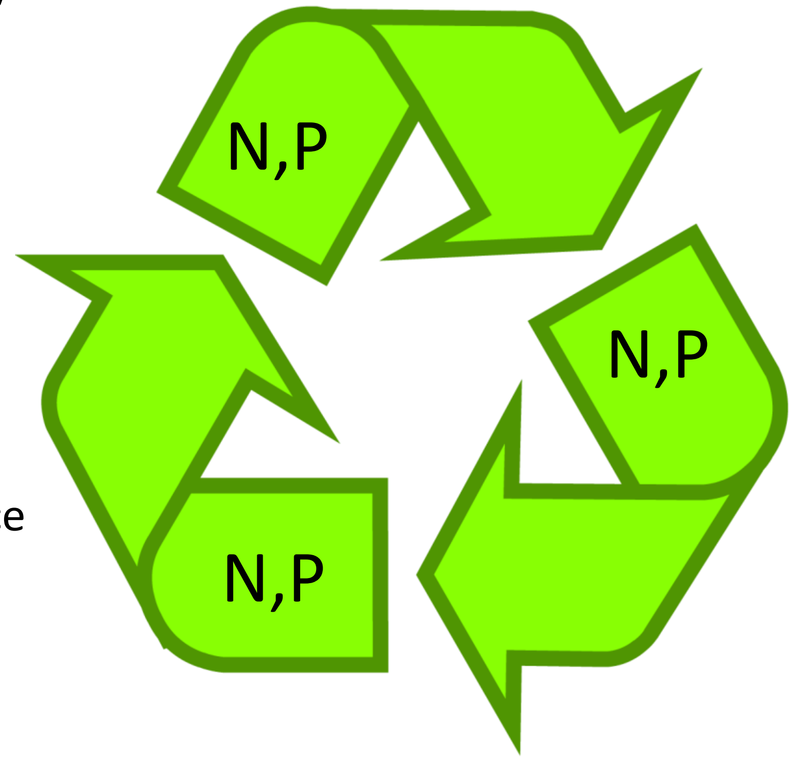
How do input loads and internal cycling affect hypoxia in Chesapeake Bay?

......and how does hypoxia affect internal cycling and fate of input loads in the estuary?



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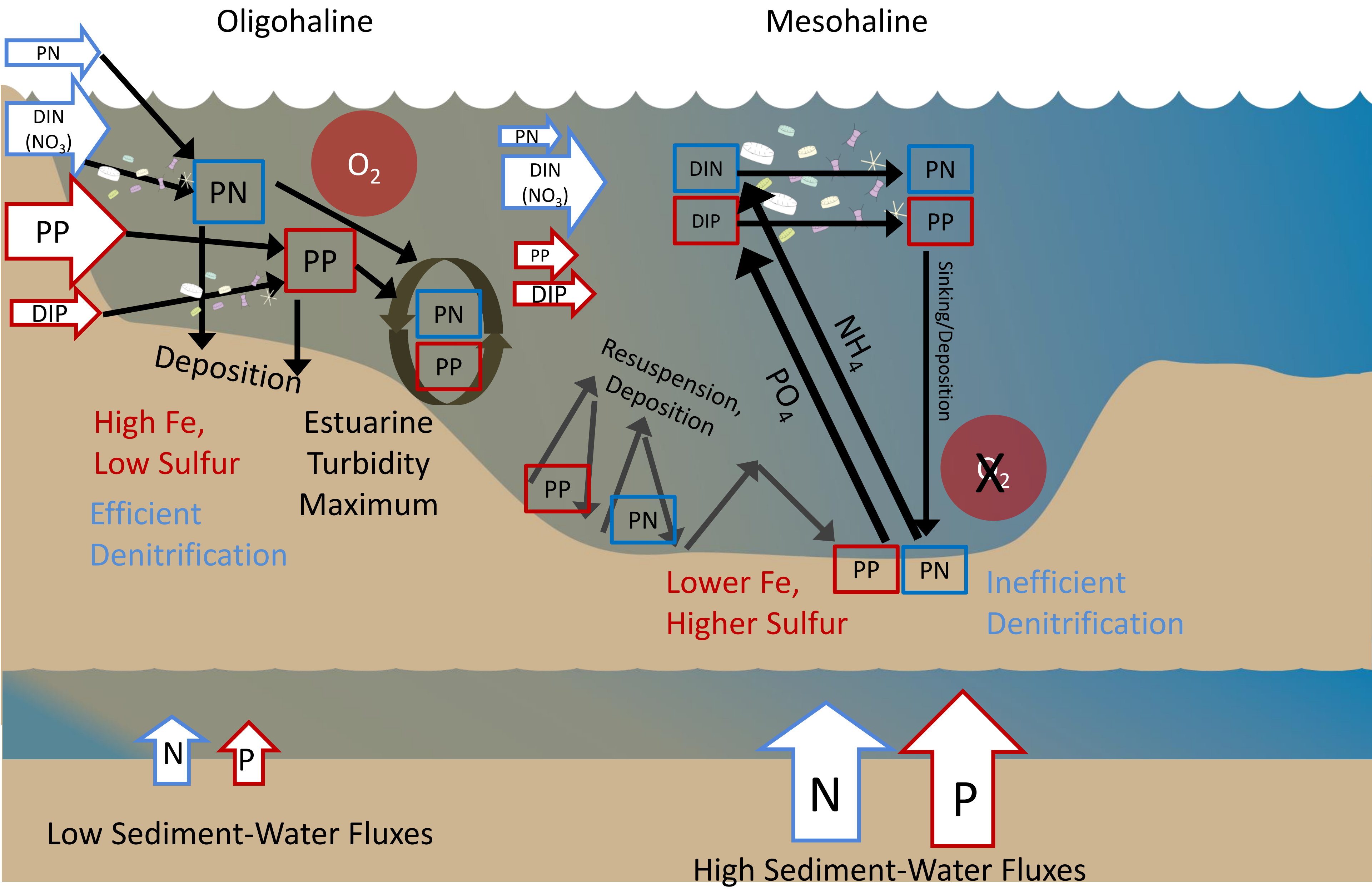
University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

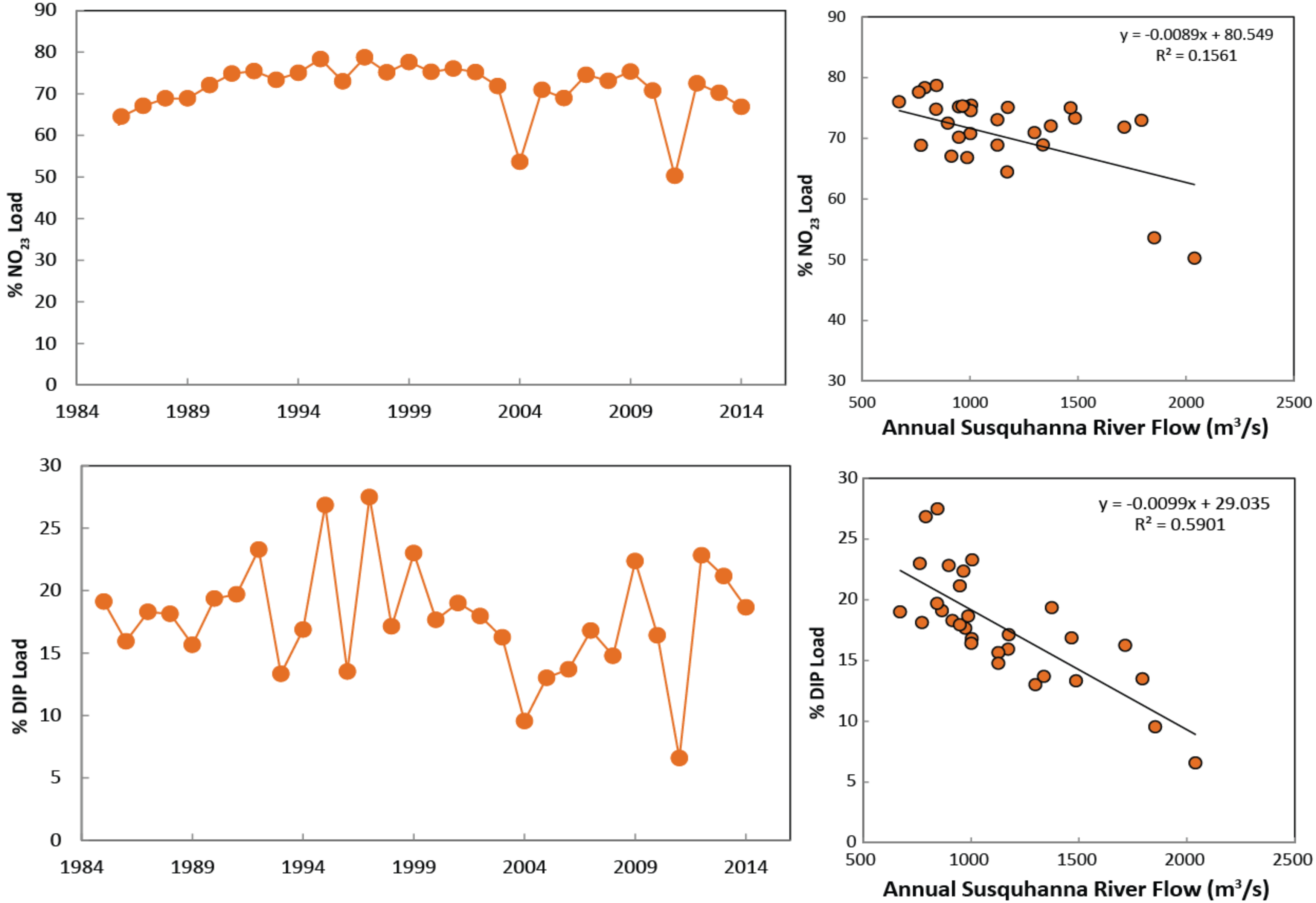
Outline

- A conceptual picture of how watershed-derived nutrients are distributed and processed within the estuary
- The modes in which these nutrients drive hypoxia
- The potential for non-dissolved materials to become bioavailable and measurably impact hypoxia
- The role and control of internal processing (i.e., ‘internal loading’) of nutrients and implications for eutrophication

Regional Variability in Inputs, Transport and Biogeochemistry

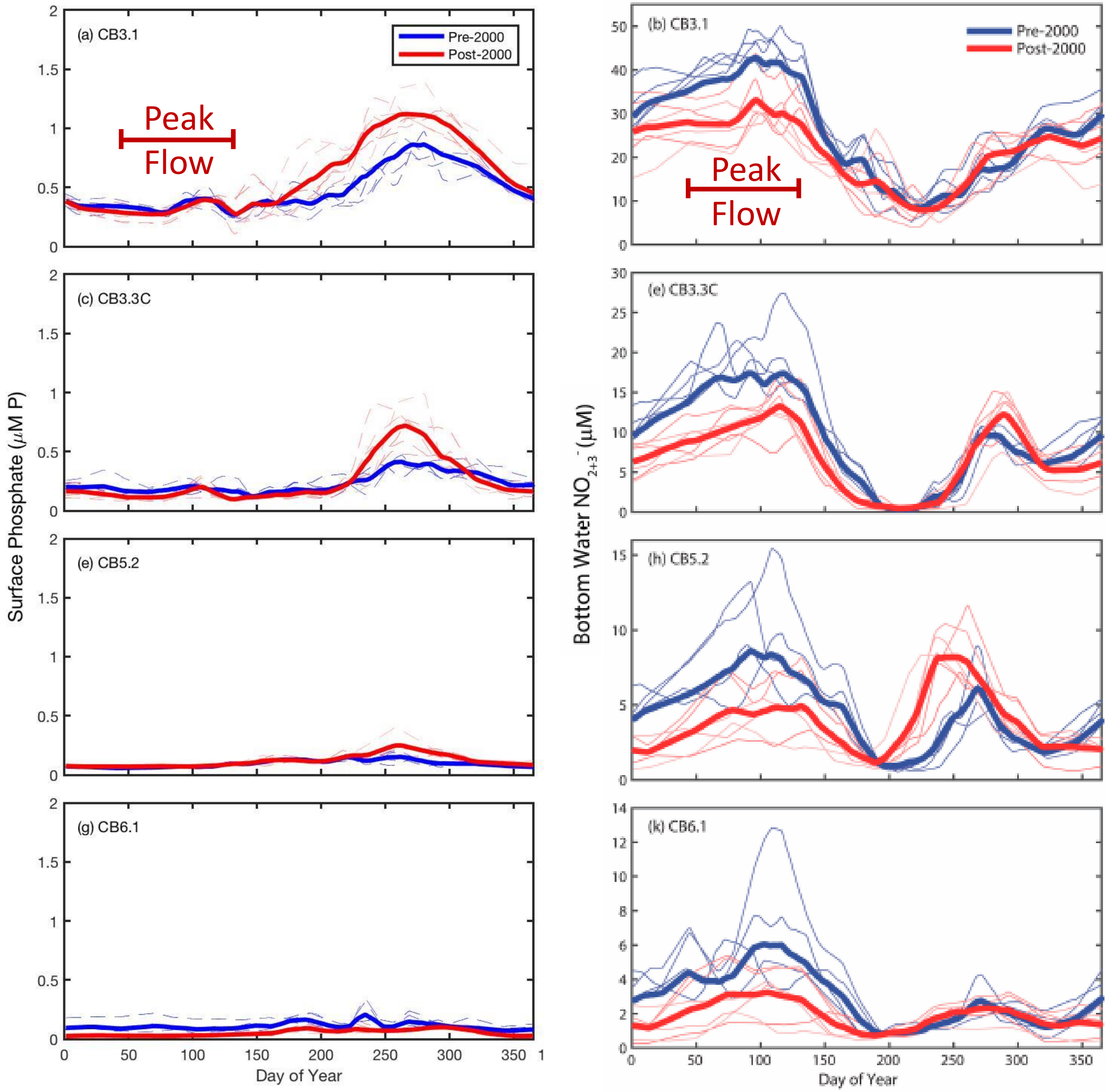


Dissolved N Dominates TN Input, Particulate P Larger Fraction of TP



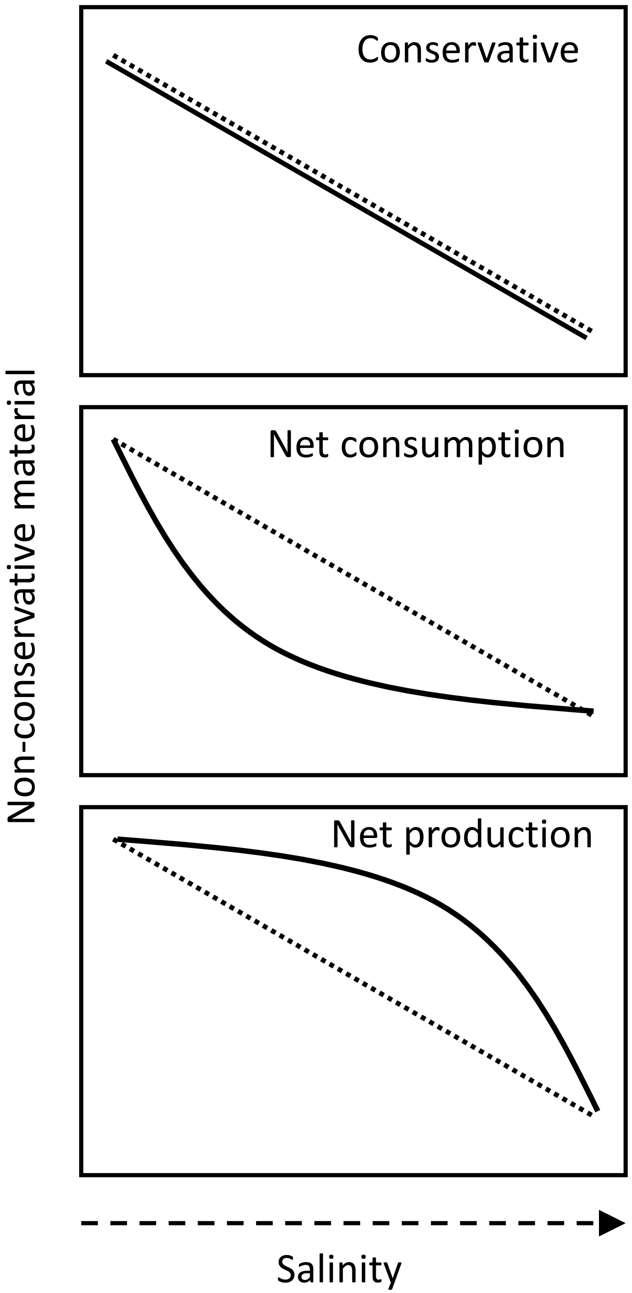
Data reanalyzed from Zhang et al. (2016)

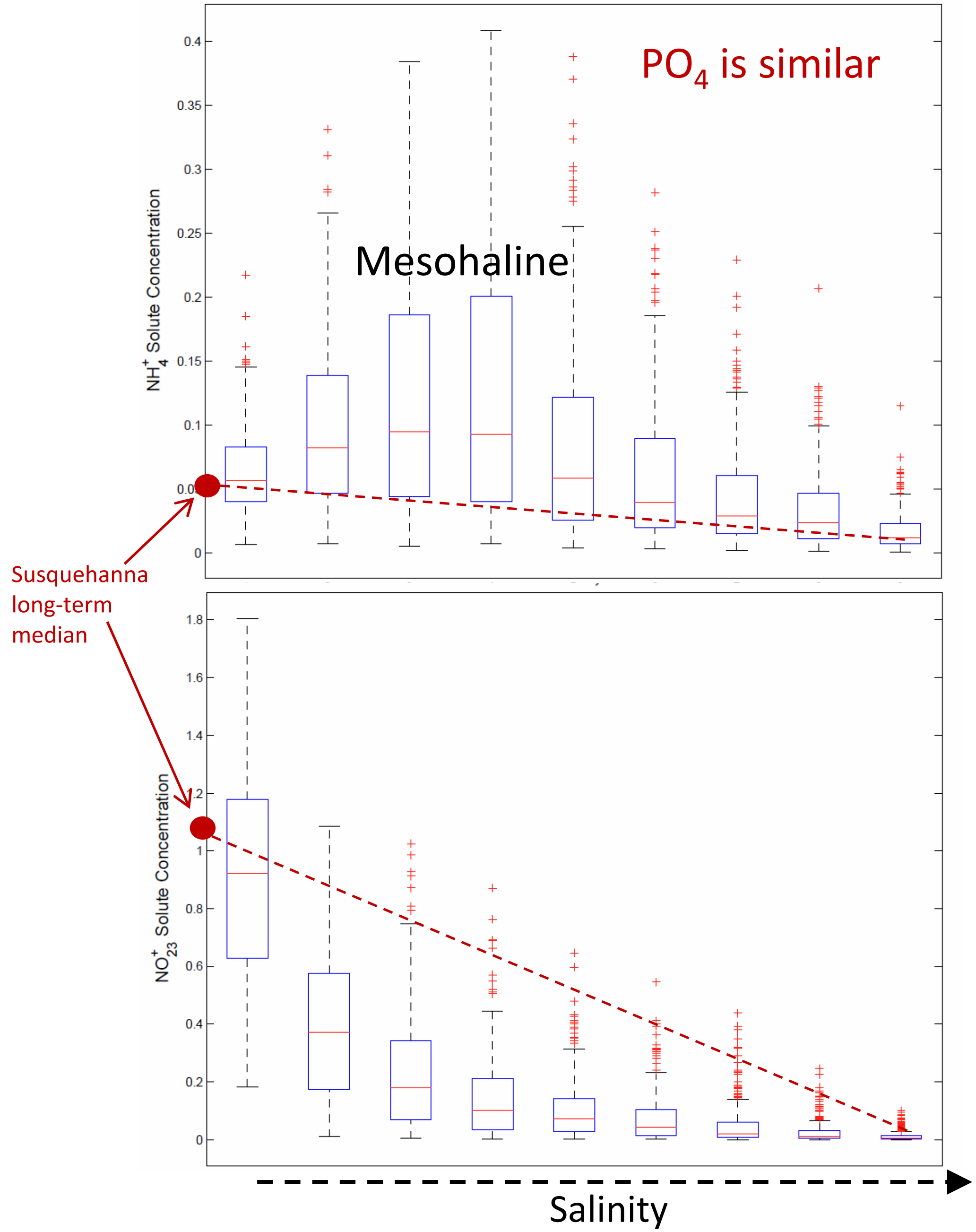
Dissolved N, P in Estuary Reveal Role of DIN, TP Input



- No PO_4 peaks during peak flow
- PO_4 peaks in late summer everywhere
- NO_{23} peaks in winter-spring with peak flow

Mixing Diagrams to Interpret Estuarine Transformations

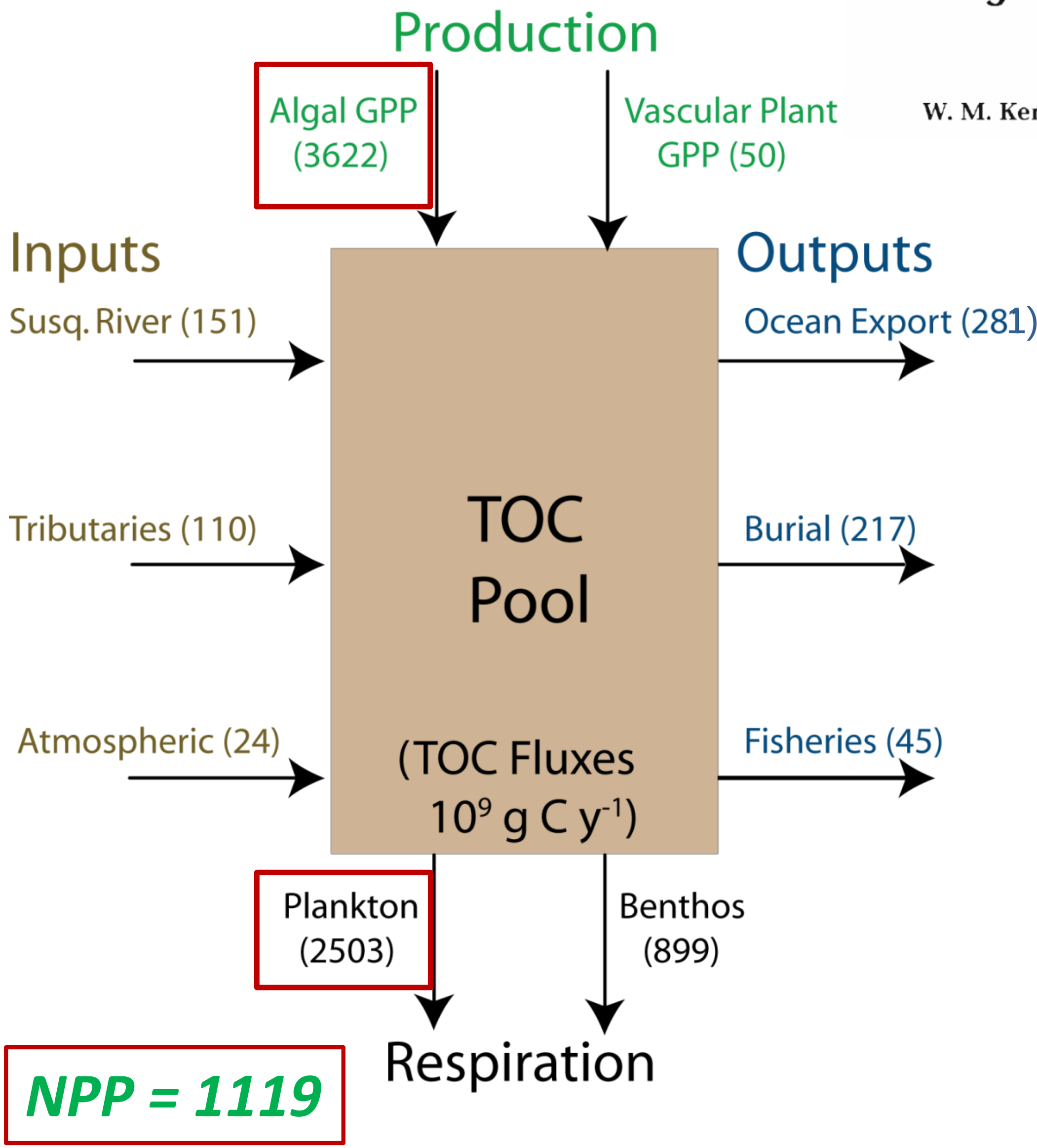




Vol. 150: 229–248, 1997 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published April 30

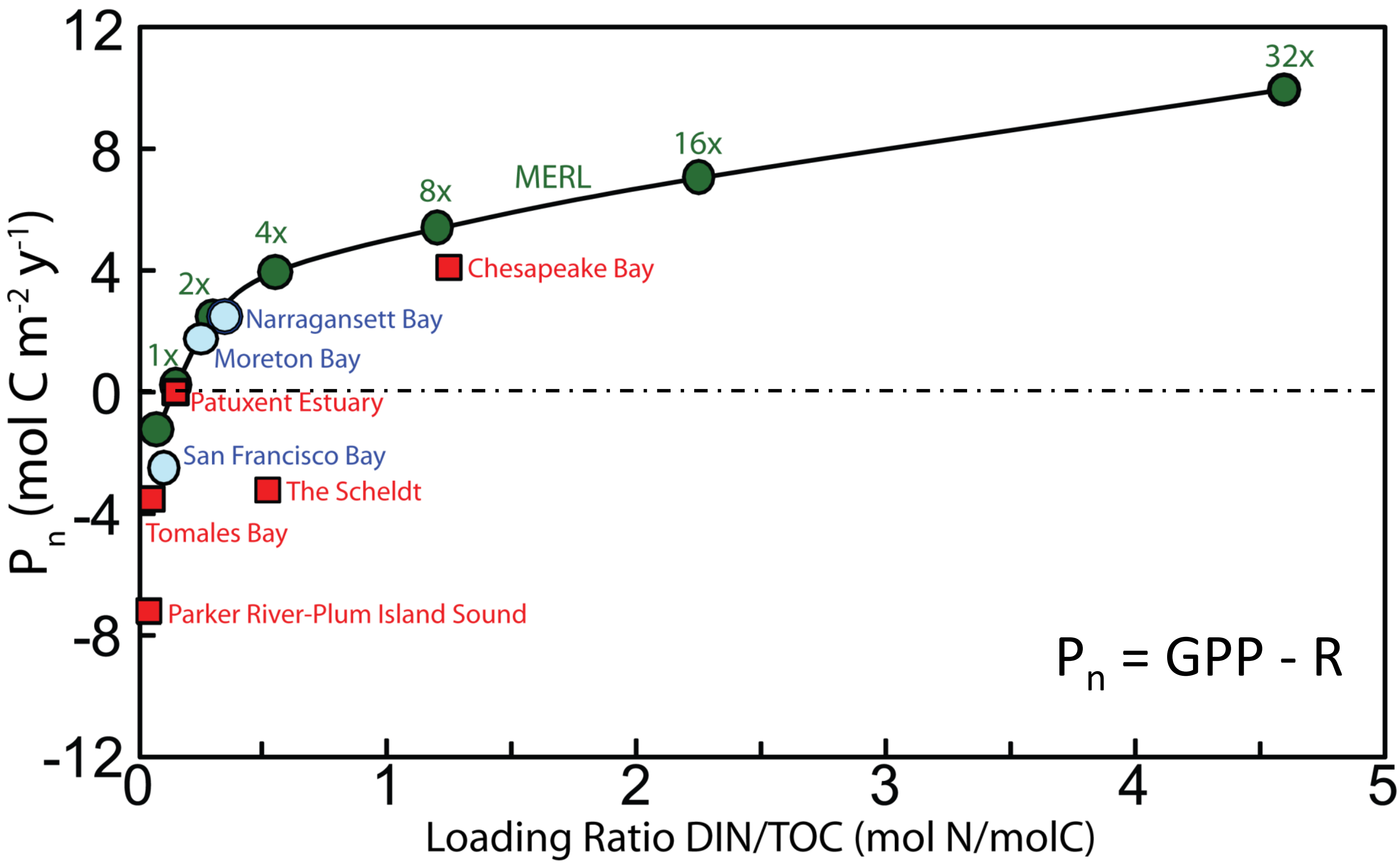
Organic carbon balance and net ecosystem metabolism in Chesapeake Bay

W. M. Kemp[1,*], E. M. Smith[1], M. Marvin-DiPasquale[2,**], W. R. Boynton[2]



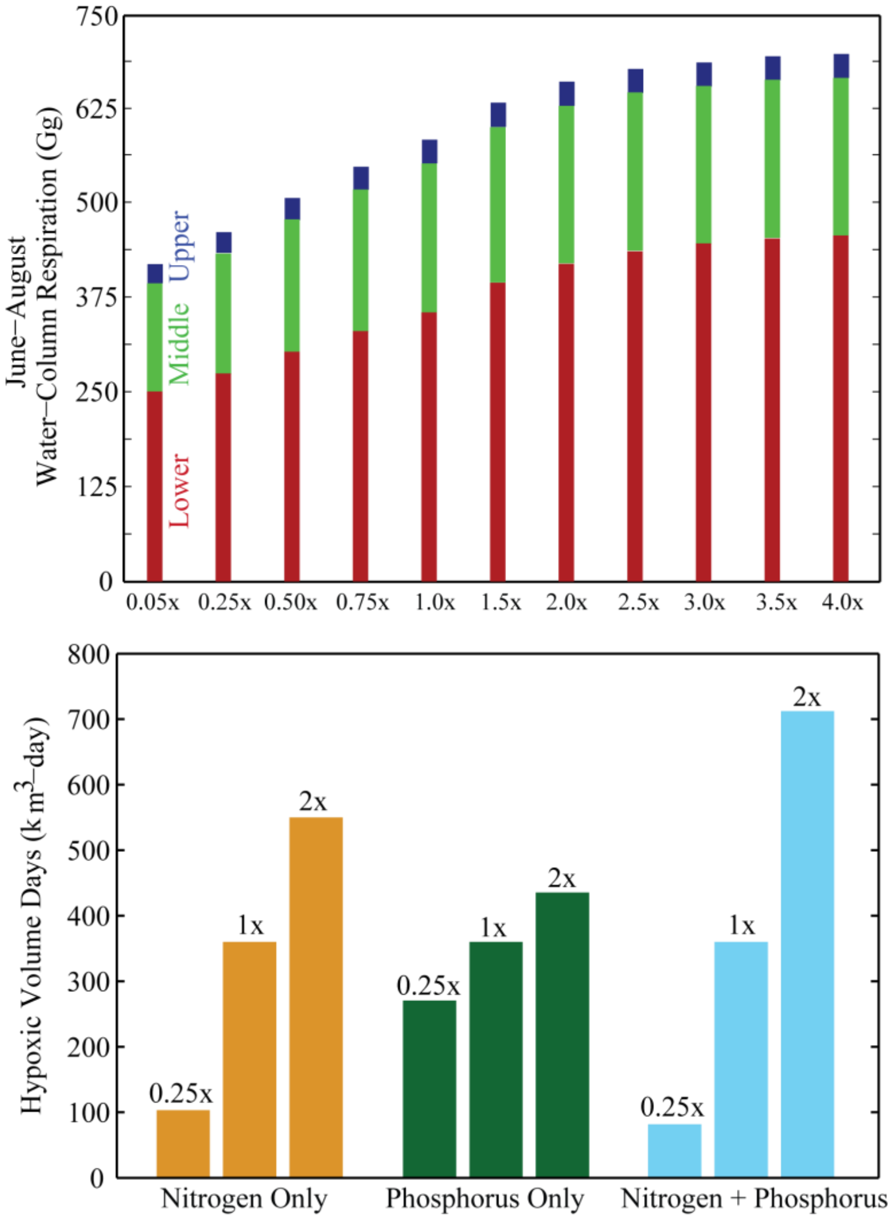
- Phytoplankton dominate organic matter pools
- Our ability to control hypoxia rests with controlling these pools
- Nutrients that support these pools primarily enter in dissolved form
- The recycling of these nutrients in driven by a combination of processes varying over space, time

Net Algal Carbon Production To Support Hypoxia Supported by Relative DIN Excess in Load



Kemp et al. 1997, Herrmann et al. 2015

Most Models Suggest that Hypoxia Responds to Both Nitrogen and Phosphorus Load Changes



Testa et al. 2016

- Experimental N and P enrichment, holding physics constant
- More sensitive to N than P – mostly a function of far greater N-limited waters in modeled mainstem
- Increase in oxygen consumption driven by seaward waters

What Do We Know About the Cycling of N and P within the Estuary?

Particulate Phosphorus "Bioavailability"

Water Column

- Desorption in the water column (± salinity) driven by physical chemistry or biological uptake
- Decomposition of organic P
- pH-related Fe-bound P release

Sediment

- Release of P adsorbed/co-precipitated with Fe oxides via iron reduction (w/o sulfides)
- Release of Fe oxide-bound P via conversion of Fe oxides to Fe sulfides
- Release of Fe-bound P via high pH
- *Not all Fe-bound P is released in sulfidic CB sediments – (0.16 mg P g^{-1} buried)[1]*

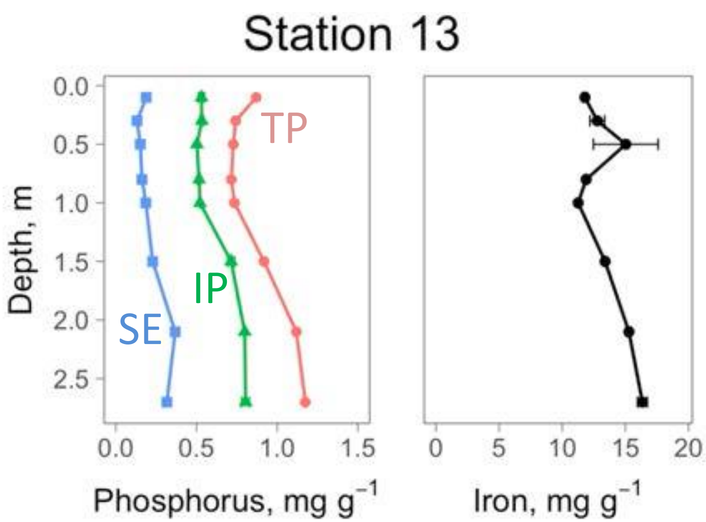
[1]Joshi, S. R., R. K. Kukkadapu, D. J. Burdige, M. E. Bowden, D. L. Sparks, and D. P. Jaisi. 2015. Organic Matter Remineralization Predominates Phosphorus Cycling in the Mid-Bay Sediments in the Chesapeake Bay. Environmental Science & Technology 49: 5887-5896.

Particulate N "bioavailability" is relatively simple

– a matter of reactivity of OM and denitrification

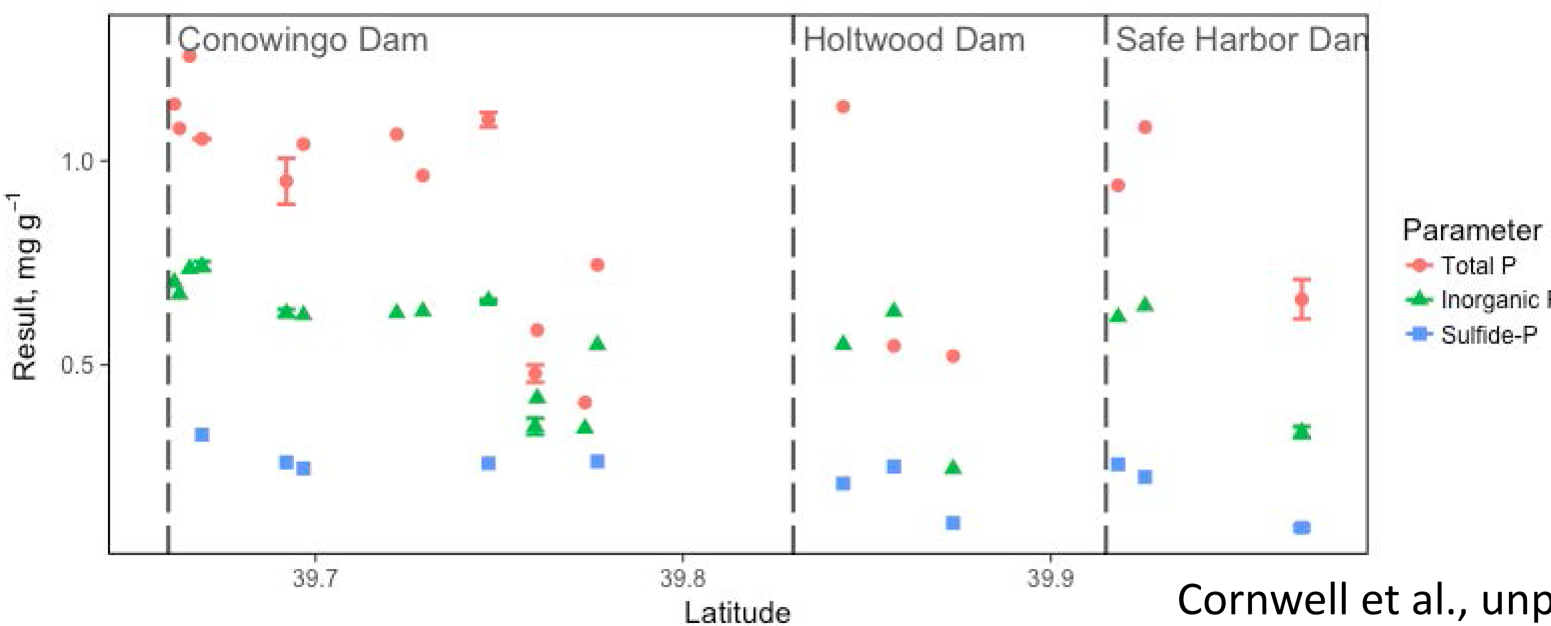
'Small' Fraction of Scoured P Could be Remineralized in Bay

Sulfide-Extractable P, Inorganic P, Total P From Susquehanna Reservoirs



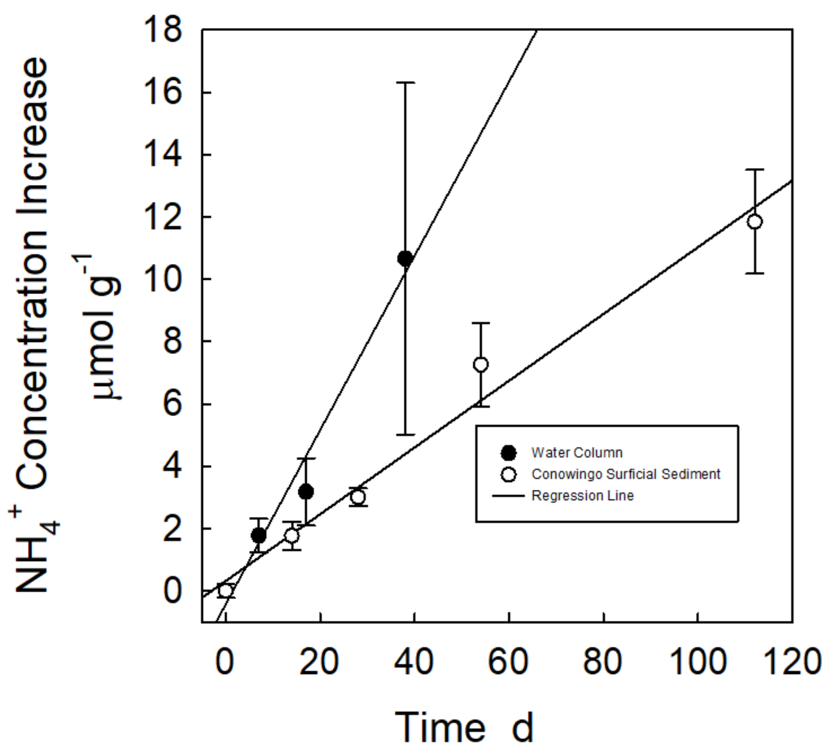
About ¼ to ⅓ of TP is sulfide-releasable

Consistent across lower Susquehanna River reservoirs



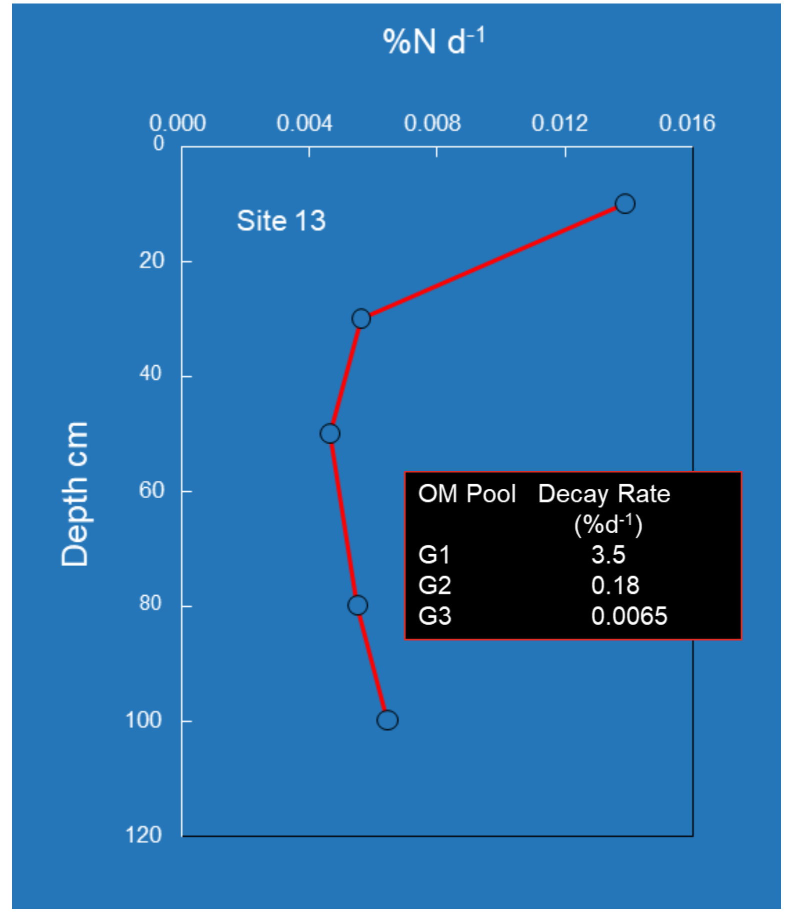
Cornwell et al., unpublished

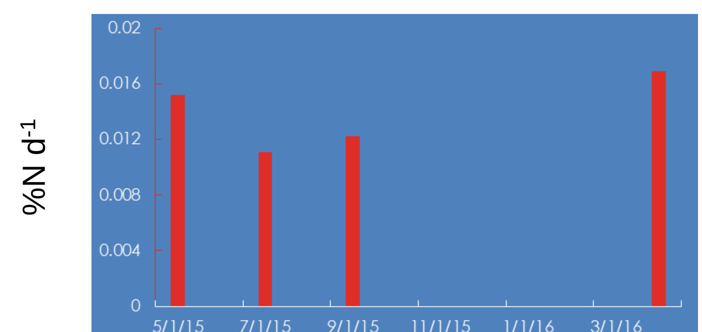
Reservoir Sediments, River Particulates Are Not Highly Reactive



The average individual time course regressions were 0.05±0.03 and 0.34±0.37 µmol g^{-1} d^{-1} for sediment and water column (at dam).

The N remineralization are << than rates expected from algal-derived organic matter





So,

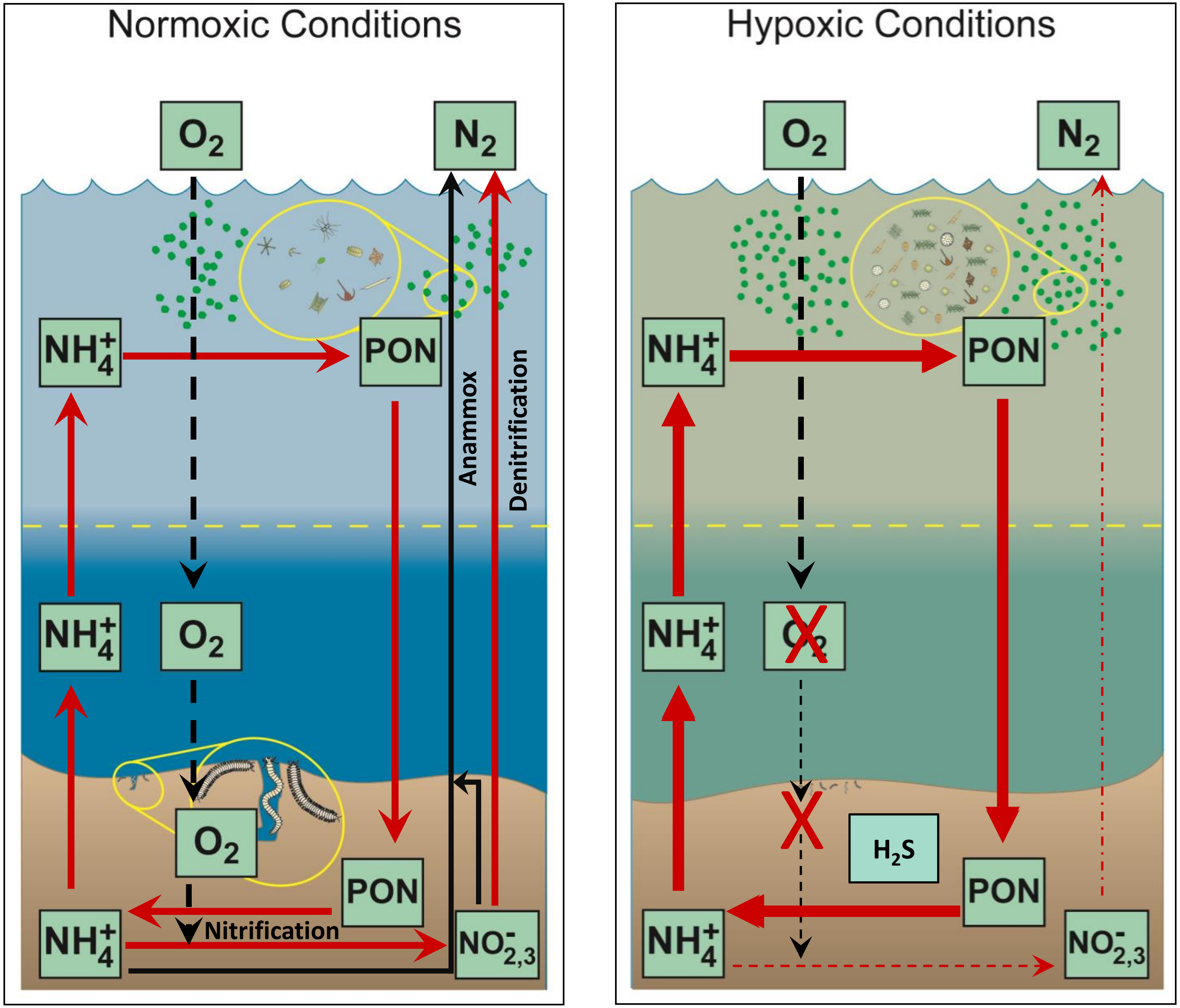
Dissolved nutrients are key drivers of phytoplankton P_n and hypoxia

Particulate N inputs are small, poorly reactive

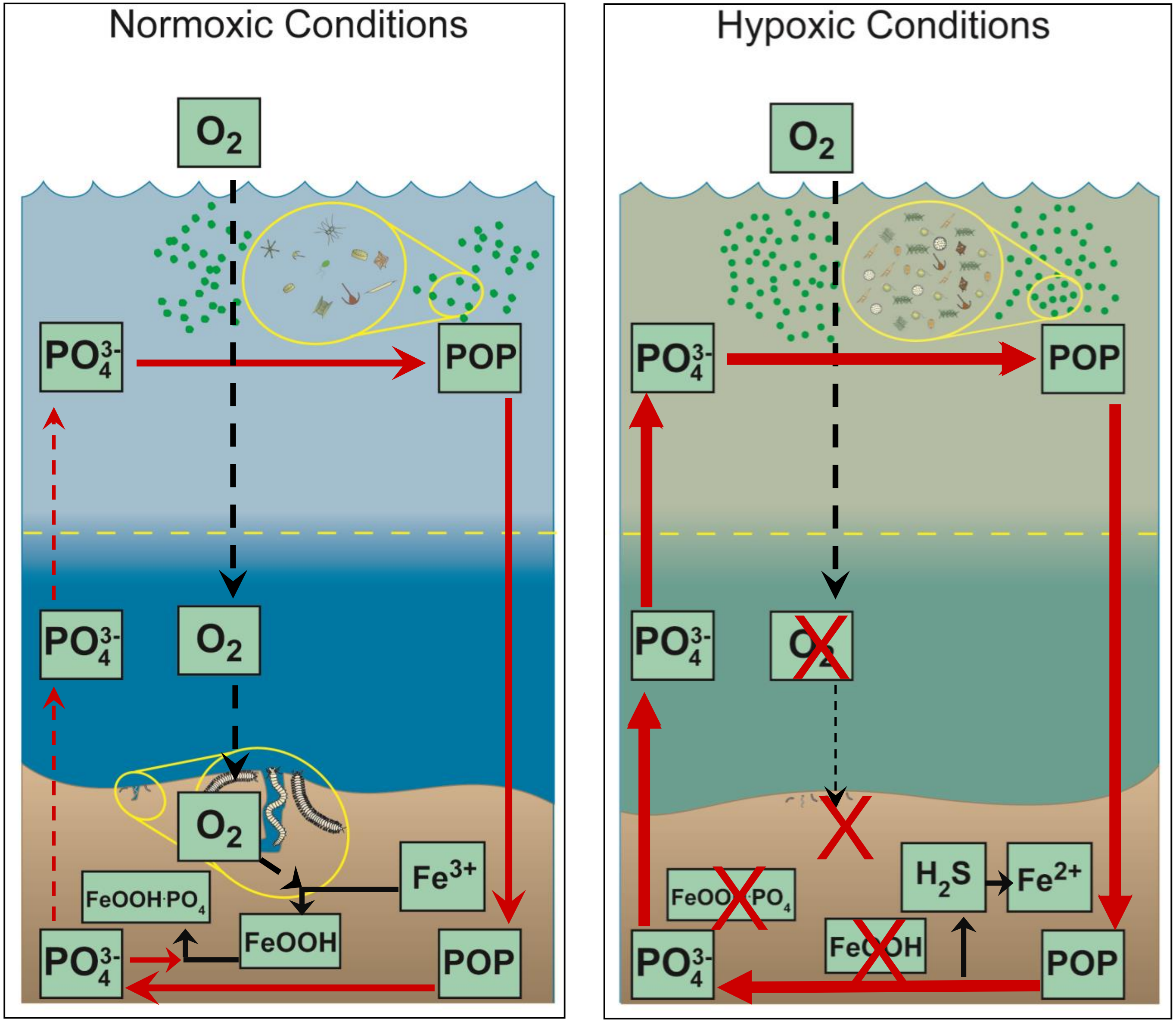
Particulate P inputs are large, somewhat unreactive

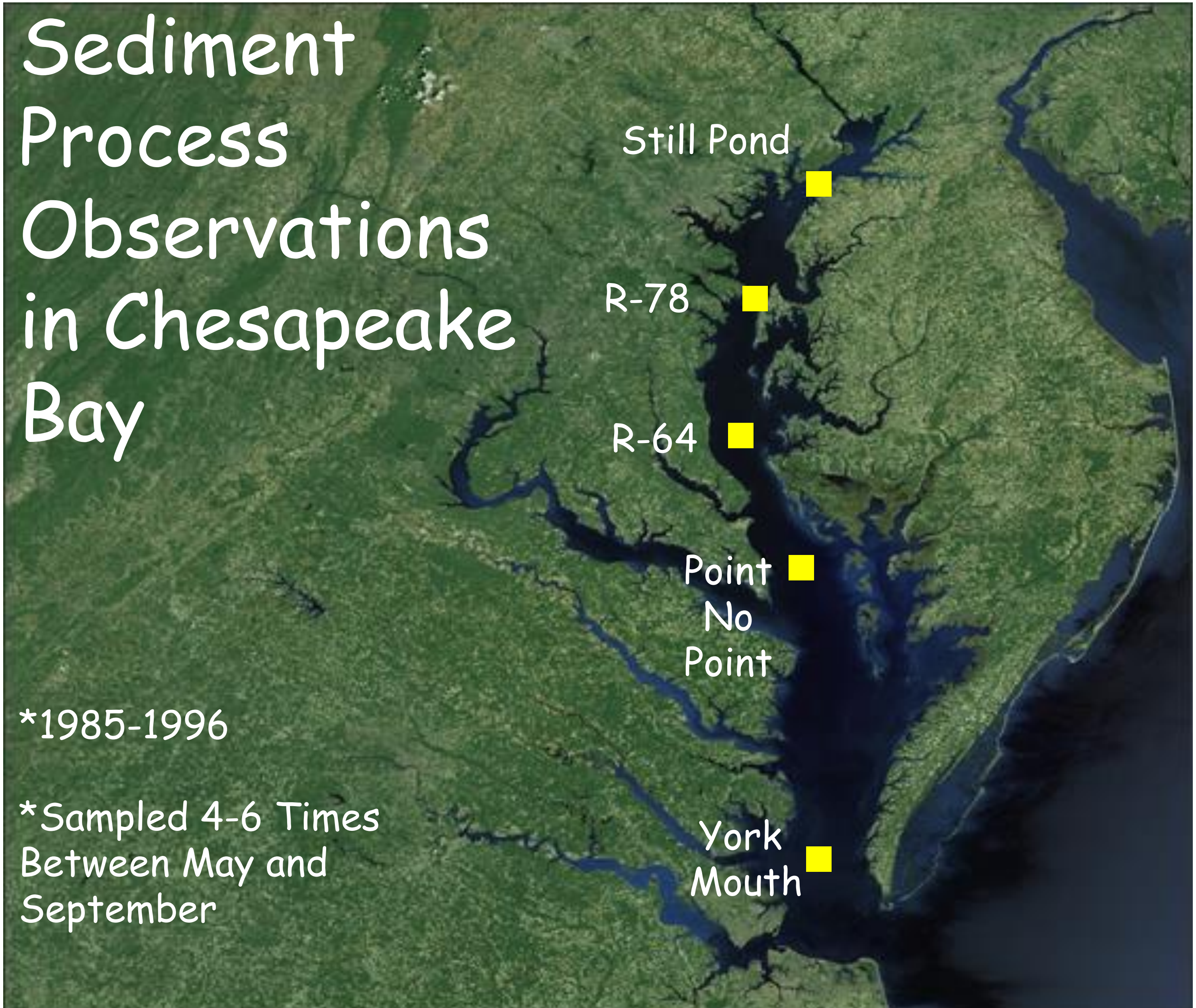
But how is the ultimate reactivity related to the estuarine conditions in which these particulates ultimately land?

Conceptual Model of O_2 Interactions with N-Cycle



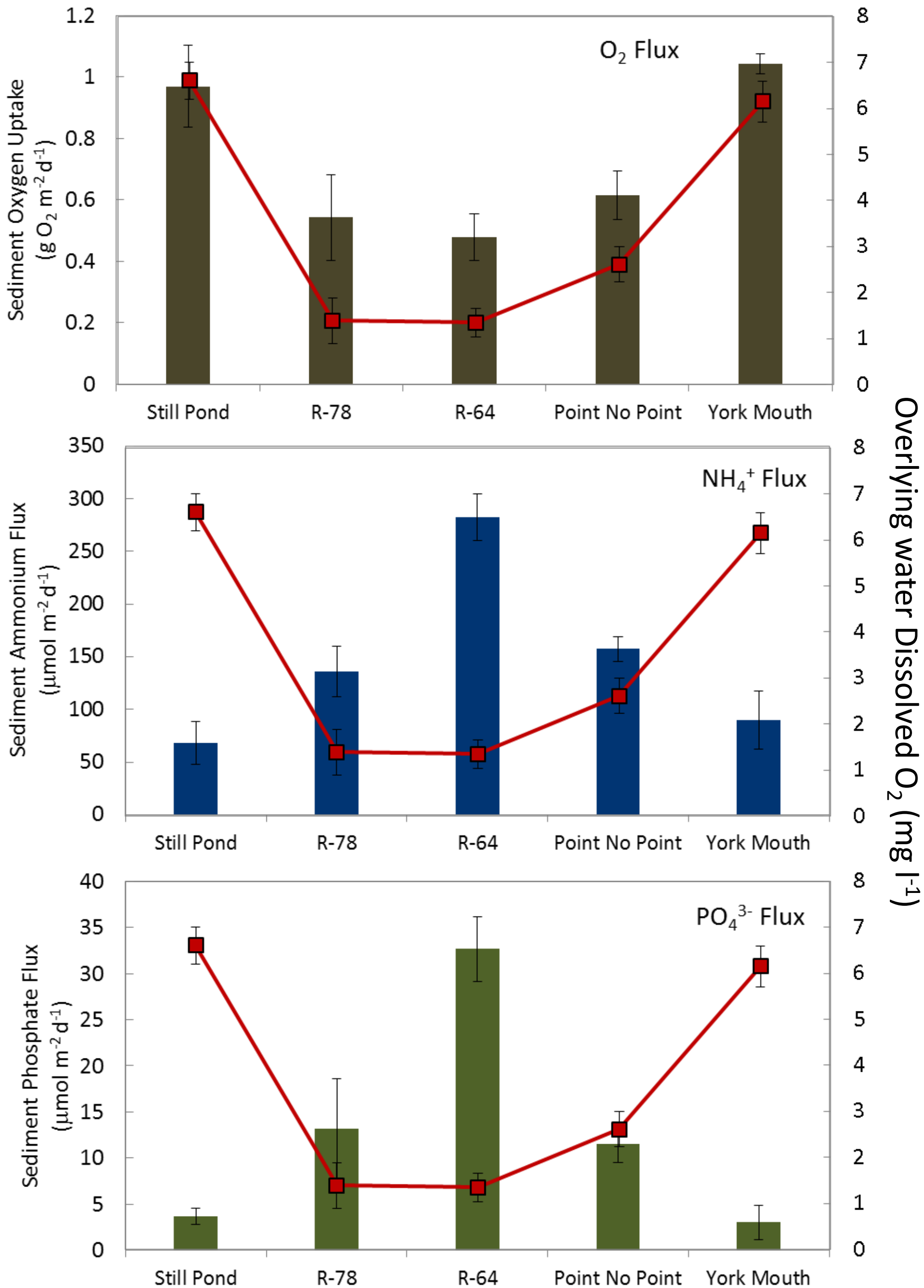
Conceptual Model of O_2 Interactions with P-Cycle



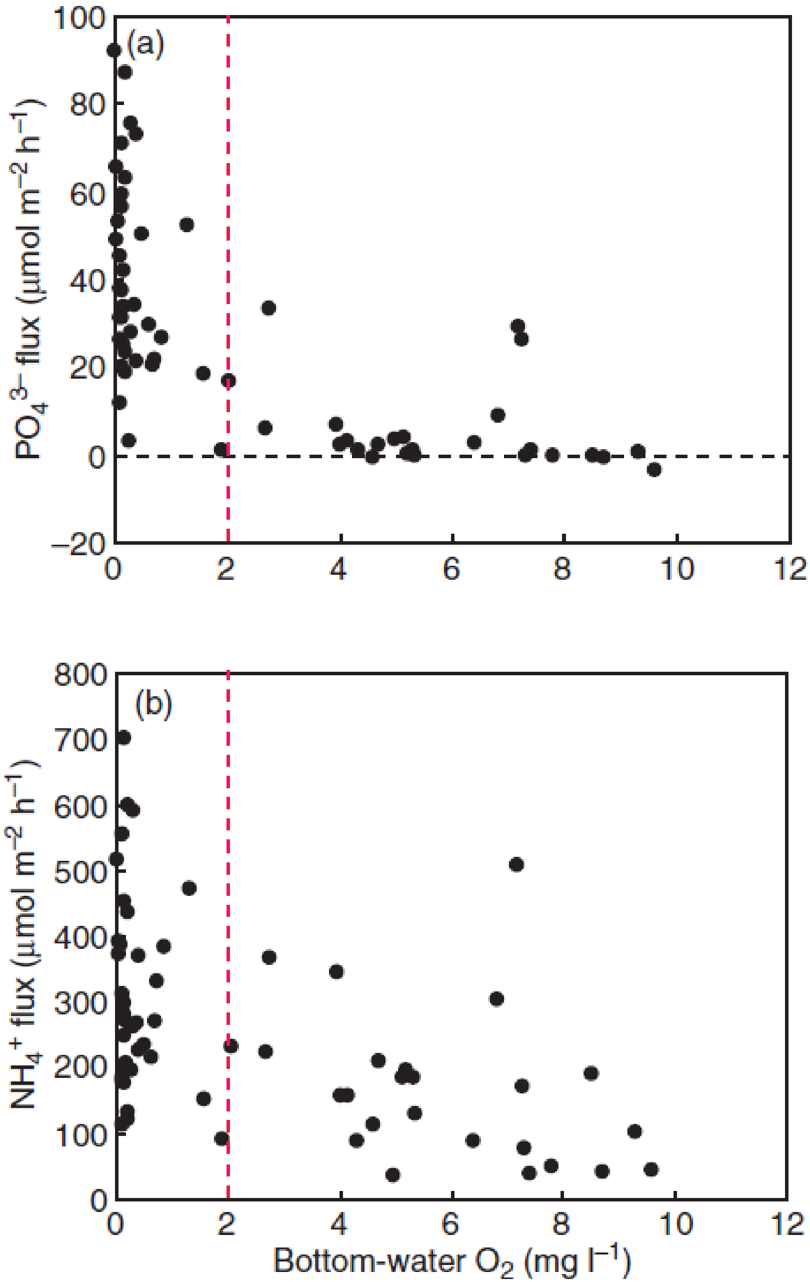

Sediment Process Observations in Chesapeake Bay
Still Pond
R-78
R-64
Point No Point
York Mouth
*1985-1996
*Sampled 4-6 Times Between May and September

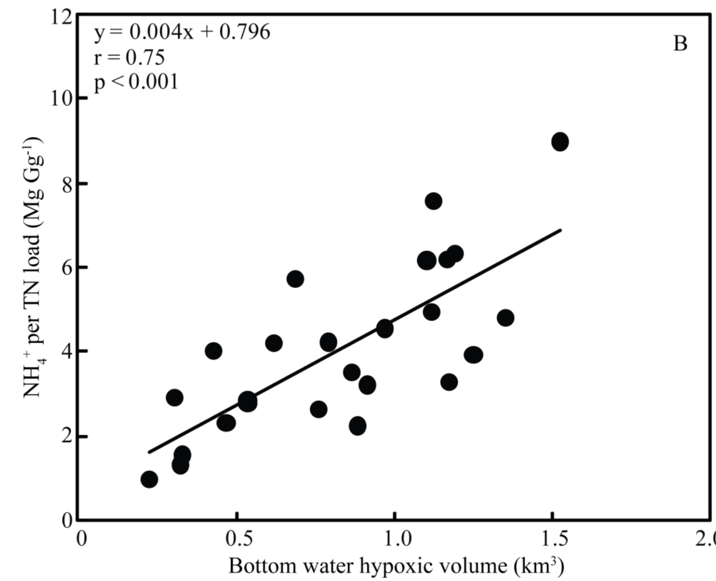
Spatial Variation in Sediment-Water Fluxes

- Sediment O_2 Uptake lowest in region between Bay Bridge and Patuxent
- NH_4^+ and PO_4^{3-} fluxes peak in mid-Bay
- Bottom-water O_2 low where N and P fluxes peak

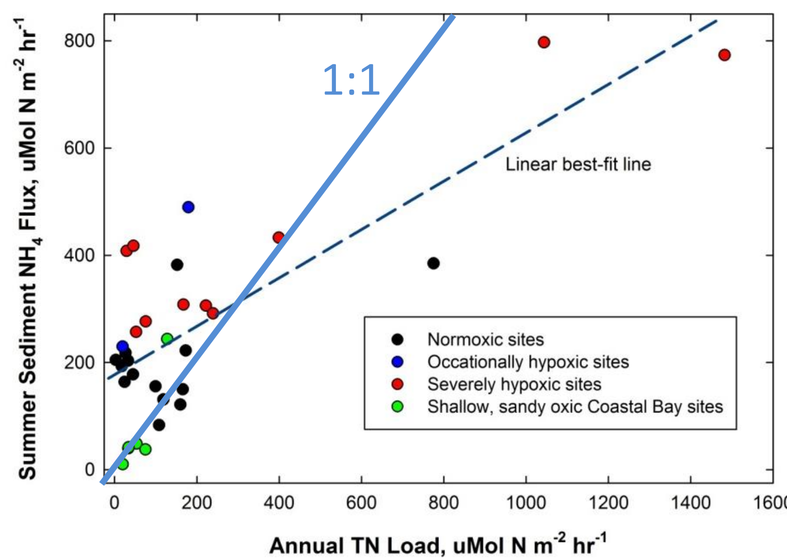


Hypoxia, Sulfide Stimulates Dissolved N, P Recycling



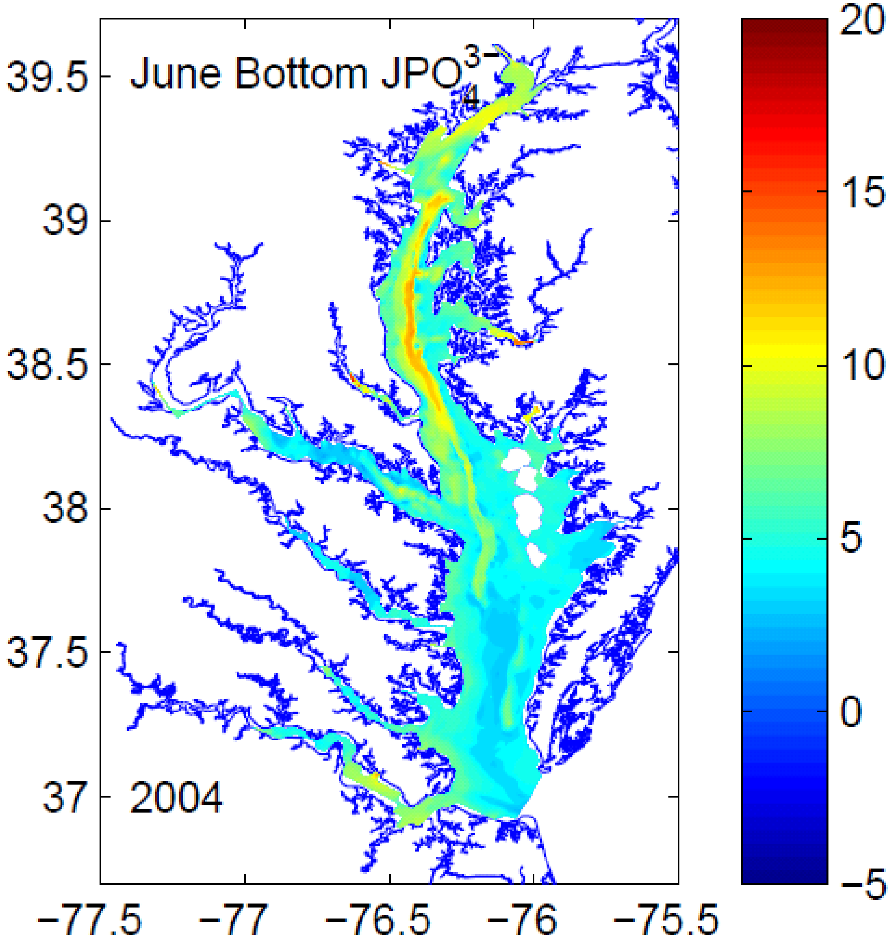


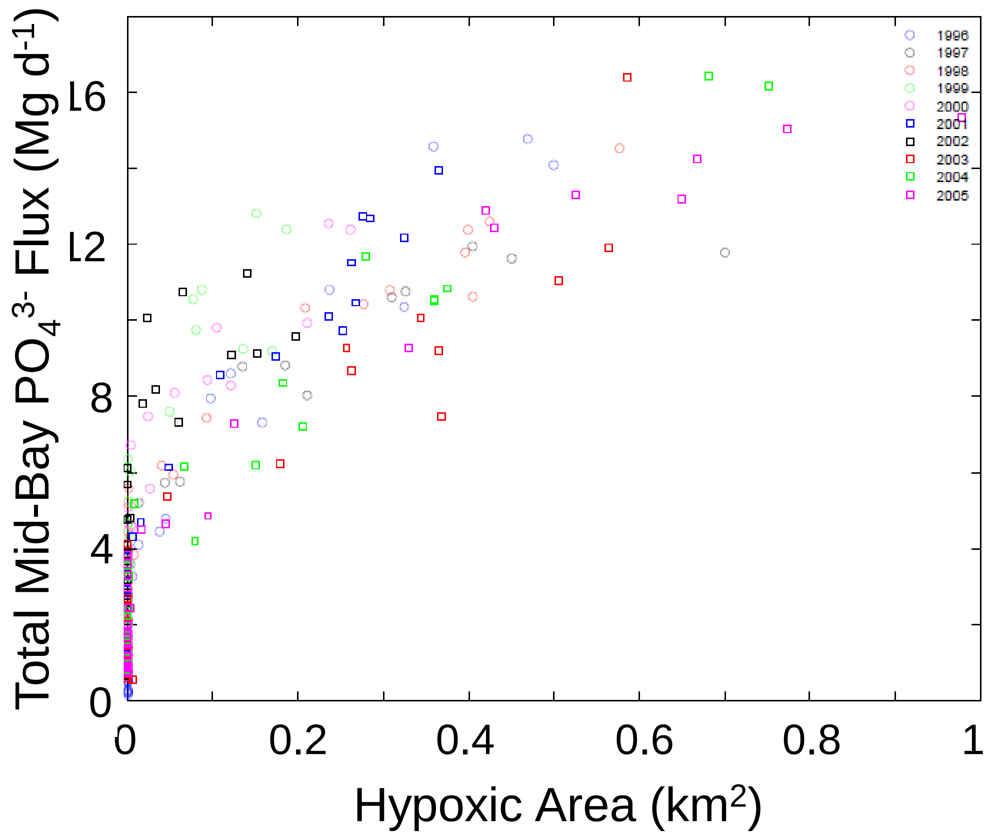
•*Larger N and P pool generated for a given load* with *higher hypoxic volumes*



Data from Walter Boynton, published in Testa and Kemp 2011, 2012

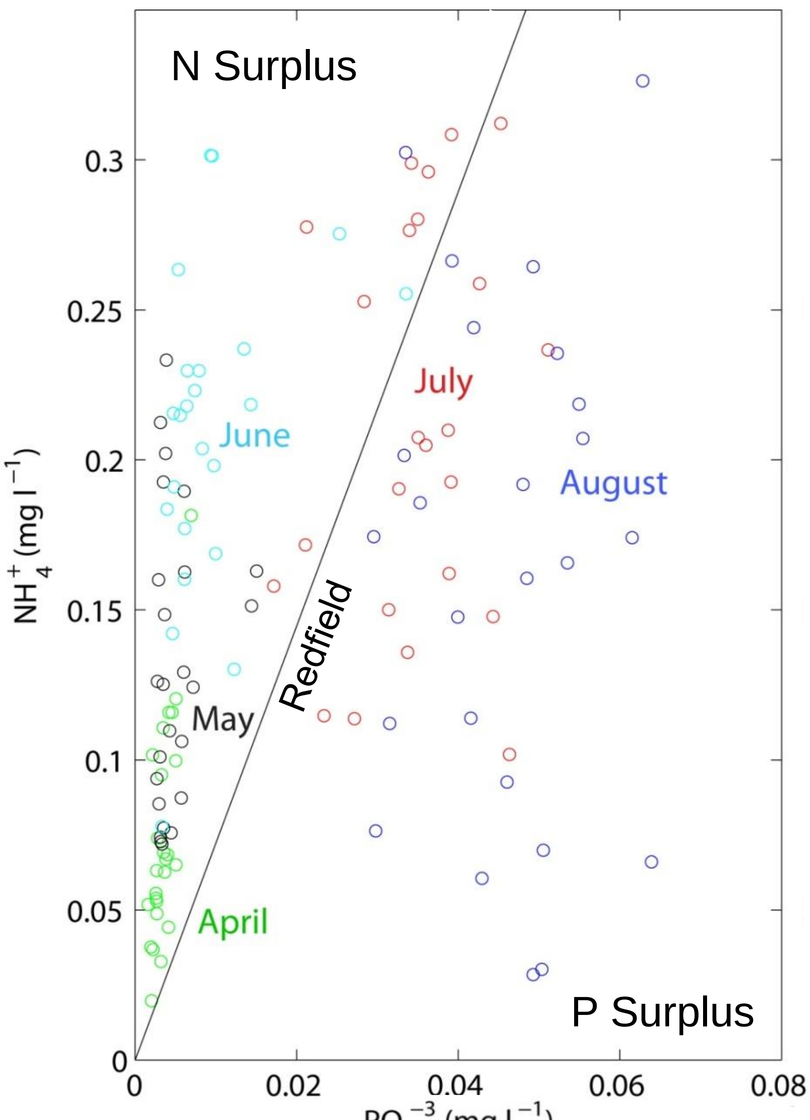
Numerical Model Distributions of P Flux



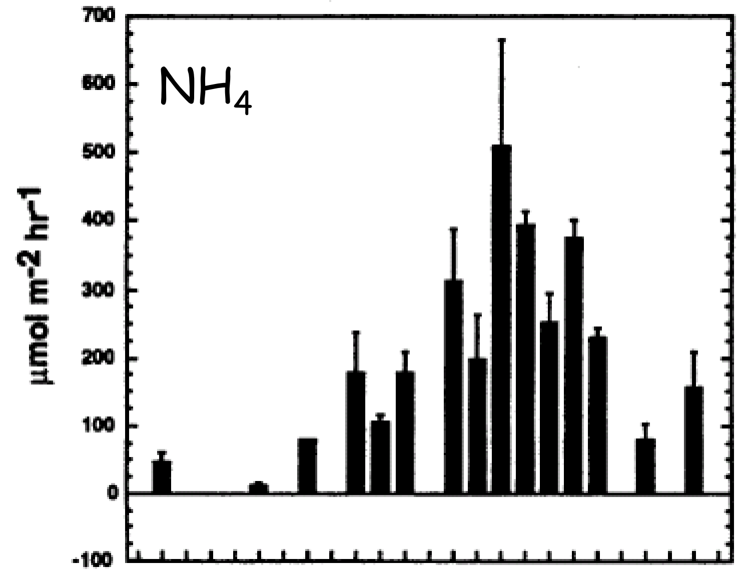


Model Simulations reported in Testa et al. 2014

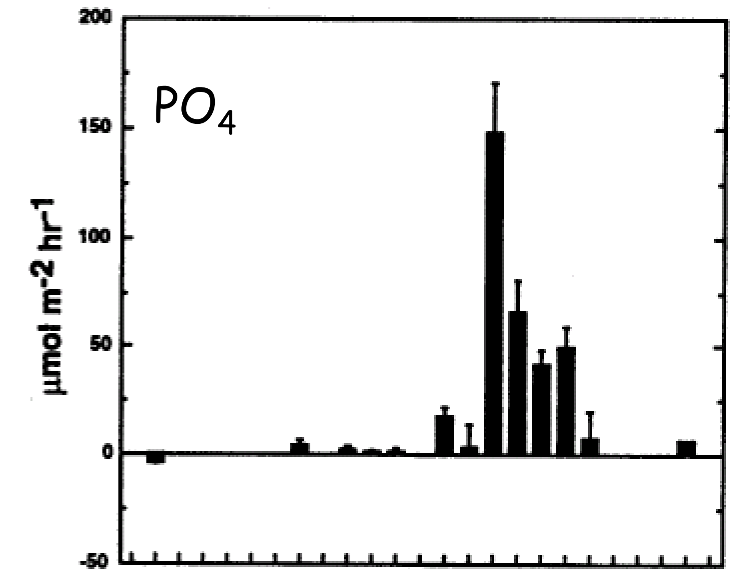
Temporal Mismatch in Fluxes Drives N:P Ratios



(Testa and Kemp 2012, L&O)



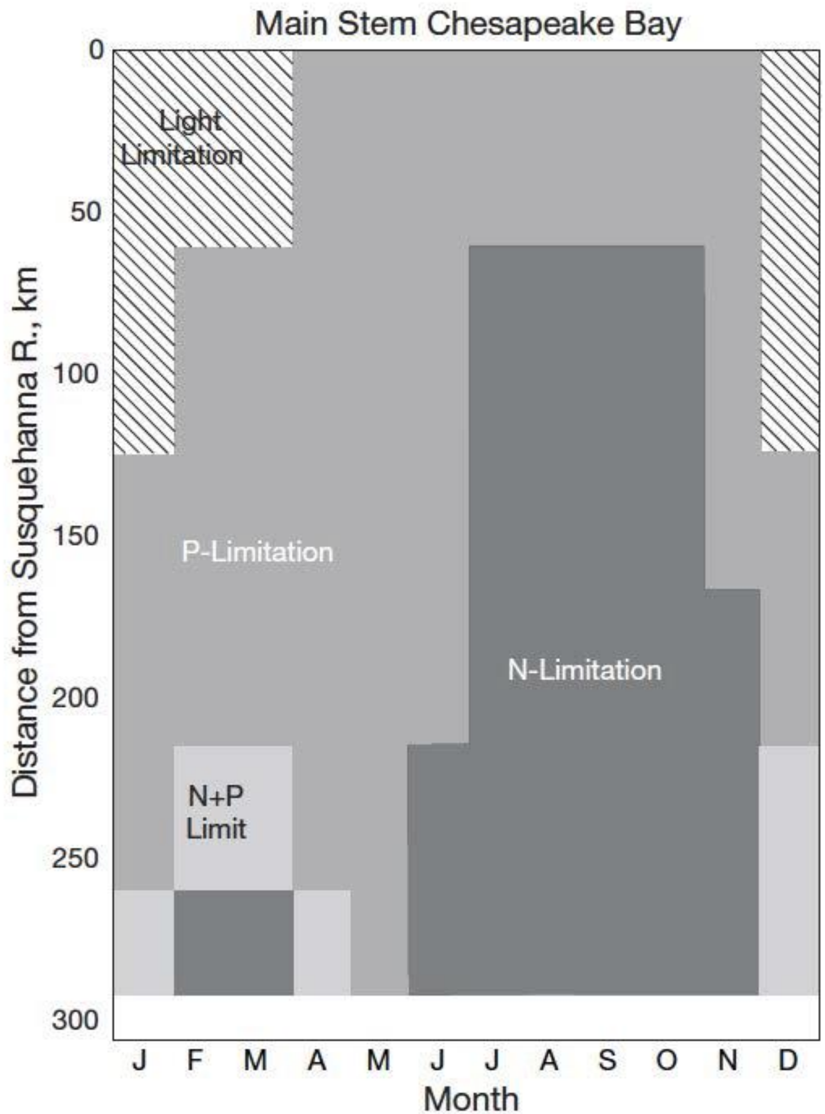
(Cowan and Boynton 1996)



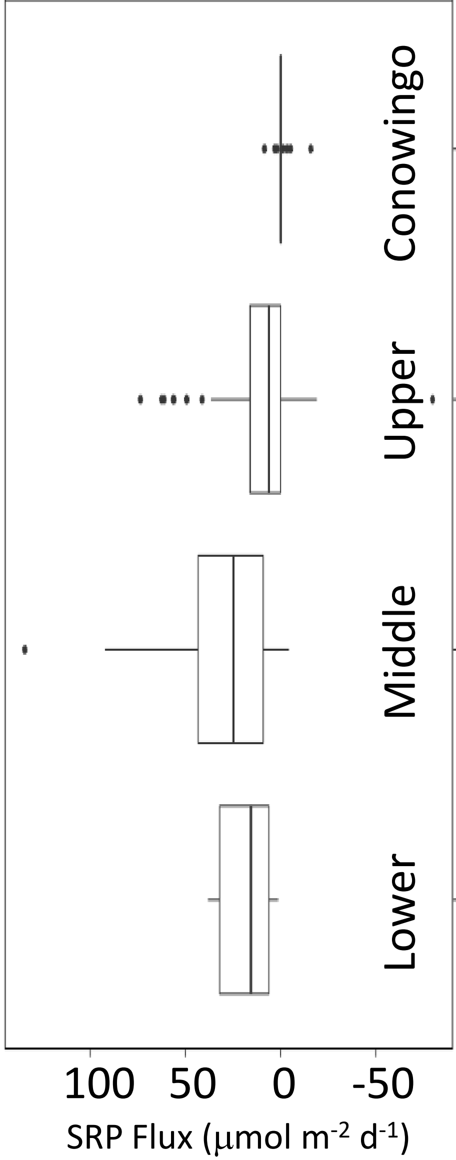
P:N in late summer >>>phytoplankton

- **It is all about location**

- Low upper bay SRP releases are in a zone of P limitation
- High mid-bay releases are in a more N-limited area



Kemp, W. M. and others 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology-Progress Series 303: 1-29.



In Conclusion.

- Phytoplankton drive biological contribution to hypoxia
- Dissolved forms of N and P are the most direct form of input to fuel phytoplankton
- Input PP is large, can be remobilized as DIP to be made bioavailable, direct PN loads a small piece of TN puzzle
- Fate of particulate N and P depends on where the are remineralized in estuary
- Hypoxia enhances the potential for N and P recycling, drives shift in N to P ratio

Thank You