear water)
- Stable flow; no scouring floods
- Constant source water chemistry
- Constant temperature

- ***Natural laboratory for coupled elemental cycling in ecosystems***

Coupled Carbon and Nitrogen Cycles

- **DIRECT**: Net primary production and $U_{a,N}$ are strongly correlated and yield plausible C:N
- **INDIRECT**: U_{den} is correlated with R <u>and</u> previous days' GPP (short and long term coupling)





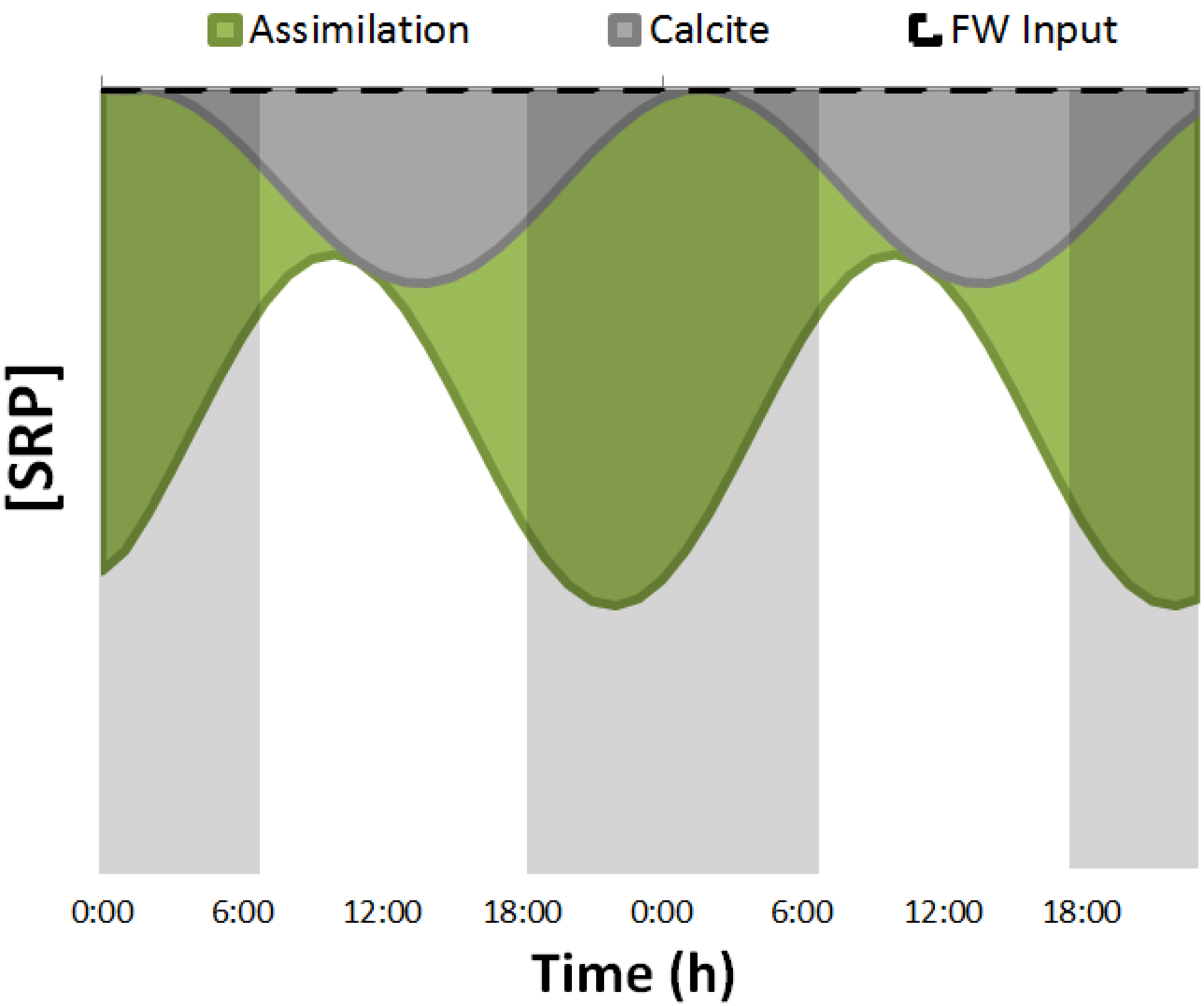
Research Questions: Coupled Carbon and Phosphorus Cycles

- Is there a **coherent diel SRP signal**?

- Is the diel signal **controlled by metabolic processes**?
  - Directly via autotrophic assimilation?
  - Indirectly via pH or redox sensitive geochemical reactions (e.g., Ca, Fe)?

- What is the **stoichiometry (C:N:P) of ecosystem metabolism** and how does it vary?
  - Does it indicate the dominant autotrophs?
  - Does it change at daily and seasonal time-scales?

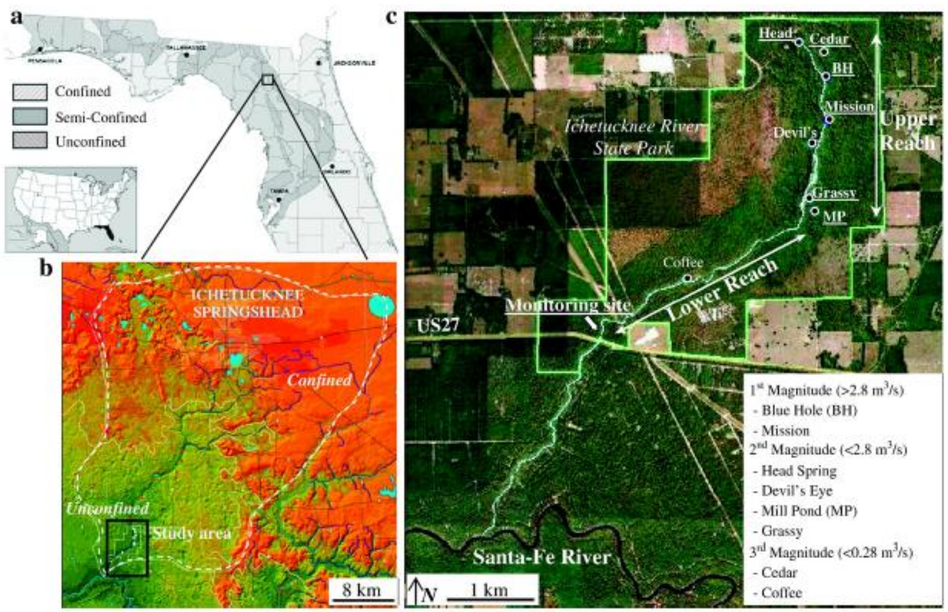
Conceptual Model of Diel P Dynamics



- Extracts P removal due to assimilation **and** co-precipitation which produce signals that are out of phase

Site

- Ichetucknee River
  - High Flow ~ 6 - 9 m^3/s
  - Constant input chemistry
    - FW NO_3 ~ 620 ppb, PO_4 ~ 48 ppb
  - High GPP (5 ± 2 g C m^{-2} d^{-1})



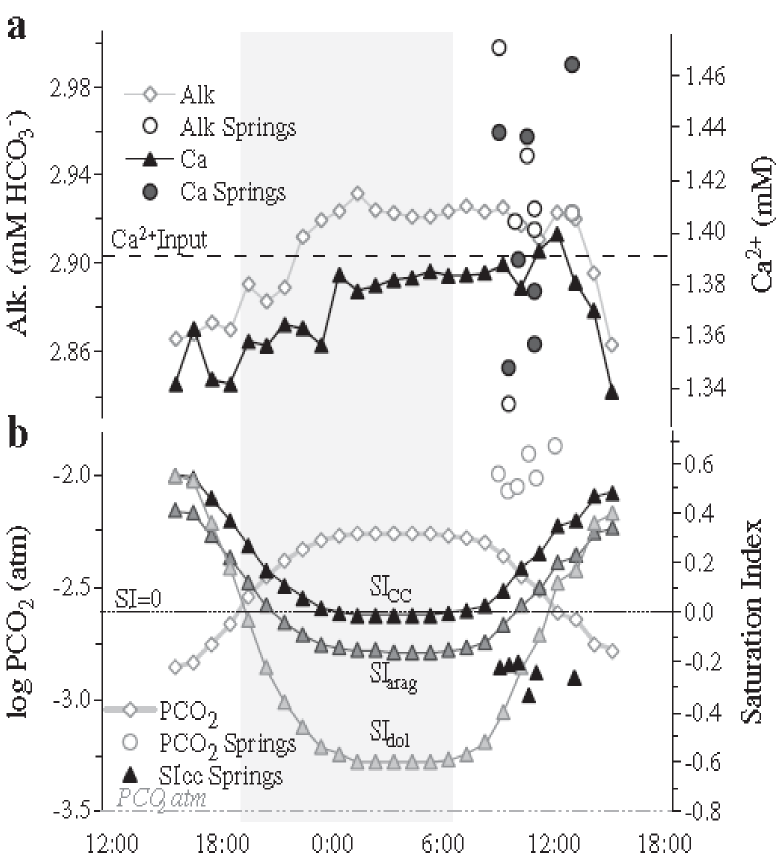
- 8 deployments, 5-12 days
  - Sensors at South Take Out, 5 km from Ichetucknee Headspring

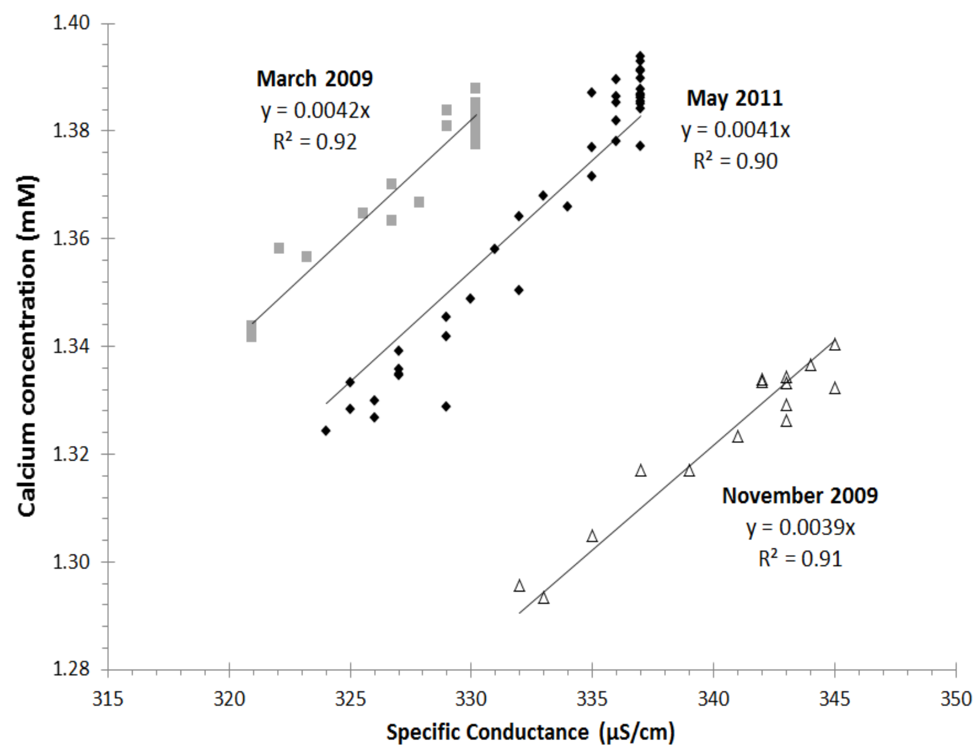
Sensors

- C fluxes + calcite dynamics
  - YSI 6920, Optical DO, SpC
- N fluxes from nitrate
  - Satlantic SUNA (UV NO3)
- P fluxes from phosphate
  - Wetlabs Cycle-PO4

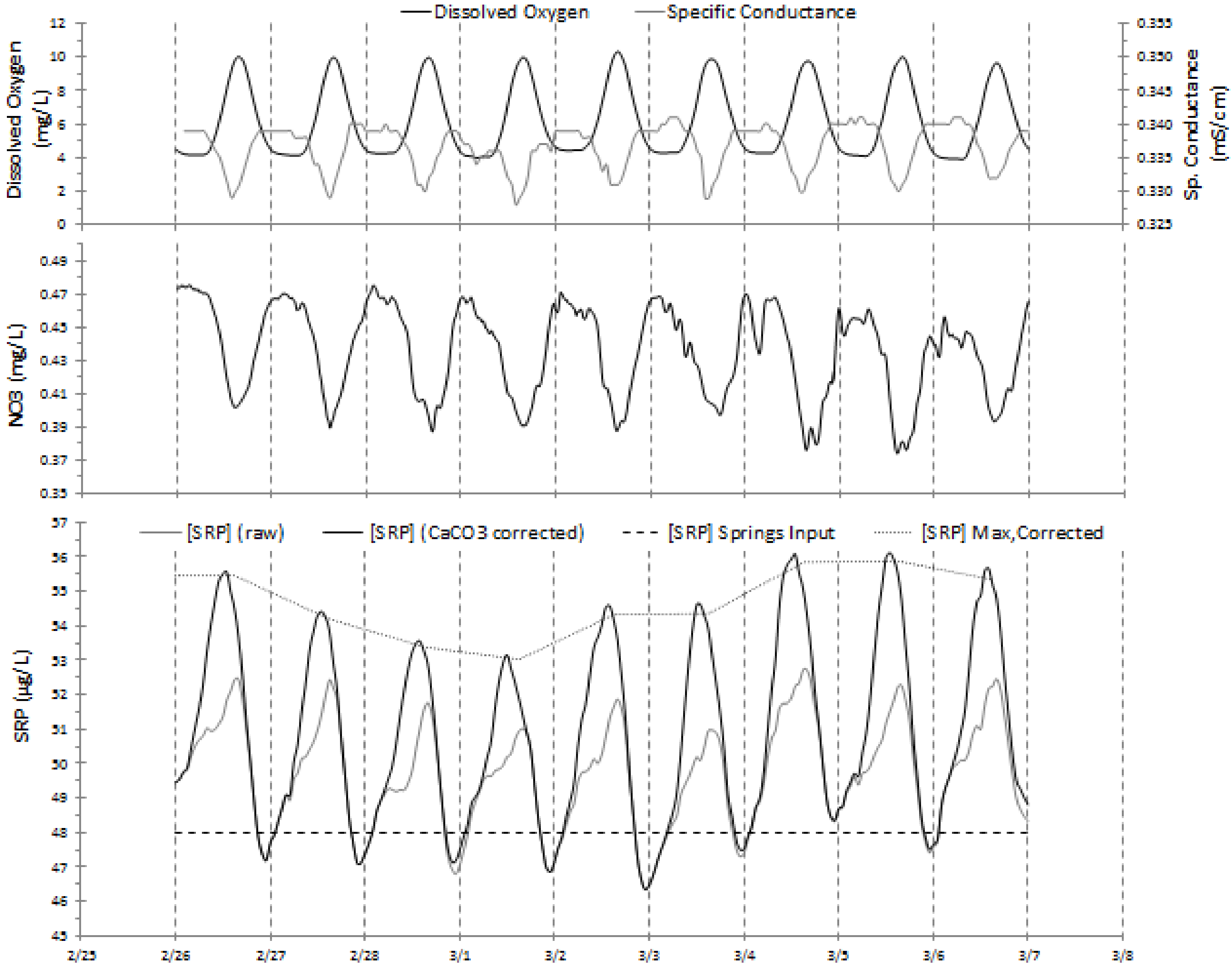
Geochemical Interactions

- Diel SI_{cal} responds to GPP
  - Day: Precipitation, Night: nothing
- No other significant geochemical sinks
- [Ca] well predicted by specific conductance (SpC)
- Calcite co-precipitation kinetics from House (1990)

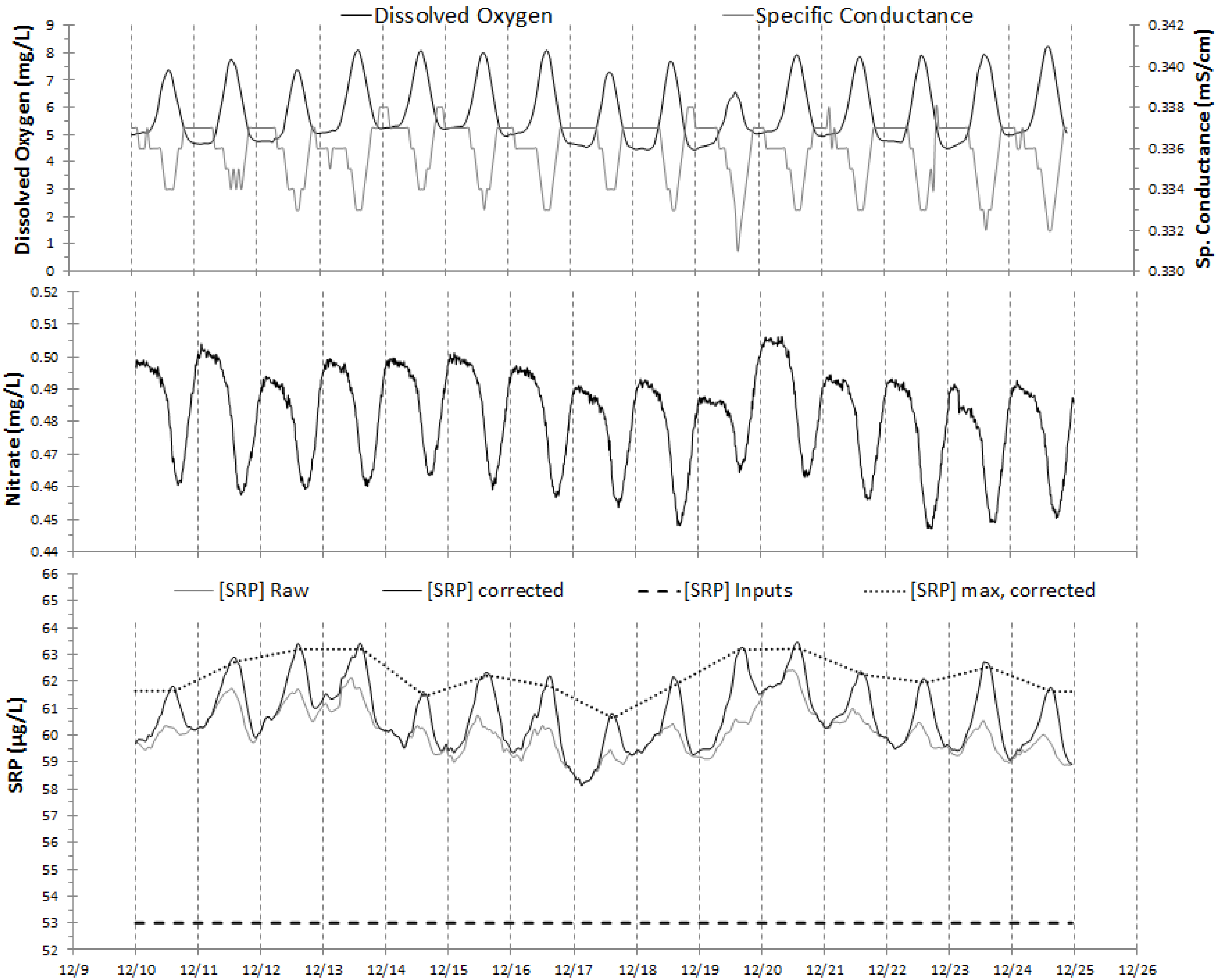




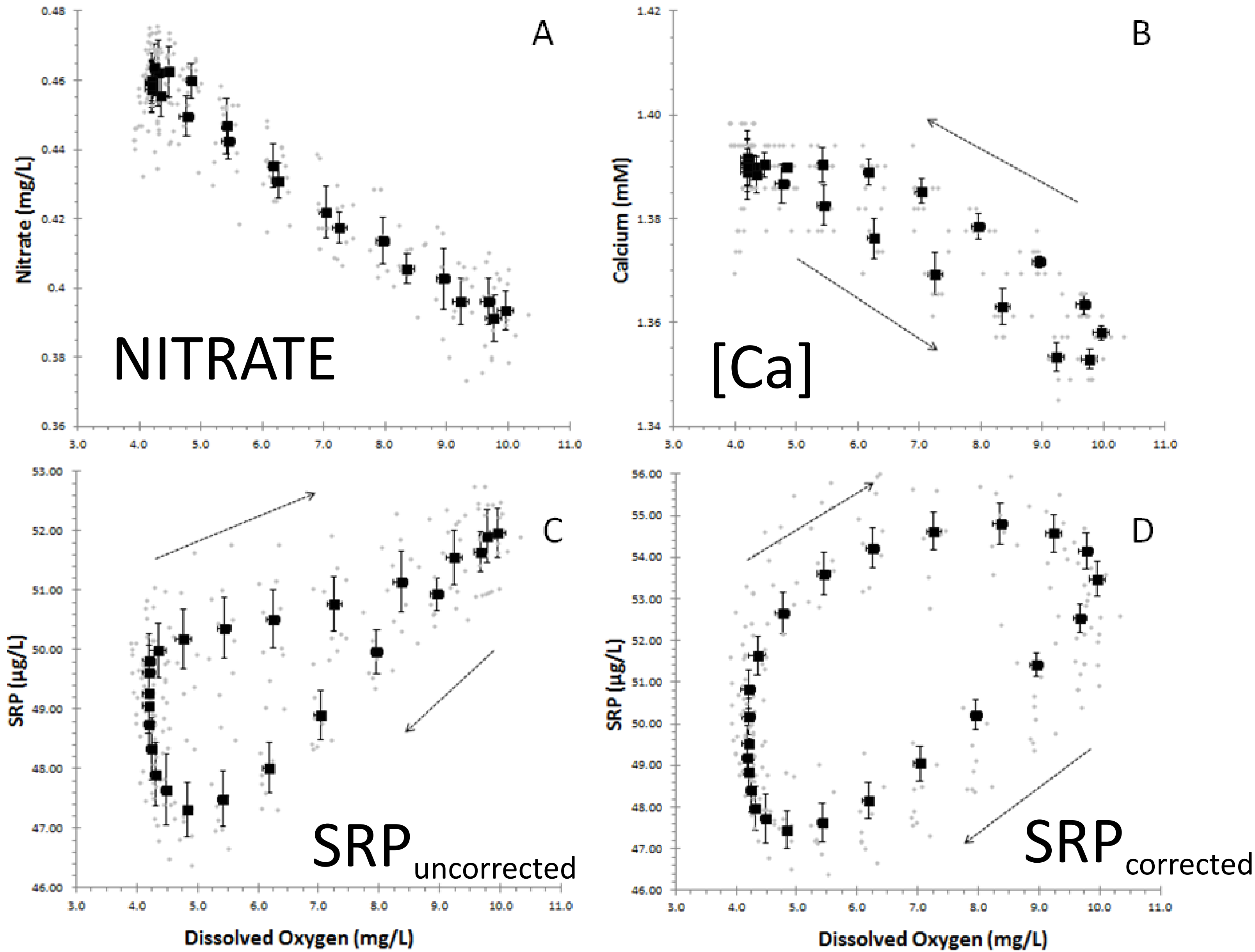
Raw Data (March 2011)



Raw Data (Dec 2010)

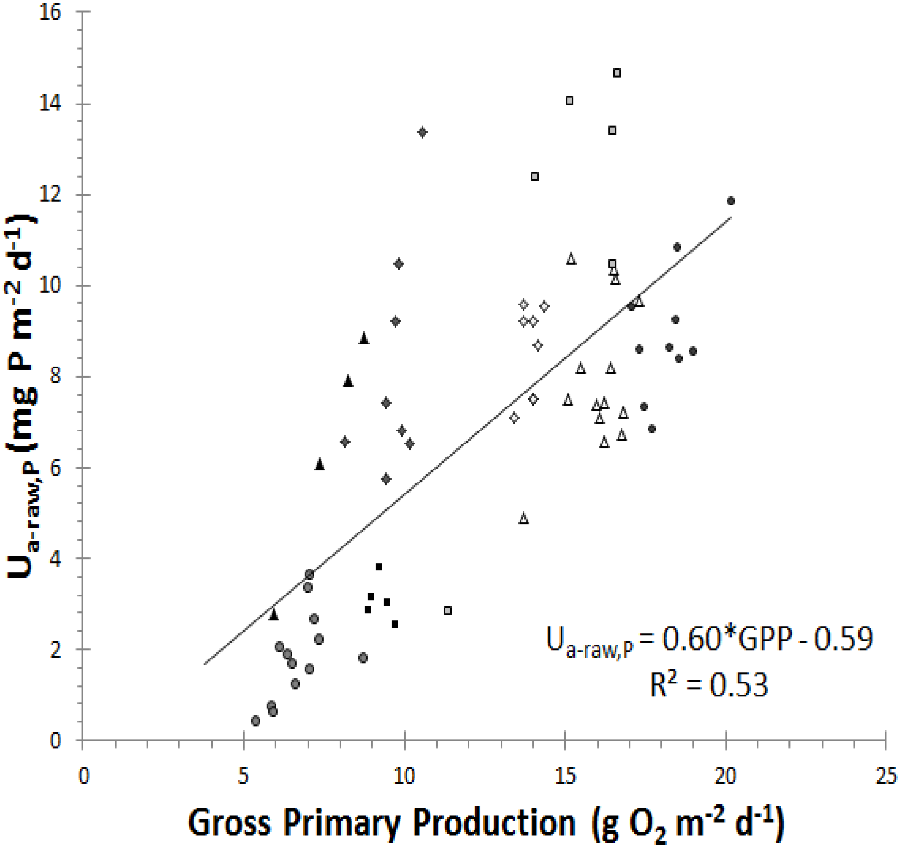


Unexpected Timing of P Dynamics

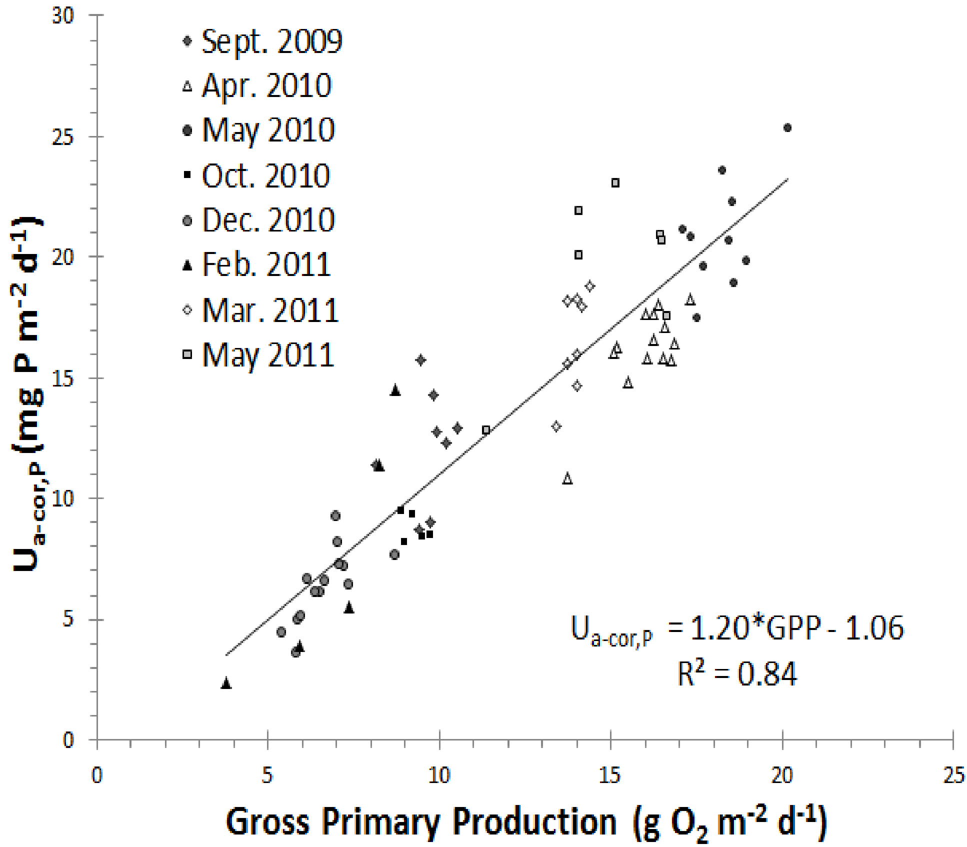


P Assimilation vs. GPP

Uncorrected - C:P ~ 945:1



Corrected - C:P ~ 466:1



$C:P_{vascular}$ ~ 480:1

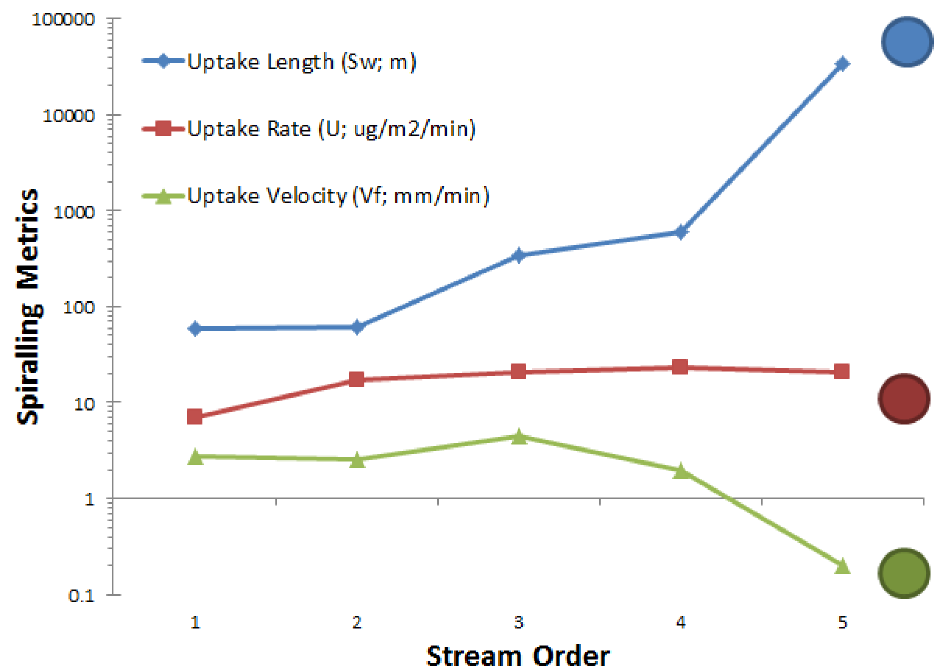
$C:P_{algae}$ ~ 430:1

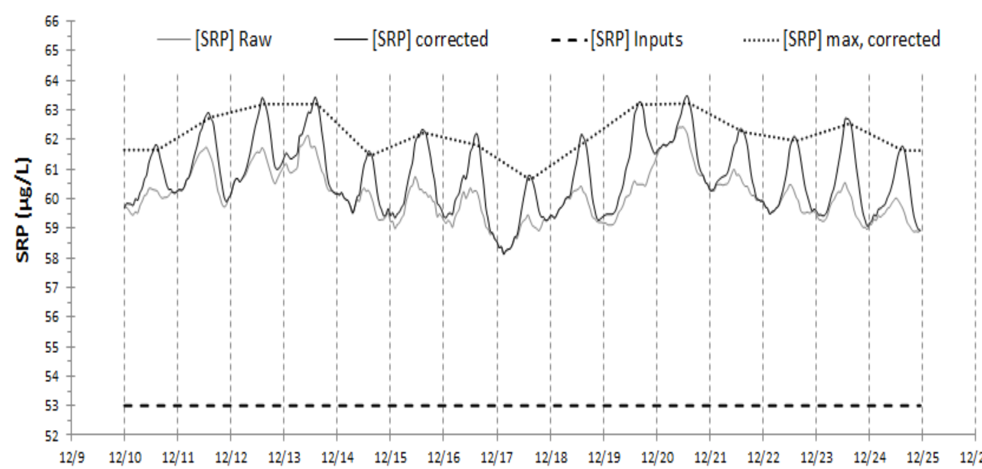
P Removal in Context

- Uptake dominates removal
  - Biotic removal ~ 70%
  - Co-precipitation ~ 30% (exported as calcite particles?)

- Spiraling metrics indicate **huge** supply vs. demand
  - Uptake length ~ 42 km
  - Matches 5th order river spiraling (Ensign & Doyle 2006)
  - Zeroth order removal?

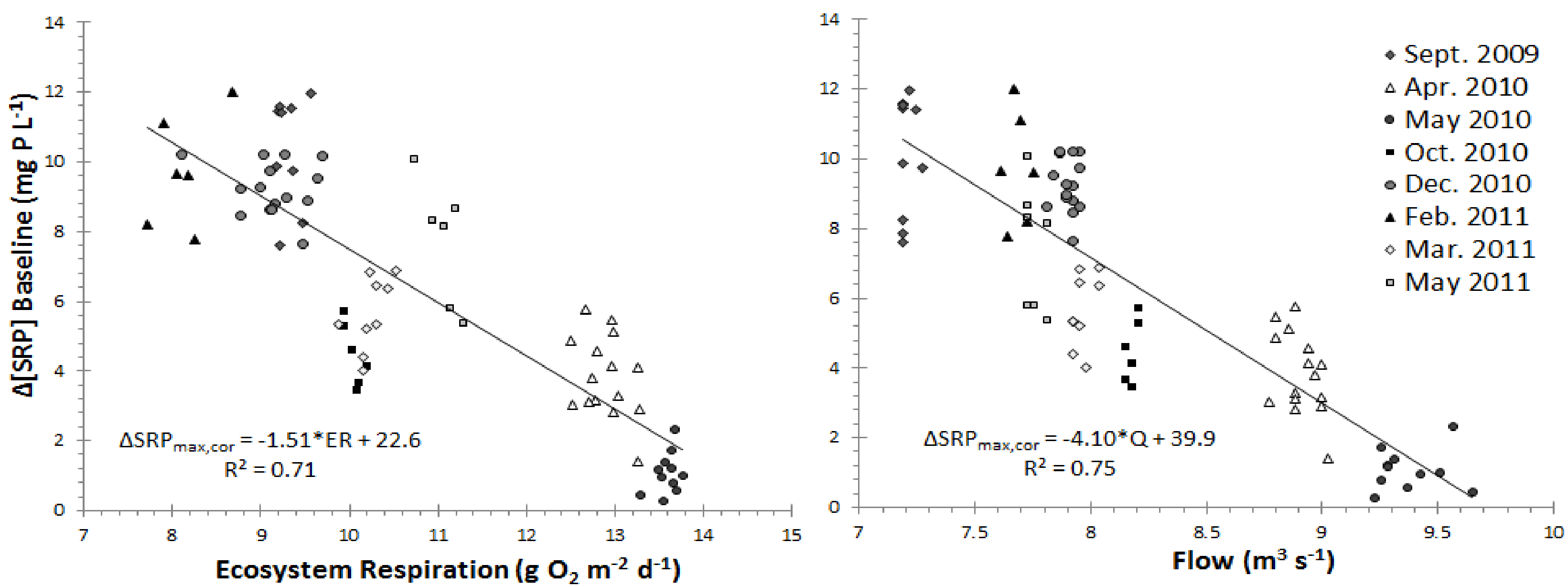
Ichetucknee is a NET SOURCE of P





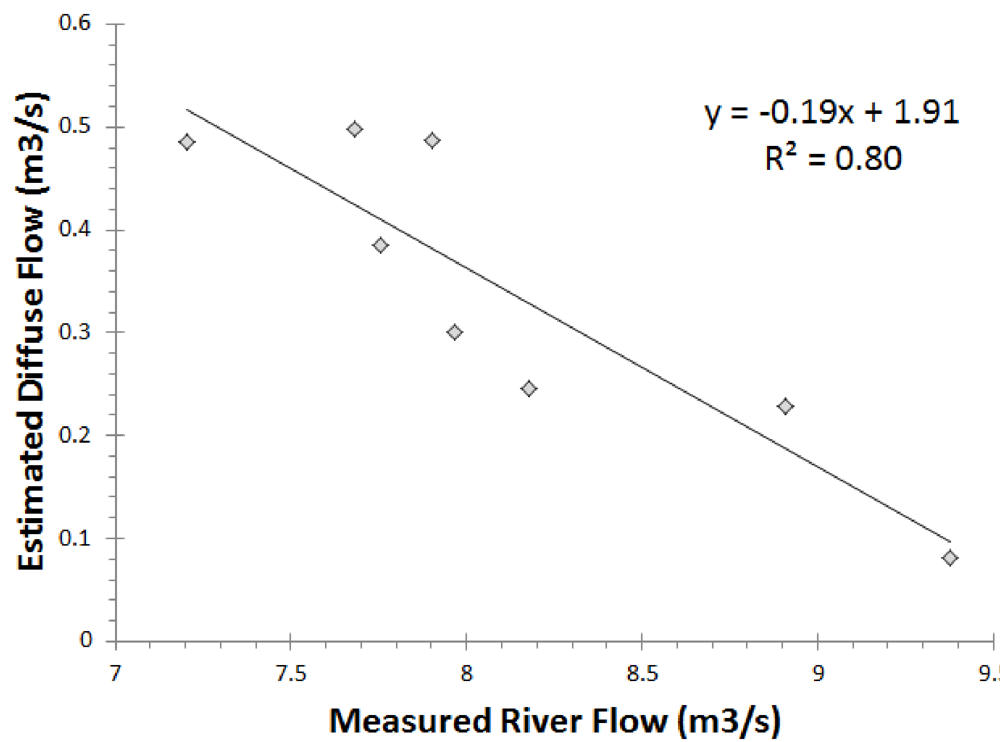
A Phosphorus Source?

- Magnitude inferred from **varying [SRP] baseline**
- Baseline covaries with respiration and flow
  - Redox sensitivity? Hydraulic gradient?
- Interstitial porewater has high SRP (ca. 150 ppb)
  - H1: [SRP] varies with R
  - H2: P flux varies with hydraulic gradient



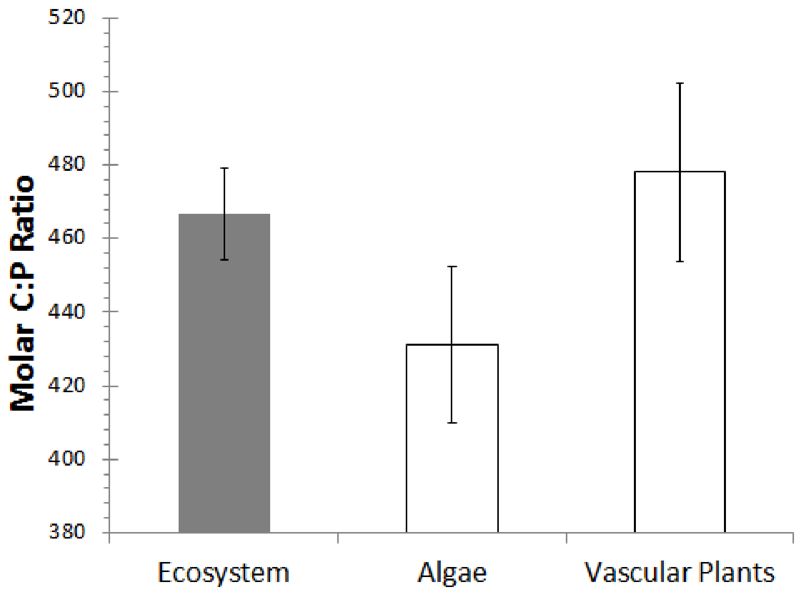
Predicting Diffuse Flow: Evidence from P Mass Balance

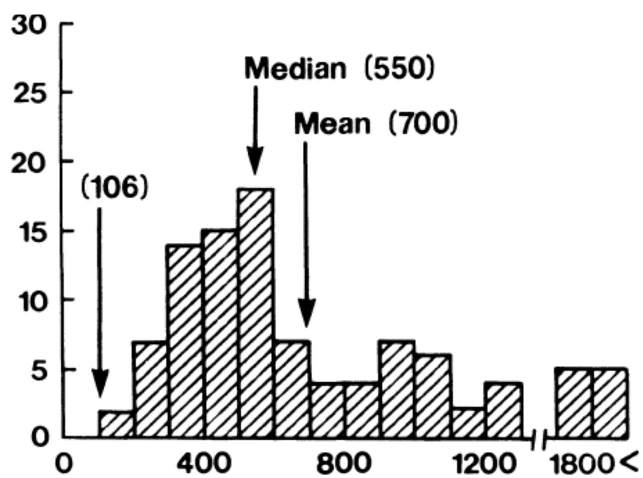
- Assuming porewater [SRP] (150 ppb), **what is diffuse lateral flow to close river P budget**?
- Strong f(flow), declining inputs at high stage
- Matches [Cl] budgeting
  - 0.6 m^3 s^{-1} (de Montety et al. 2011)



Ecosystem C:P Stoichiometry

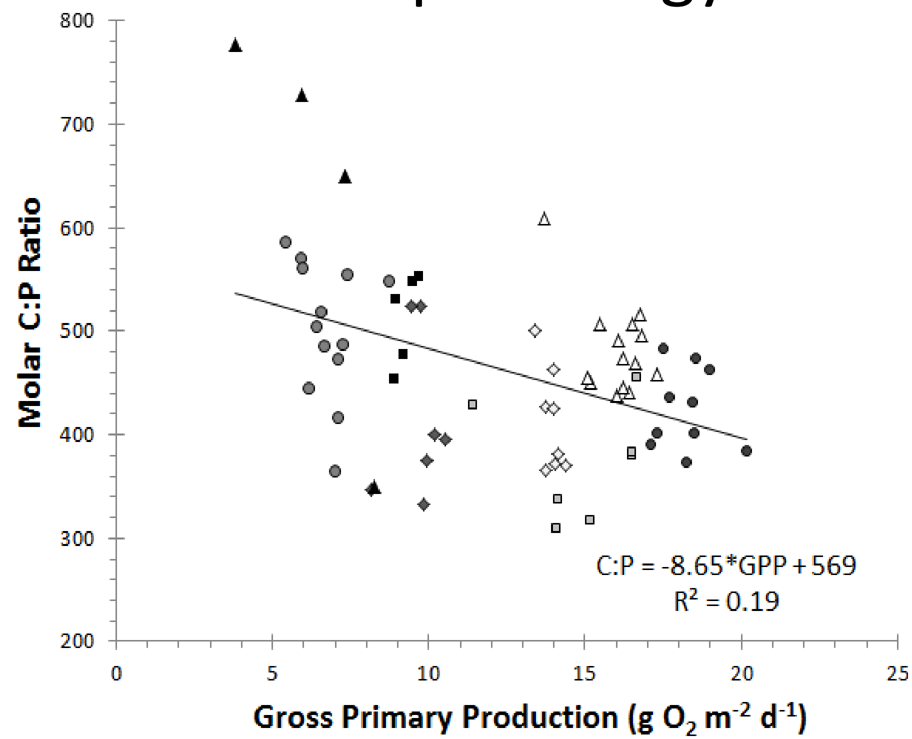
Plausible mixture





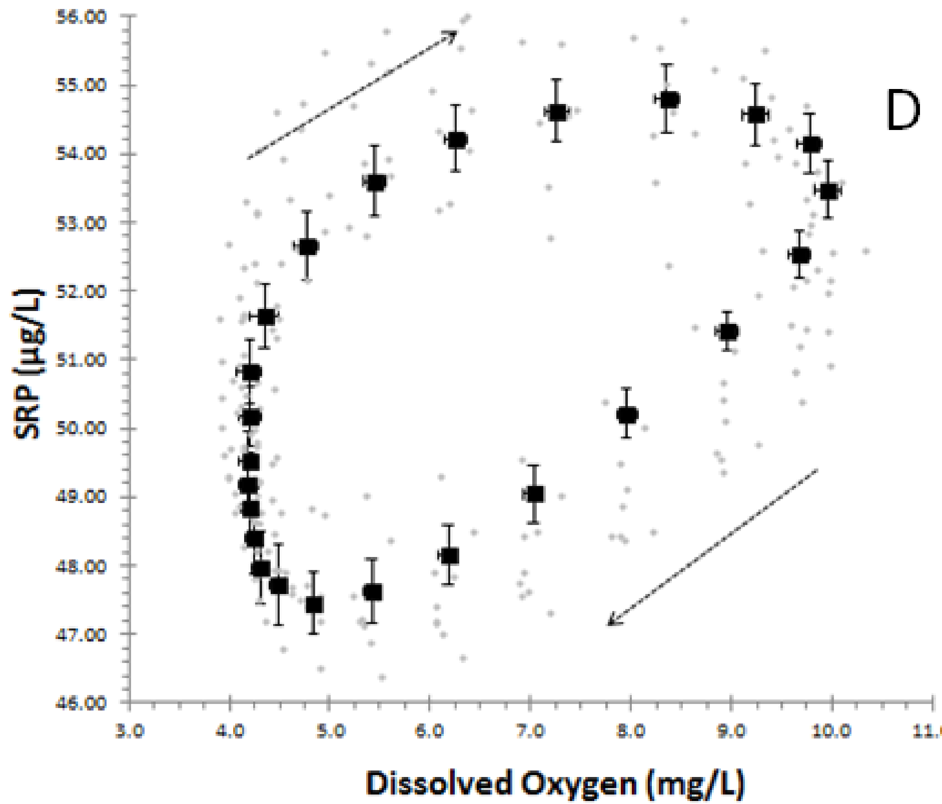
C:P Atkinson and Smith (1983)

Weak phenology



P Assimilation **LAGS** Primary Production

- H: Ribosome production occurs when cell energy stores are maximum
  - Ribosomes dominate P demand (Falkowski 2000, Elser and Sterner 2002)
  - Literature evidence that rRNA **maximum** is at midnight (Paul et al. 1988)
  - *H_1: Diel rRNA:DNA variation with peak at maximum P removal*



Summary:
Ecosystem Scale C and P Coupling

- Coherent diel [SRP] signal, varying amplitude
- Signal is convolution of 2 out-of-phase processes
  - Calcite co-precipitation (ca. 30% of removal)
  - Biotic assimilation (ca. 70% of removal)
  - Combined removal < 10% of total P flux
- Calcite-corrected removal yields plausible C:P
- Discrete springs are NOT the only source of P
  - Lateral seepage flux controlled by R_{eco} and hydraulics
- P assimilation lags GPP by ca. 8 hours
  - Signal from the cell to the ecosystem?

Thank You.

mjc@ufl.edu

Acknowledgements:

Larry Korhnak, Ginger Morgan, Rob Mattson and Erich Marzolf

Funding:

NSF EAR-0838369/EAR-0609968, Three Rivers Trust, SJRWMD #25941