The Kinetics of Nutrient Uptake in Rivers: Using Sensors to Detect Nutrient Saturation Thresholds

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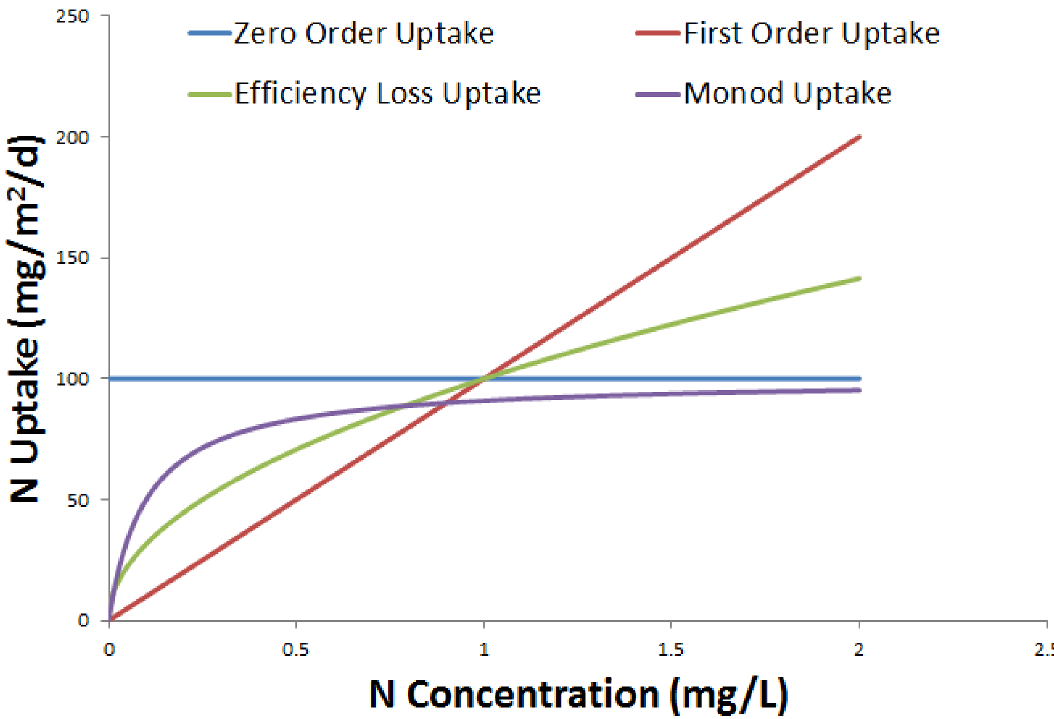
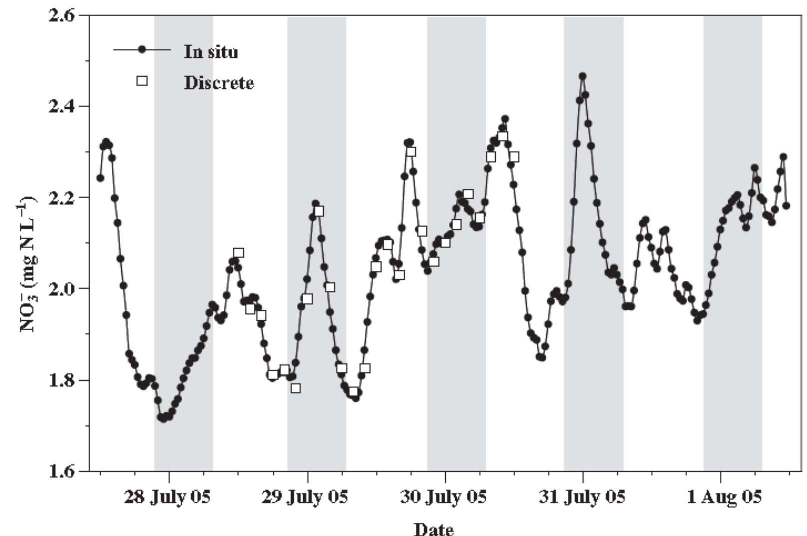
Motivating Question:
Sensors to Predict River Eutrophication

- Uptake kinetics describe how uptake rates (e.g., assimilation) change vs. concentration
- Predicting how rivers respond to enrichment is required to manage rivers and catchments

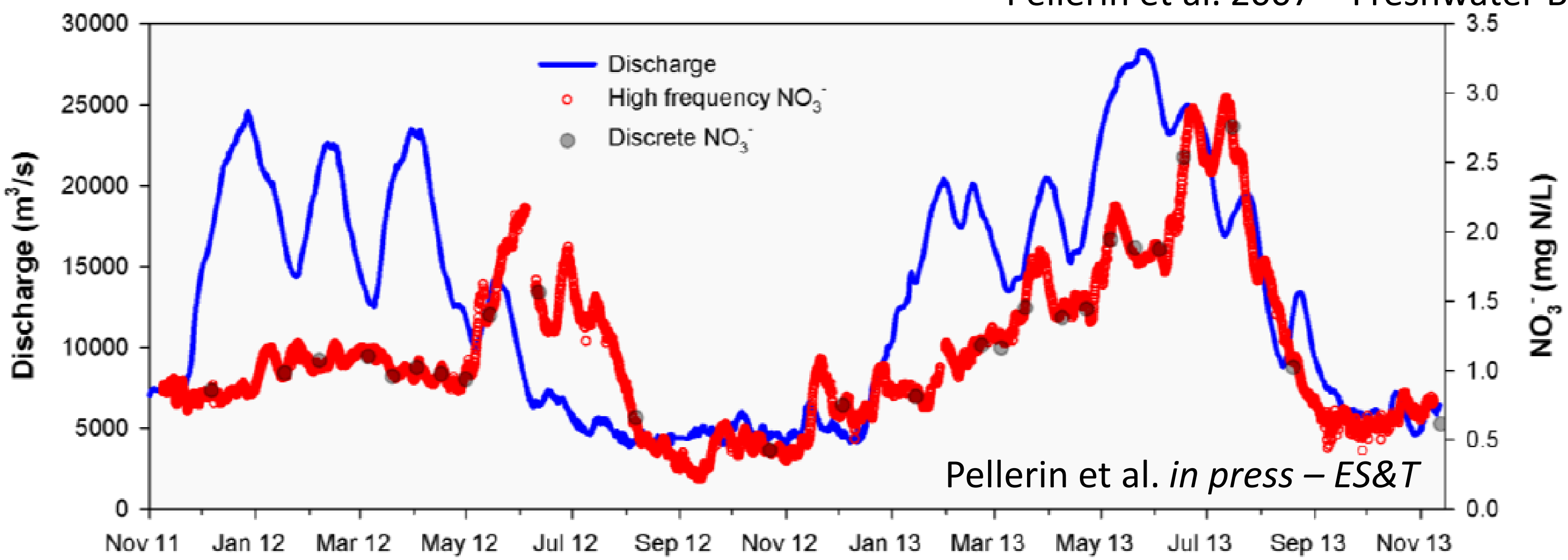


High Frequency Solute Signals – **Adventures in Deconvolution**

- New sensors → new patterns → new insights
- Signal origins?
  - Catchment processes
  - Stream processes
  - Superposition vs. interaction



Pellerin et al. 2007 – Freshwater Biology

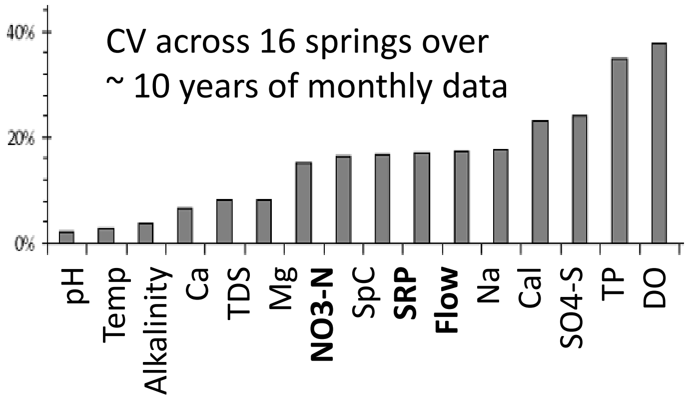


Pellerin et al. *in press – ES&T*

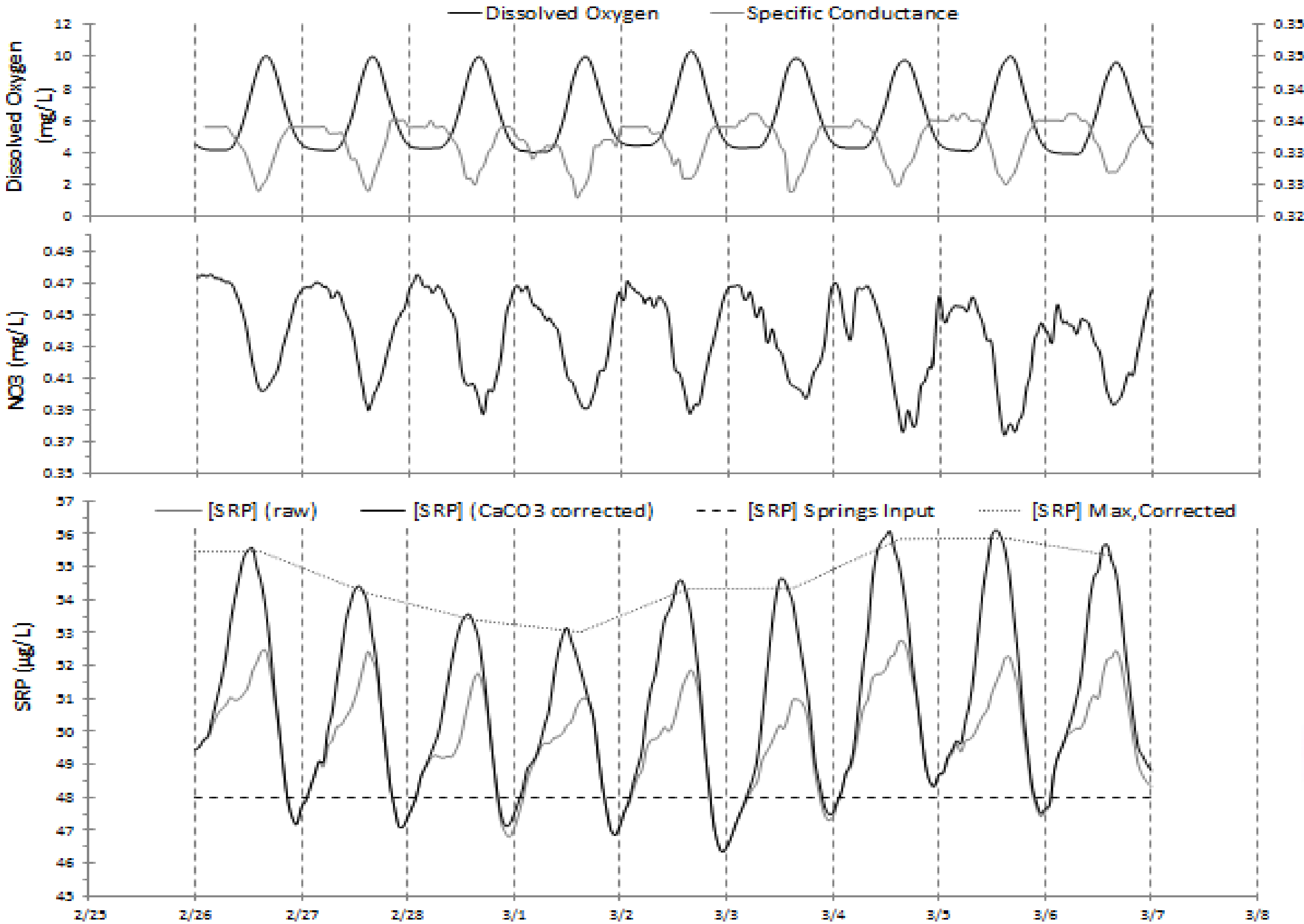
Deconvolution Step 1:
Catchment vs. River Signals

- Two sources of (unknown) variation requires model systems where one source is controlled

Florida's Springs – unparalleled water clarity and stability



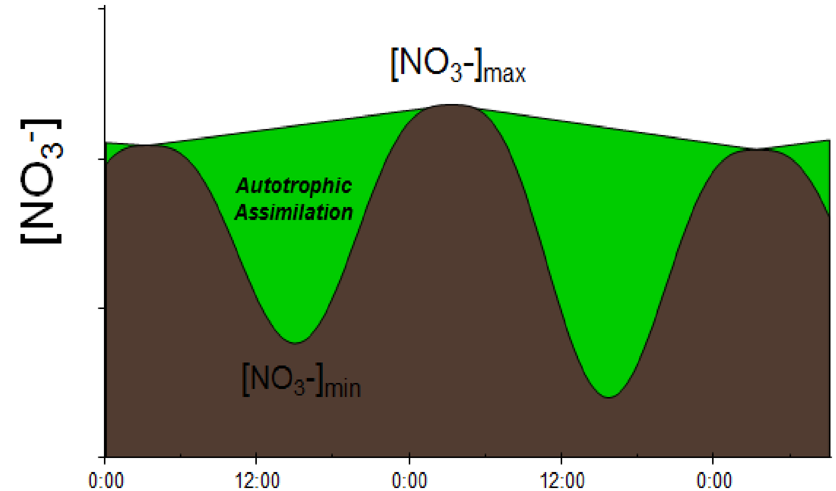
A “Pure” River Signal

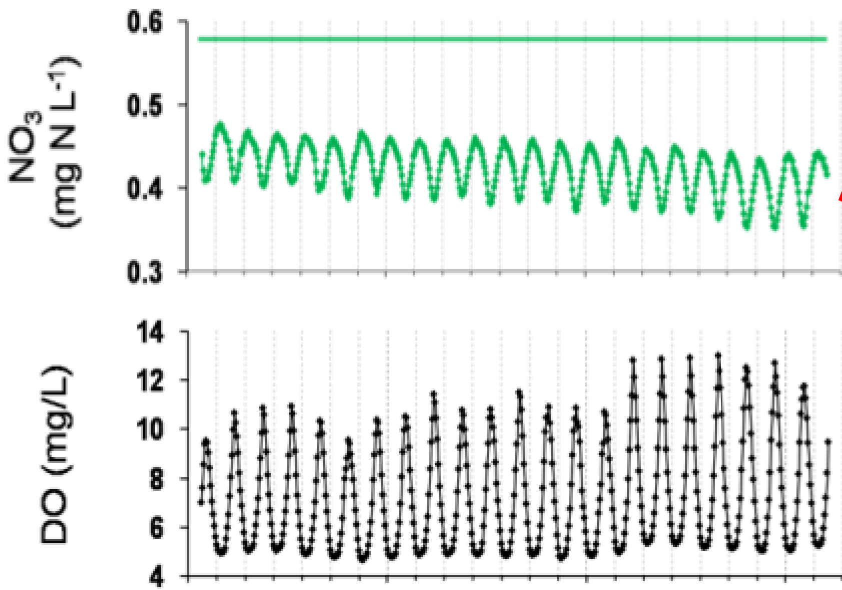


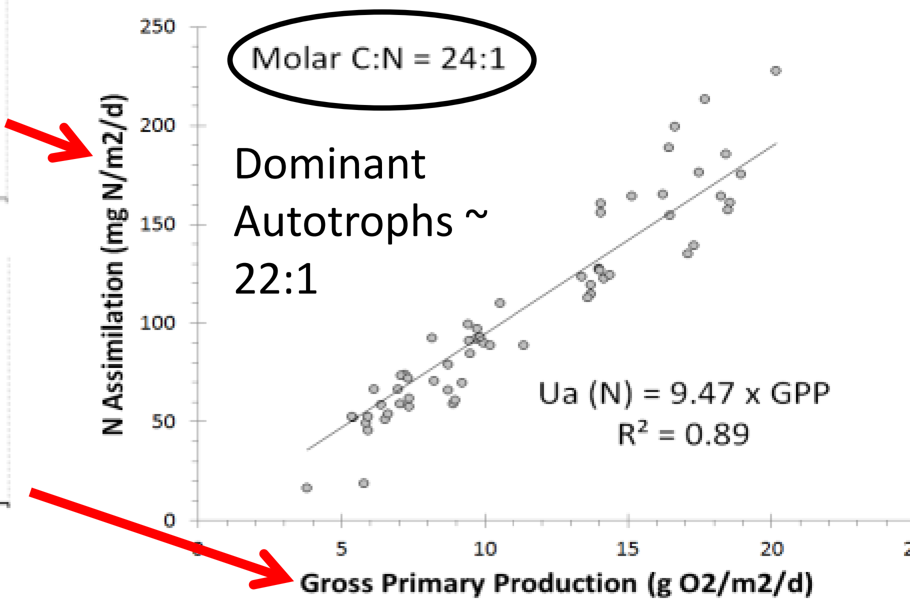
Cohen et al. 2013 – Ecological Monographs

Deconvolution Step 2:
Assimilation from Diel NO_3 Variation

- N retention due to solar-forcing is plant uptake
  - *What controls magnitude and variation of U_a?*



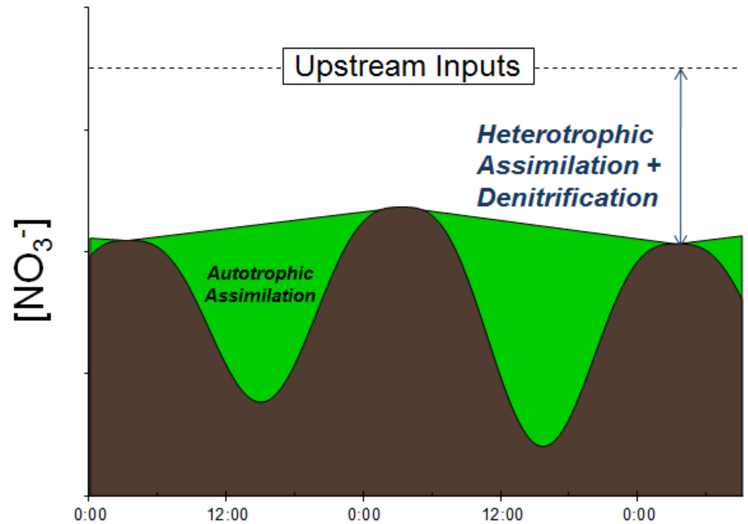


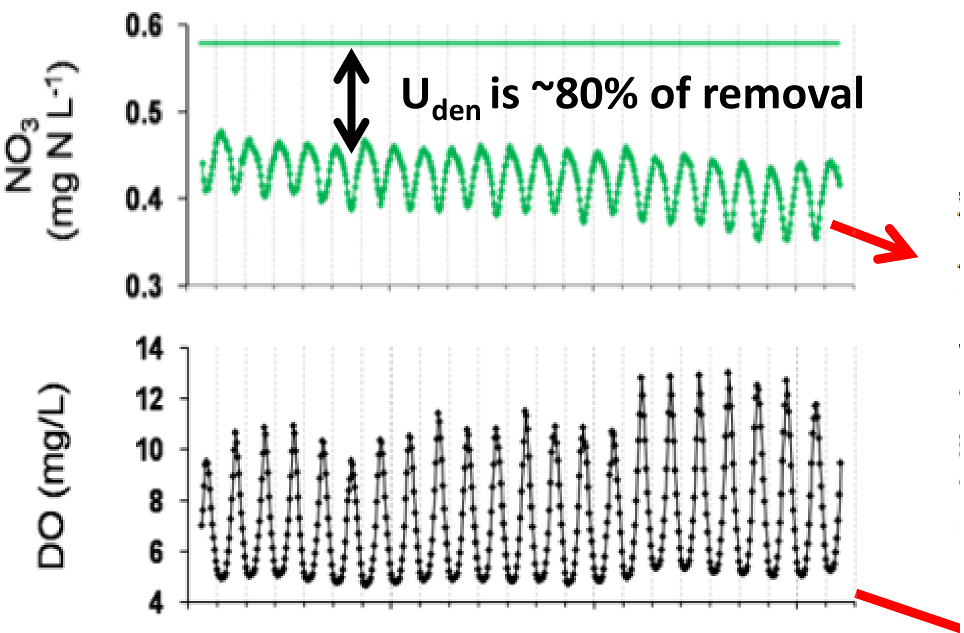


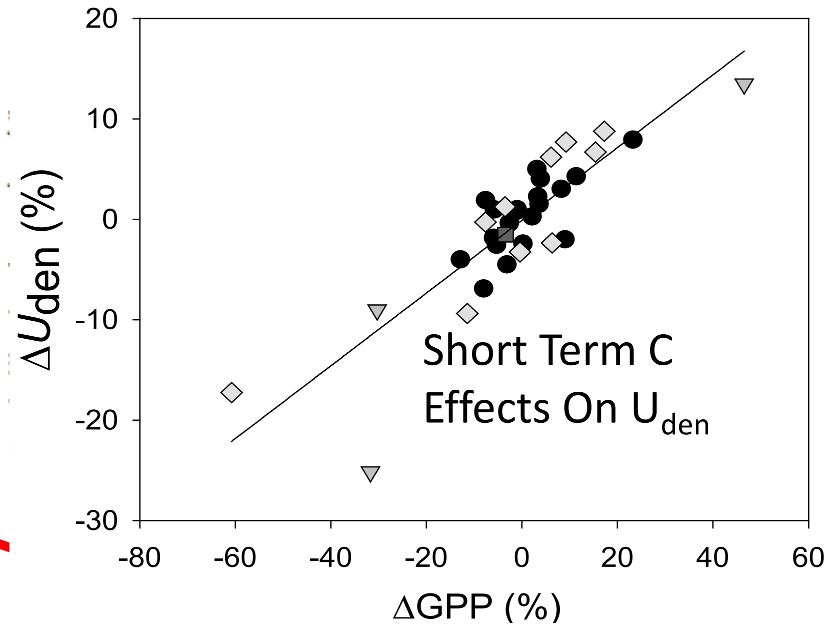
Heffernan and Cohen (2010) – L&O

Deconvolution Step 2:
Denitrification by Difference

- Mass retention is 2 processes:
  - Uptake and denitrification
  - $R - U_a = U_{den}$
  - *What controls magnitude and variation in* U_{den}*?*



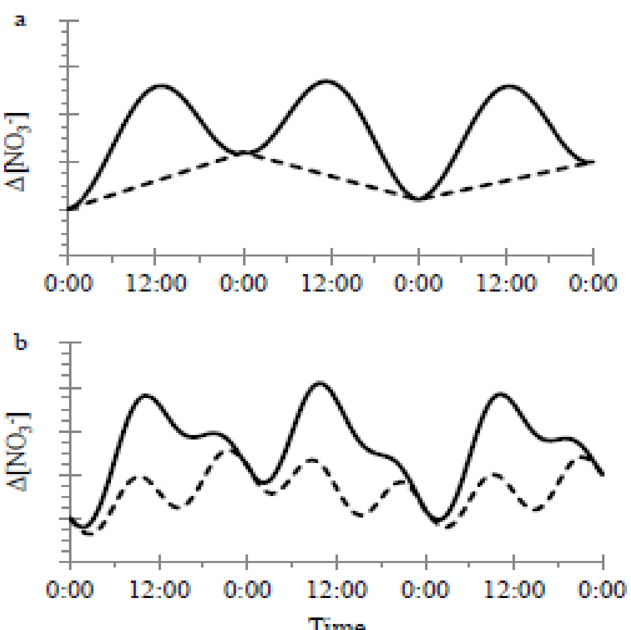


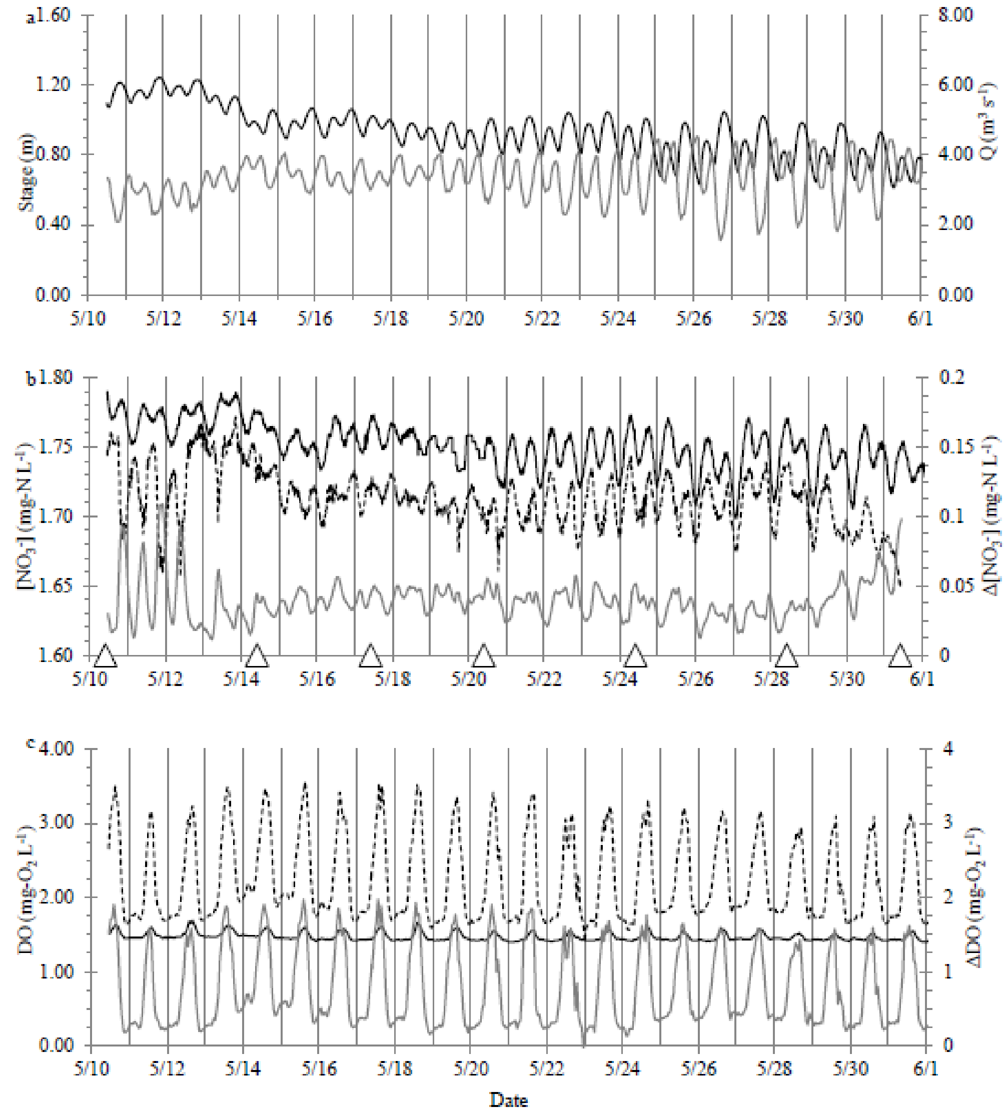


Heffernan and Cohen (2010) – L&O

Deconvolution Step 3:
(Predictable) Hydraulic Variation

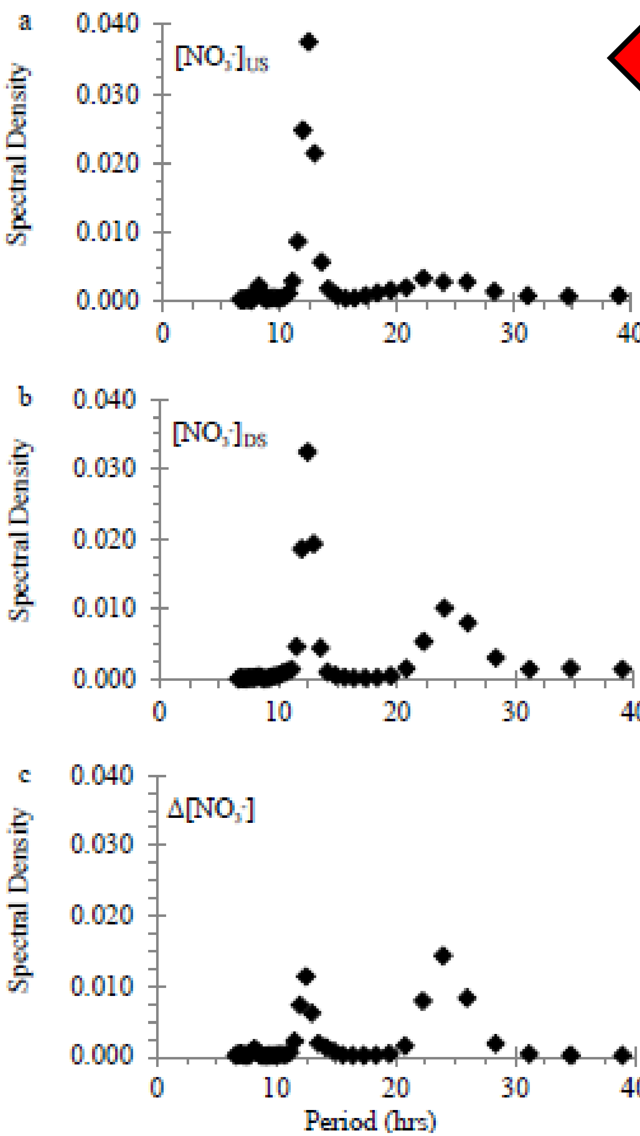
- Semi-diurnal tidal spring-fed river
- Estimate uptake using **two stations**





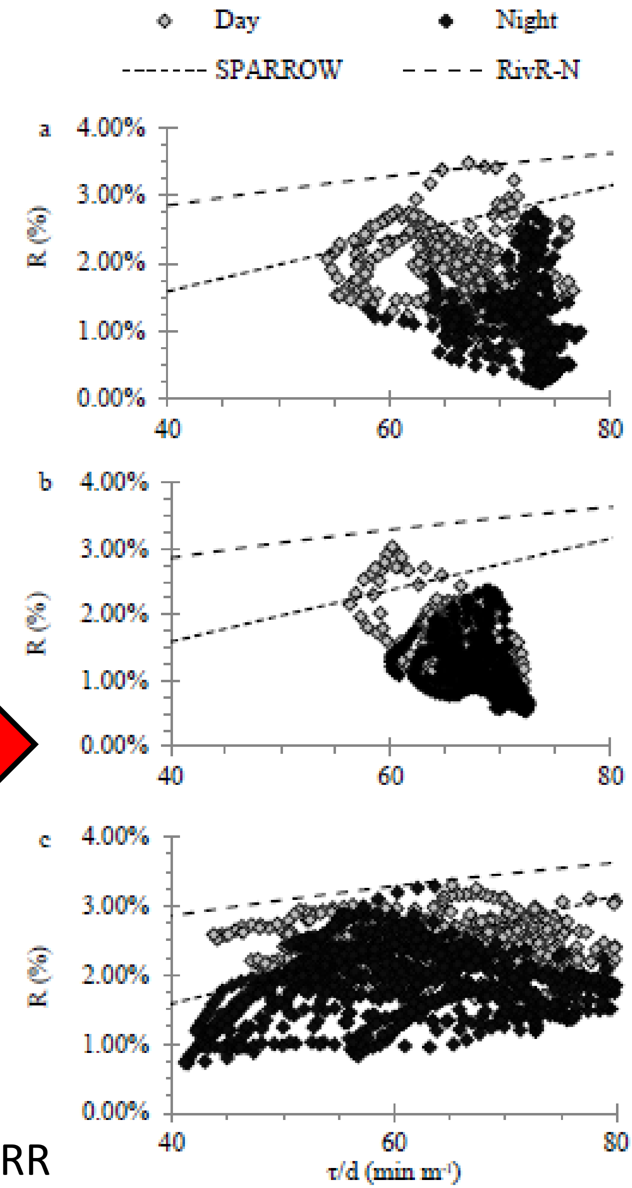
Hensley et al. (in review) – WRR

Time Scales of and Controls on Retention



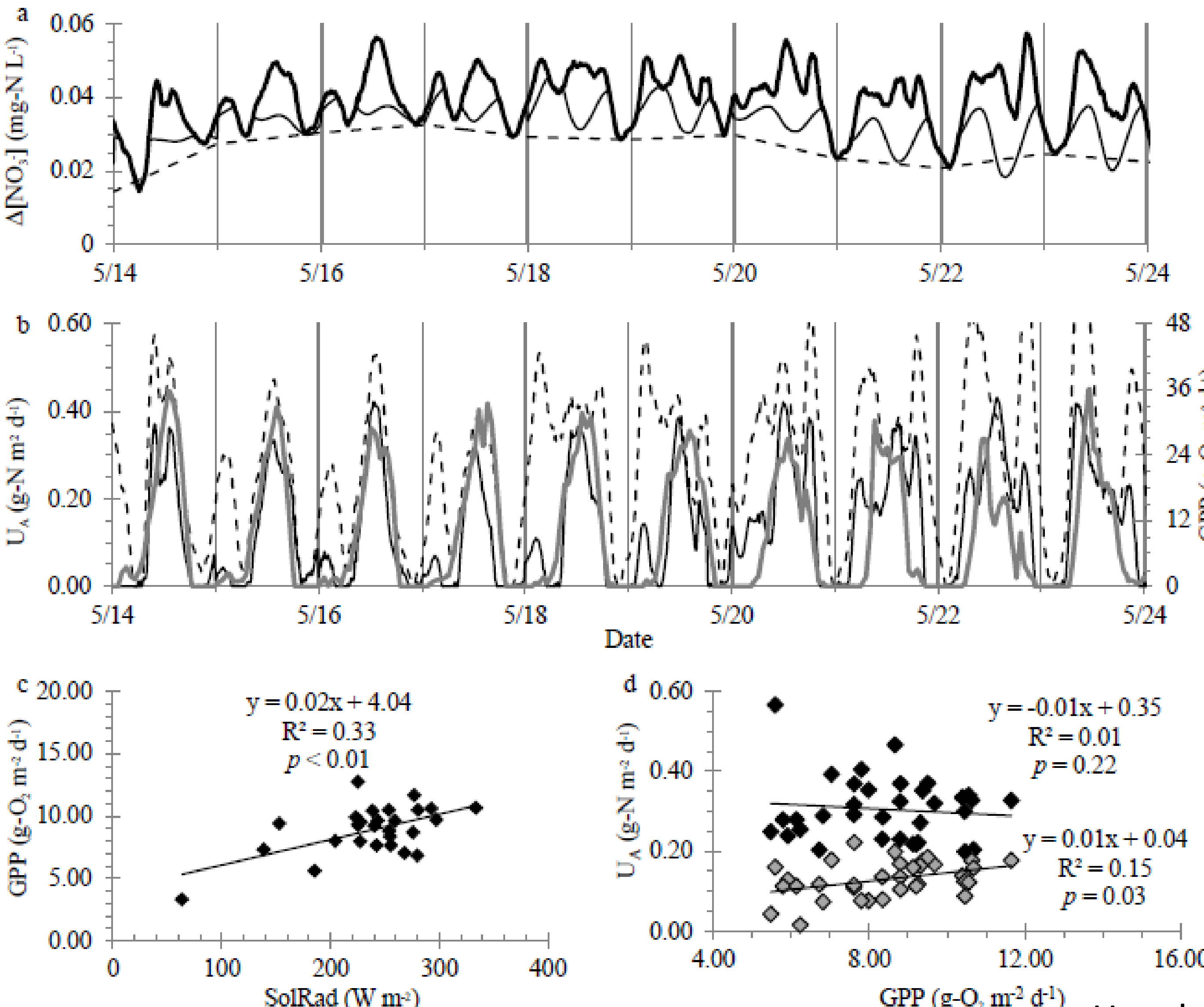
Tide dominates upstream and downstream time series, but **sunlight** variation dominates removal

Removal is <u>**inversely**</u> related to residence time:depth (τ/d)



Hensley et al. (in review) – WRR

Extracting Assimilation (U_a)



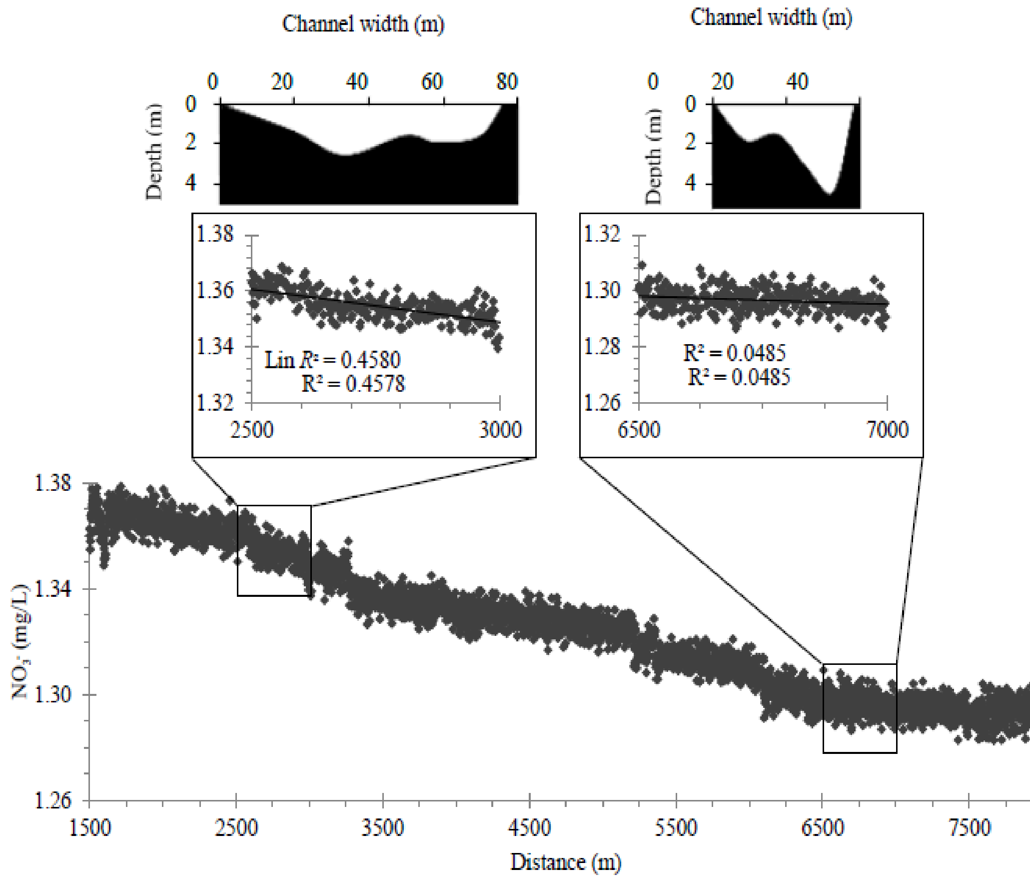
Molar C:N of extracted U_a signal ~ **11:1**

Tissue C:N of autotrophs ~ **10:1**

Hensley et al. (in review) – WRR

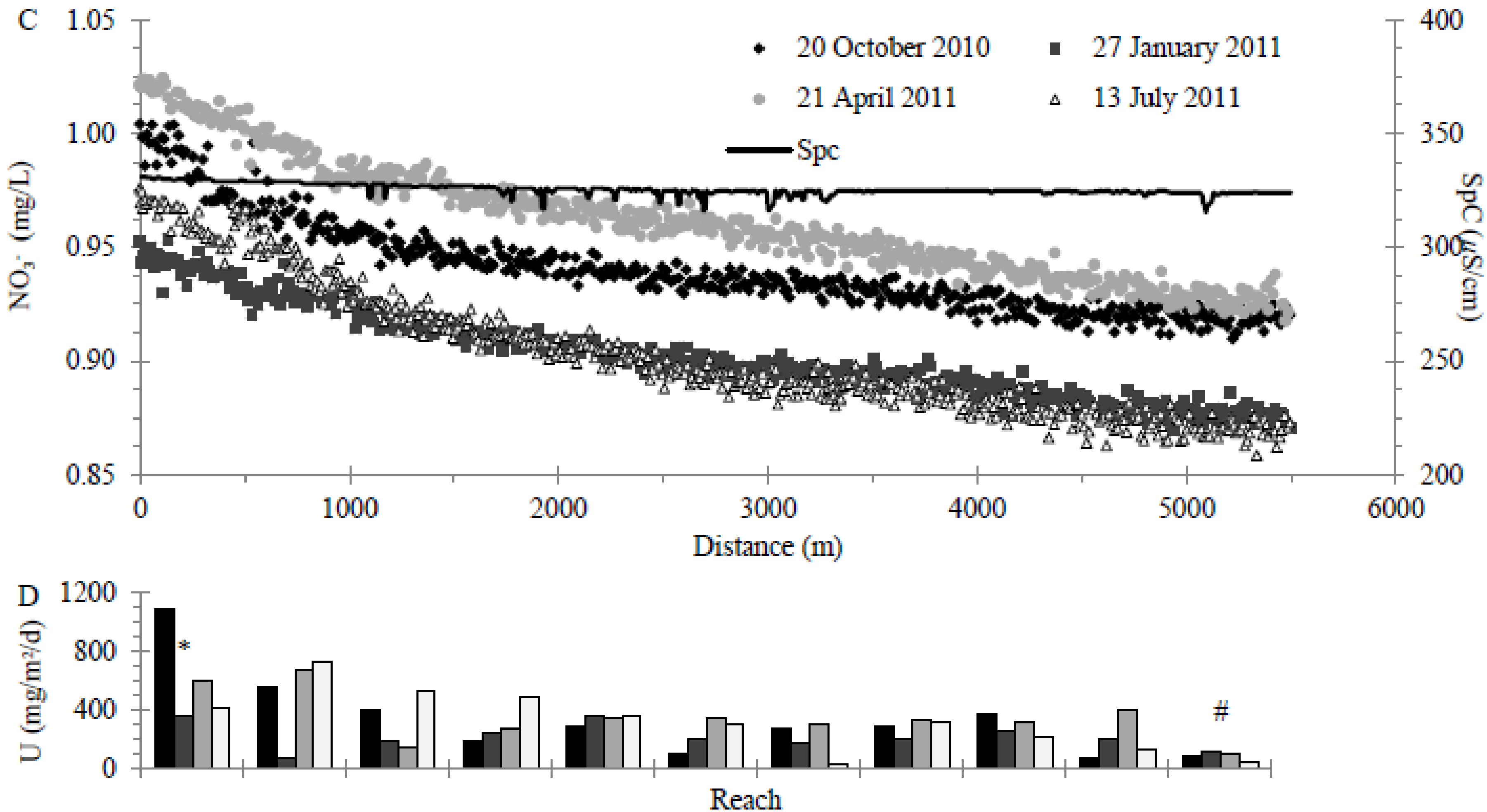
Deconvolution Step 4:
Longitudinal Concentration Profiles

- Spatial disaggregated uptake **rates**
- Profile geometry (finally) for uptake **kinetics**



Hensley et al. (2014) – L&O

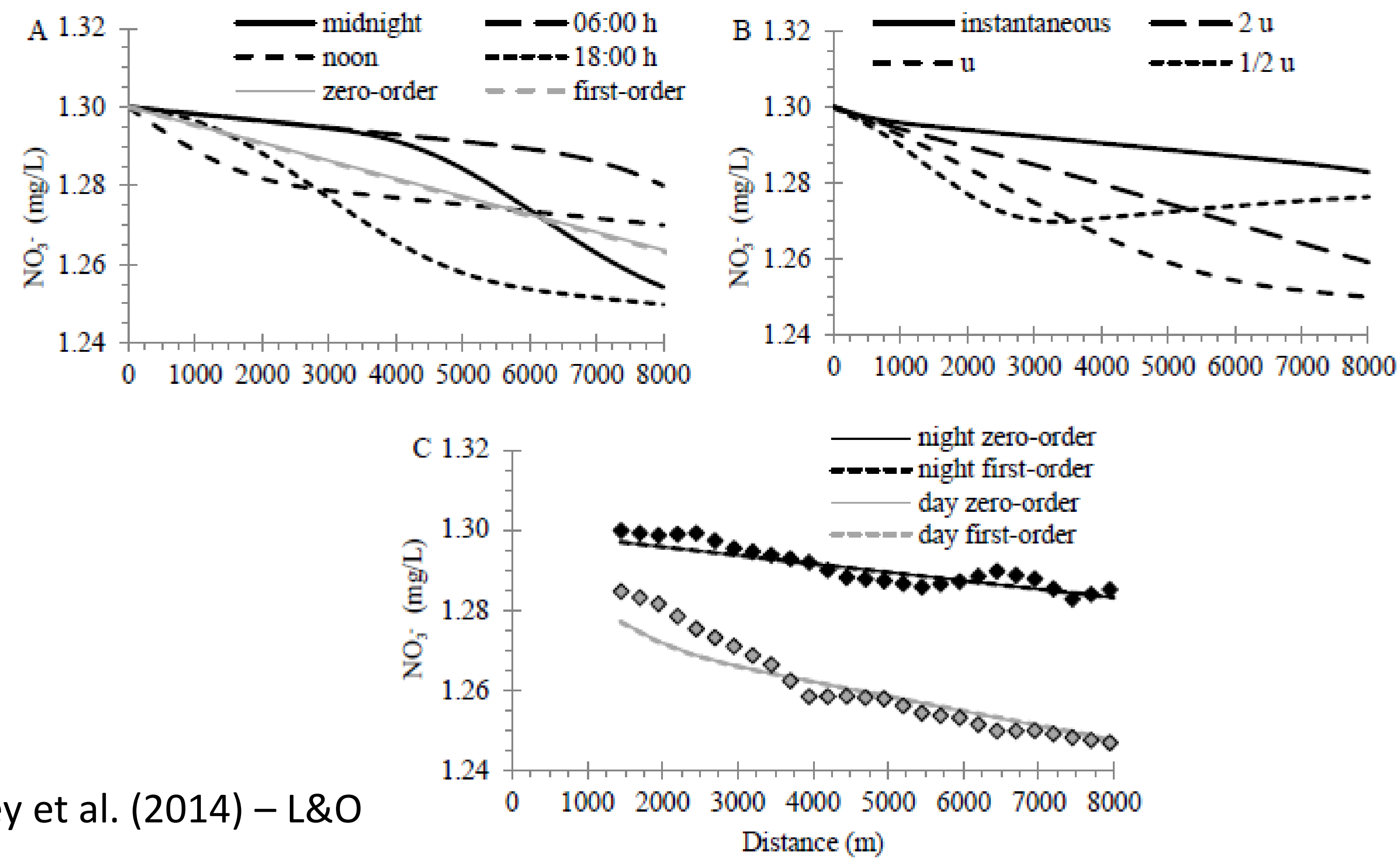
Clear Uptake Signal – The “First Spiral”



Hensley et al. (2014) – L&O

Profile geometry is **confounded**

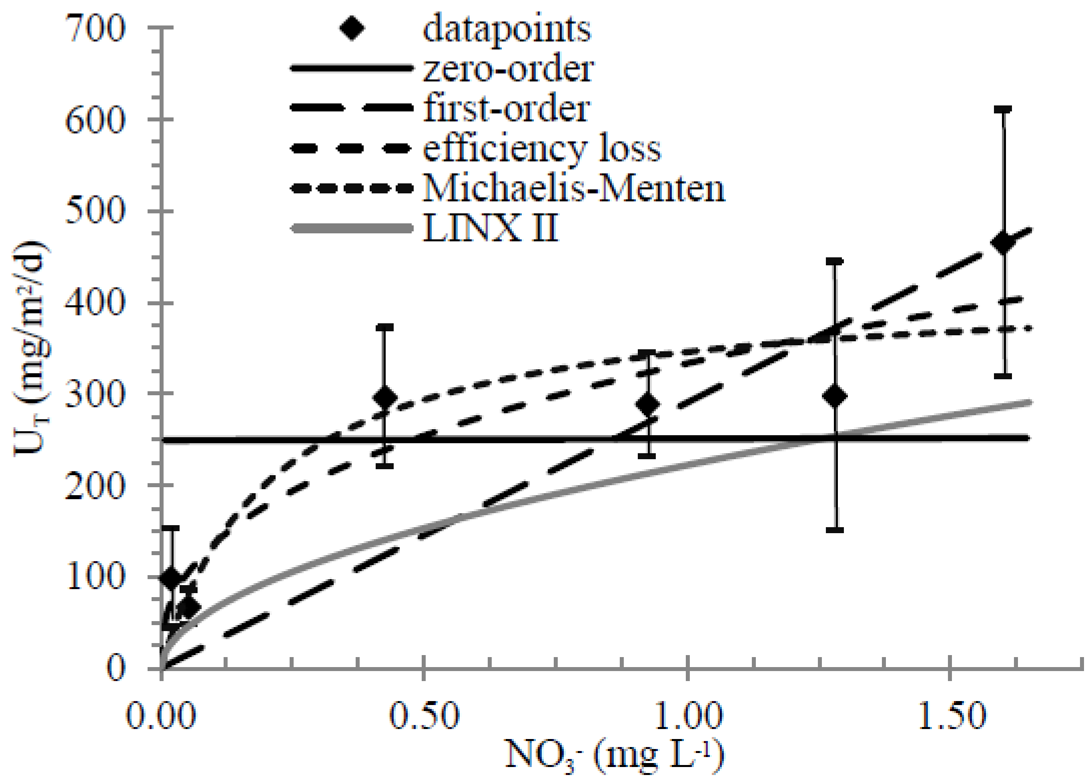
- Time varying uptake + sampling velocity effects are >> larger than differences between kinetic models



Hensley et al. (2014) – L&O

Cross-Site Comparison Suggests NOT 1st Order Kinetics

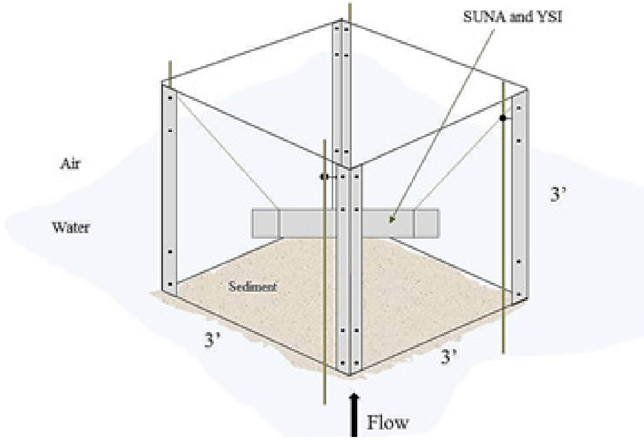
- Efficiency loss and Michaelis-Menten kinetics fit data
  - Clearly NOT 1st or 0th order
  - $k_{1/2}$ ~ 0.1 mg N L^{-1}
- Where we can partition **U_a is zero-order** and **U_{den} is first-order**

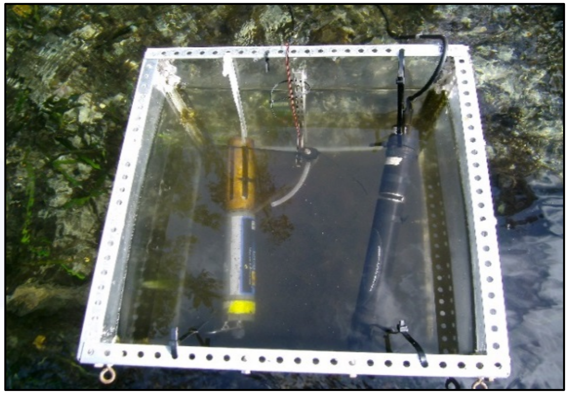


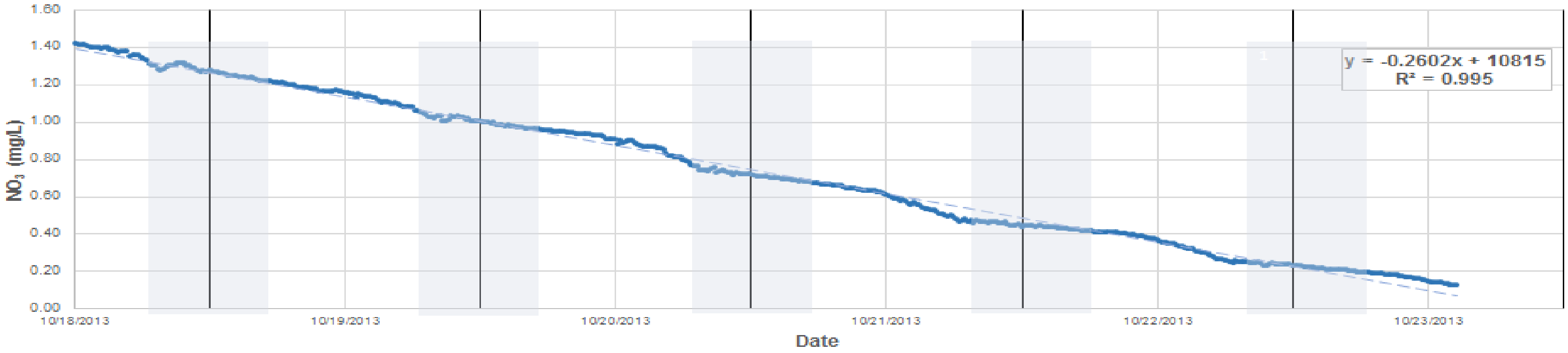
Deconvolution Step 5: **Removing Flow to Lower Concentrations**

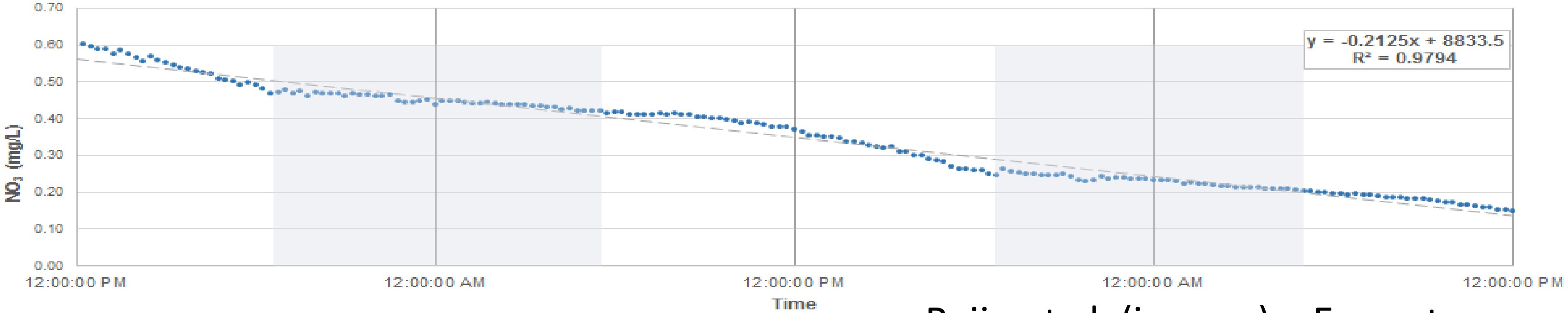
- Hydraulic controls mask kinetic inferences
- Nutrient enrichment experiments (e.g., TASCC; Covino et al. 2010) could yield kinetics
  - But we're not interested in what happens at **<u>higher</u>** nutrients, but at **<u>lower</u>** nutrients
- Continuous advection replaces nutrients, so we removed advection

Depletion using "Benthos Boxes"



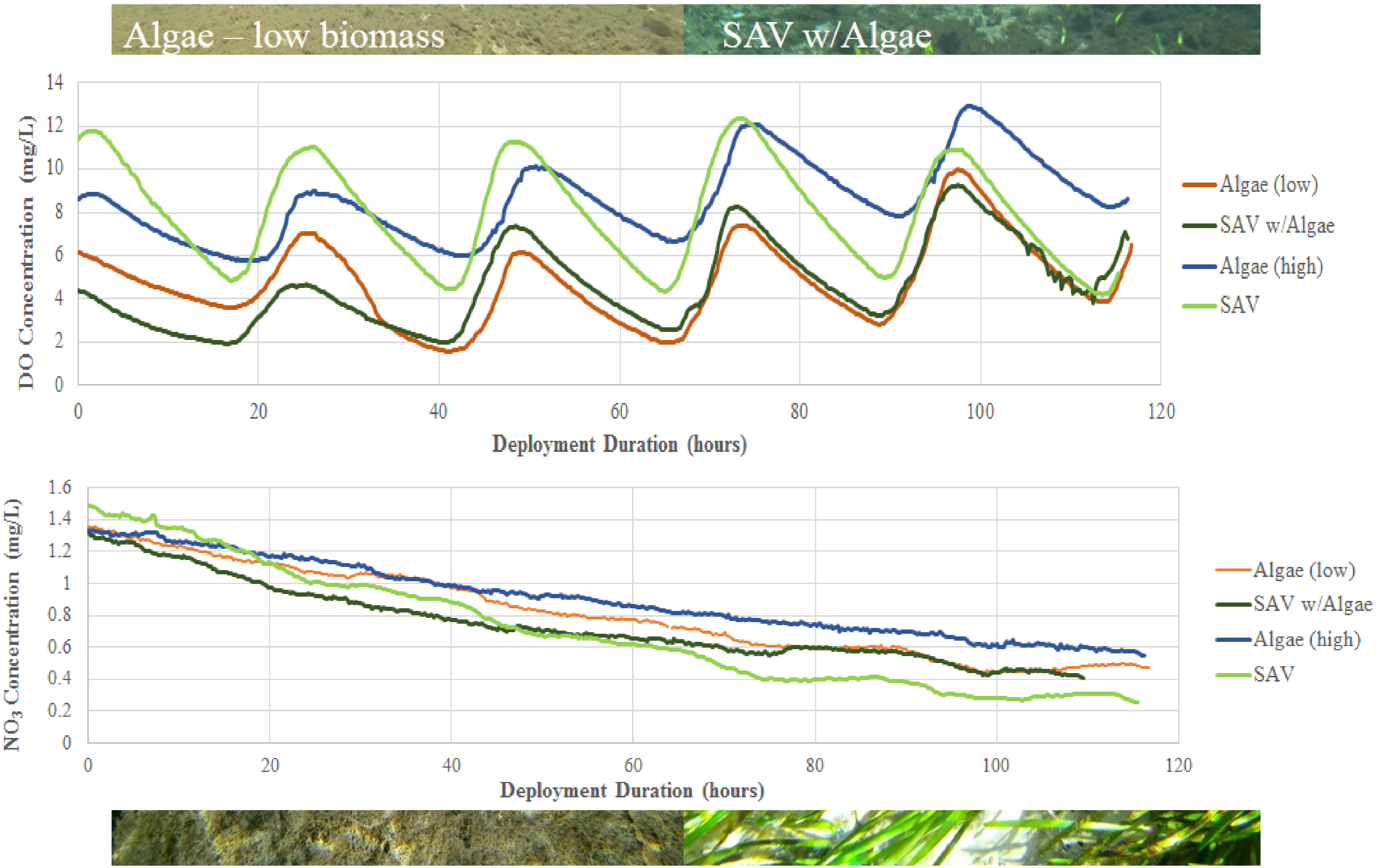






Reijo et al. (in prep) – Ecosystems

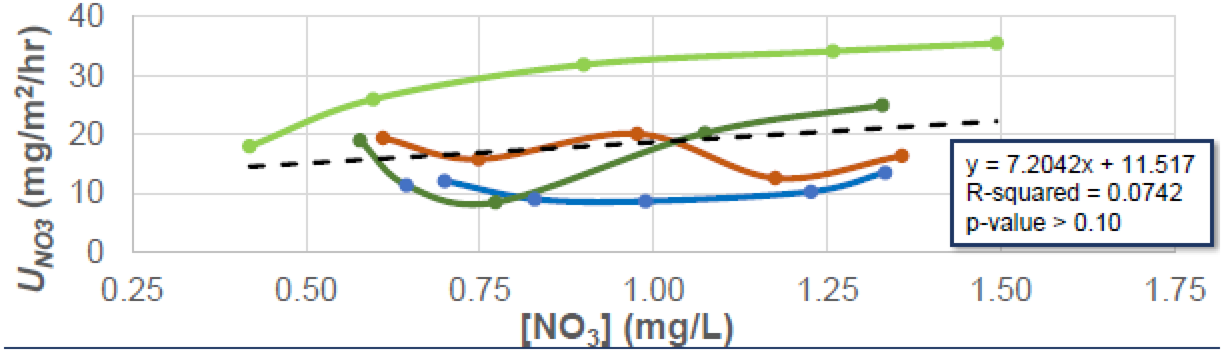
Primary Producer Community Structure



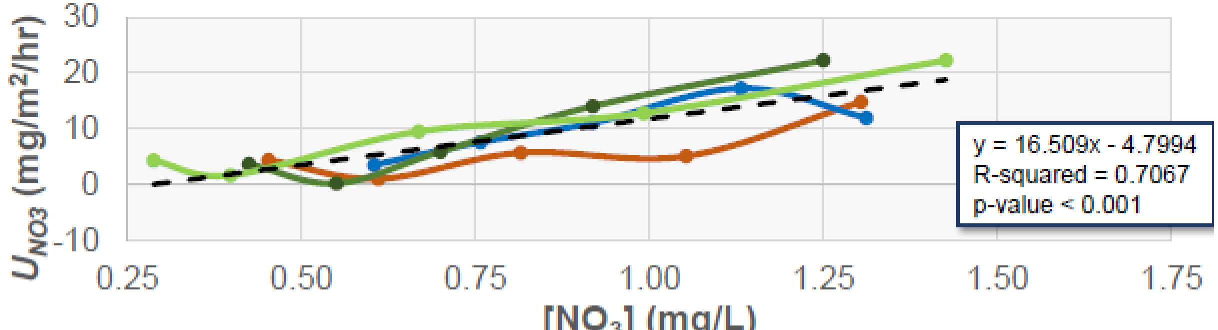
Reijo et al. (in prep) – Ecosystems

Preliminary Removal Kinetics

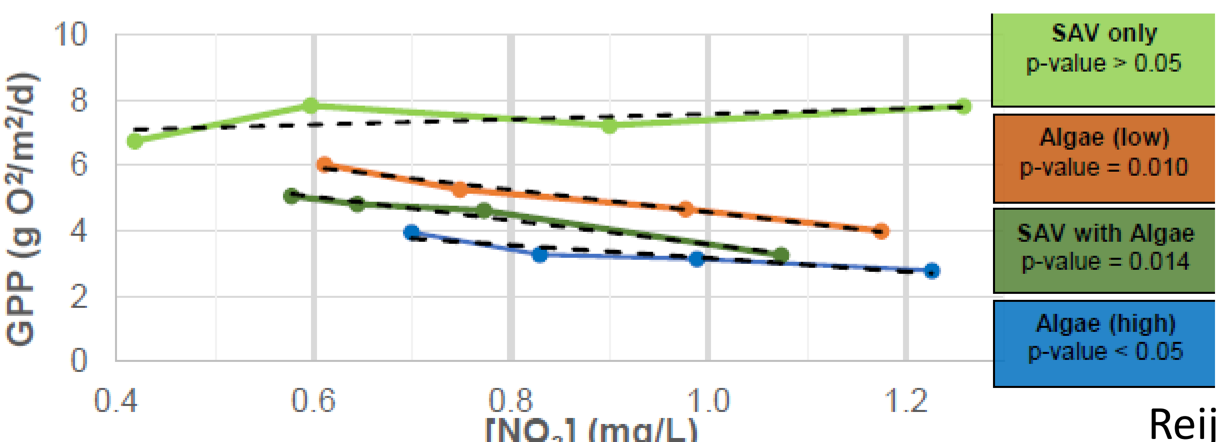
(C. Reijo, unpublished data)



Daytime Removal is Zero-Order



Nighttime Removal is First-Order



$[NO_3]$ has **no effect** on GPP_{SAV} and may **inhibit** GPP_{ALG}

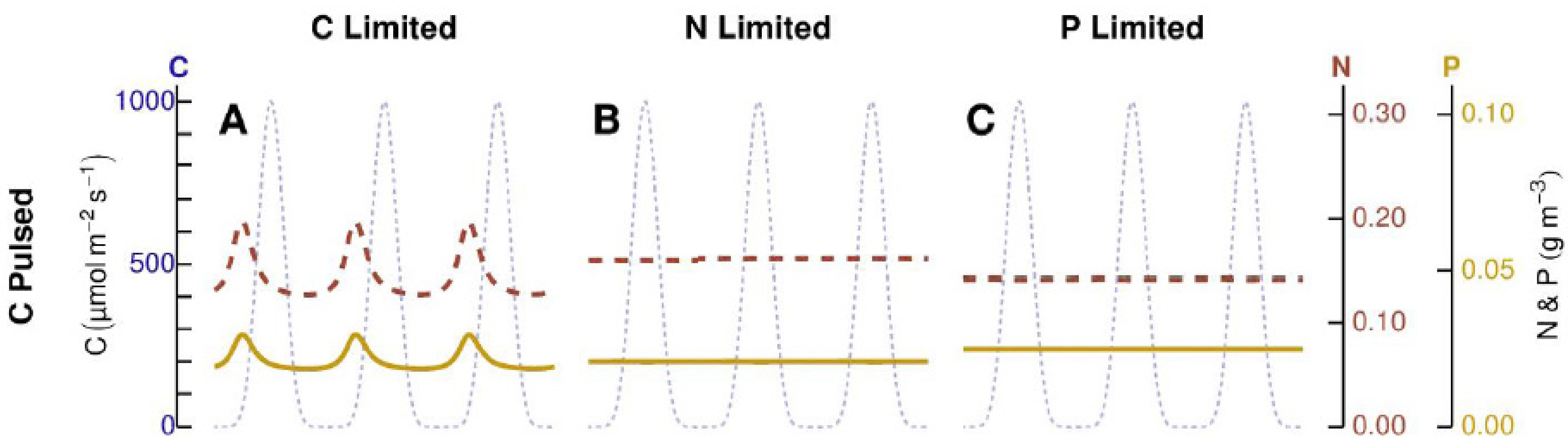
Reijo et al. (in prep) – Ecosystems

Summary

- Existing sensors have enabled transformative methods for measuring **uptake**
- Preliminary data on chamber methods for measuring **kinetics** is promising
  - Need to evaluate hydraulic impacts/artifacts
- Taking these tools to rivers where both catchment AND river processes control solute dynamics is an important next step

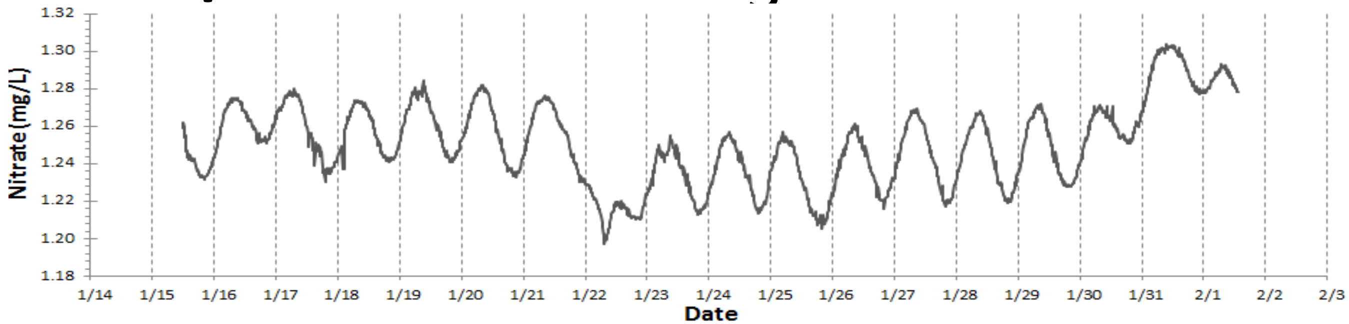
A Closing Thought on Diel Signals

- A recent physiological model of uptake and limitation suggests **diel variation in solutes (N and P) was diagnostic of light limitation**
  - Where a nutrient limits primary production, concentration is static in response to solar forcing

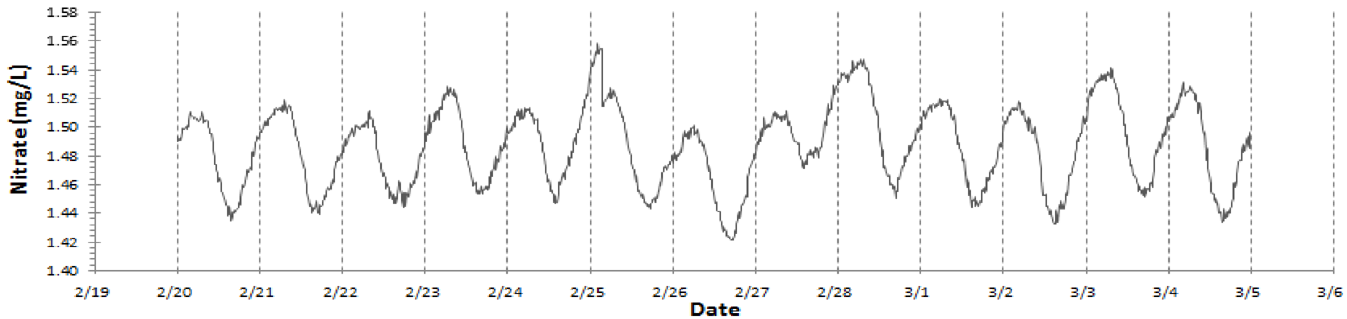


Appling and Heffernan (in press) – American Naturalist

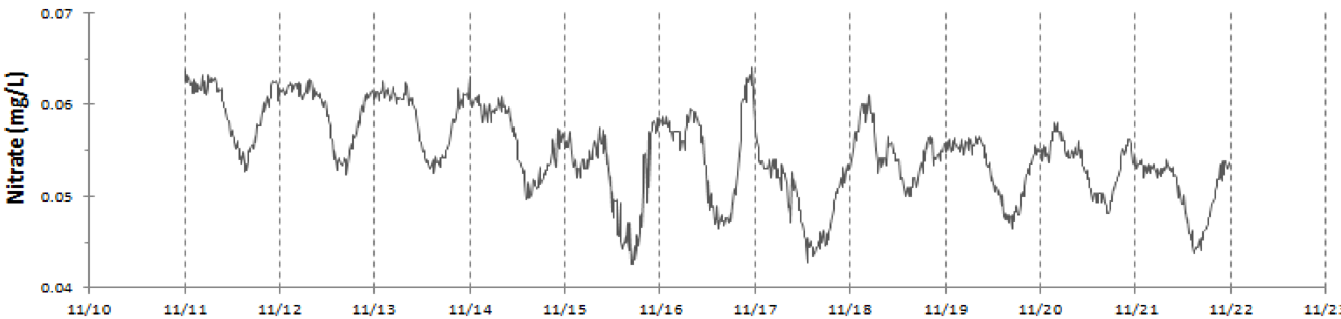
Compare Diel NO_3 Variation Across Rivers



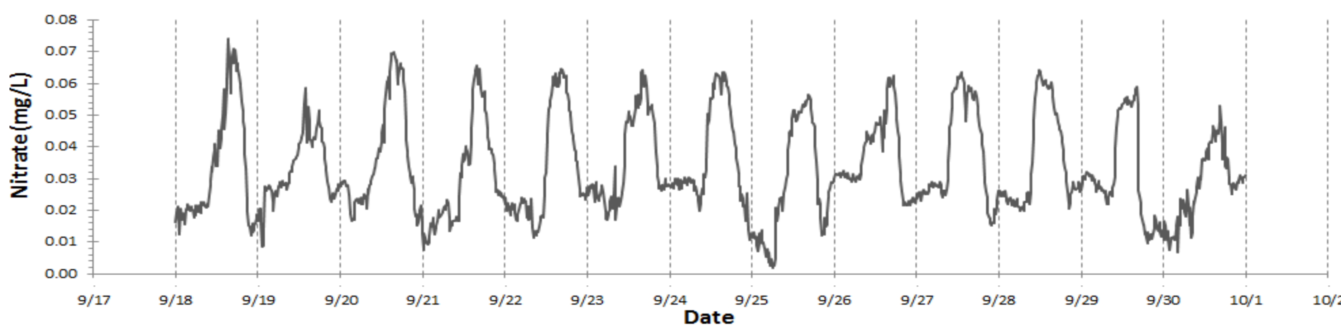
Silver River (Jan, 2010)
NO_3 = 1.3 mg N/L
GPP ~ 10 g O_2 m^{-2} d^{-1}



Rainbow River (Feb 2010)
NO_3 = 1.6 mg N/L
GPP ~ 13 g O_2 m^{-2} d^{-1}

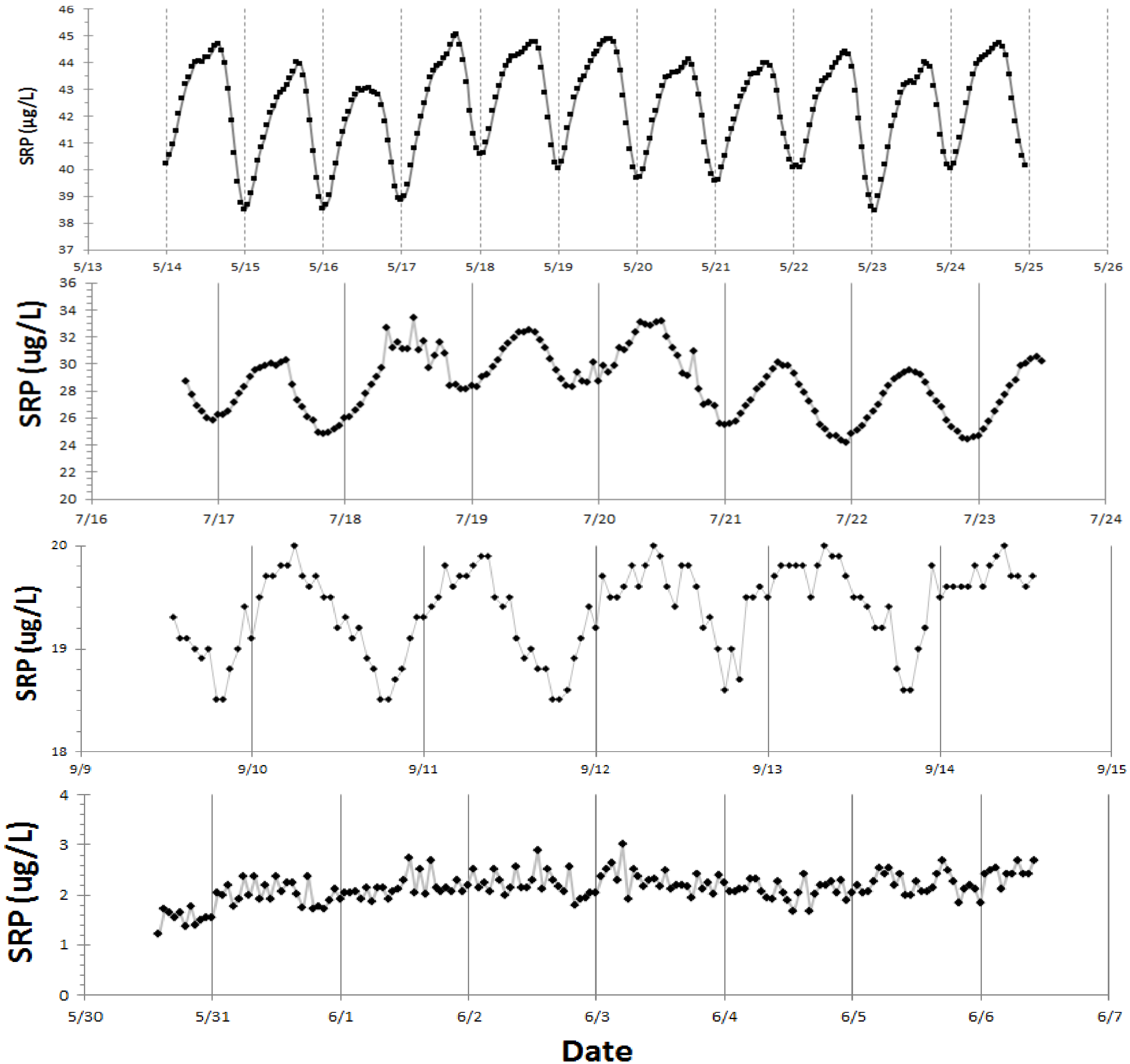


Juniper River (Nov 2010)
NO_3 = 0.1 mg N/L
GPP ~ 2 g O_2 m^{-2} d^{-1}



Alexander (Sept 2010)
NO_3= 0.05 mg N/L
GPP ~ 17 g O_2 m^{-2} d^{-1}

Compare PO_4 Variation Across Rivers



Ichetucknee (May, 2010)
SRP = 42 µg N/L
GPP ~ 17 g O_2 m^{-2} d^{-1}

Silver (July , 2012)
SRP = 27 µg N/L
GPP ~ 15 g O_2 m^{-2} d^{-1}

Gum Slough (Sept, 2012)
SRP = 18 µg N/L
GPP ~ 9 g O_2 m^{-2} d^{-1}

Weeki Wachee (June, 2012)
SRP = 6 µg N/L
GPP ~ 7 g O_2 m^{-2} d^{-1}


Thank You!
Questions?
Photo Credit: Jenny Adler