Hypoxia and Nutrient Biogeochemistry: Lessons from Chesapeake Bay

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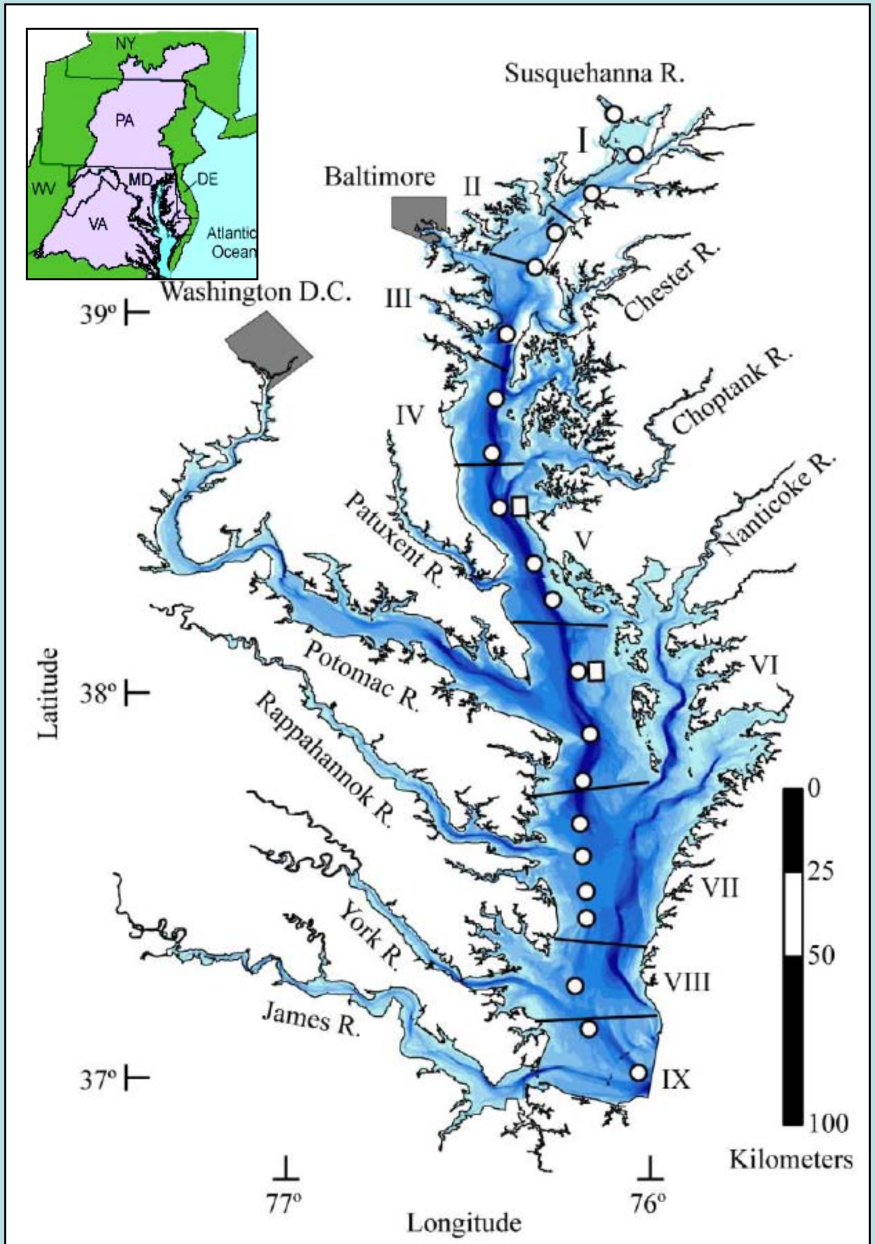
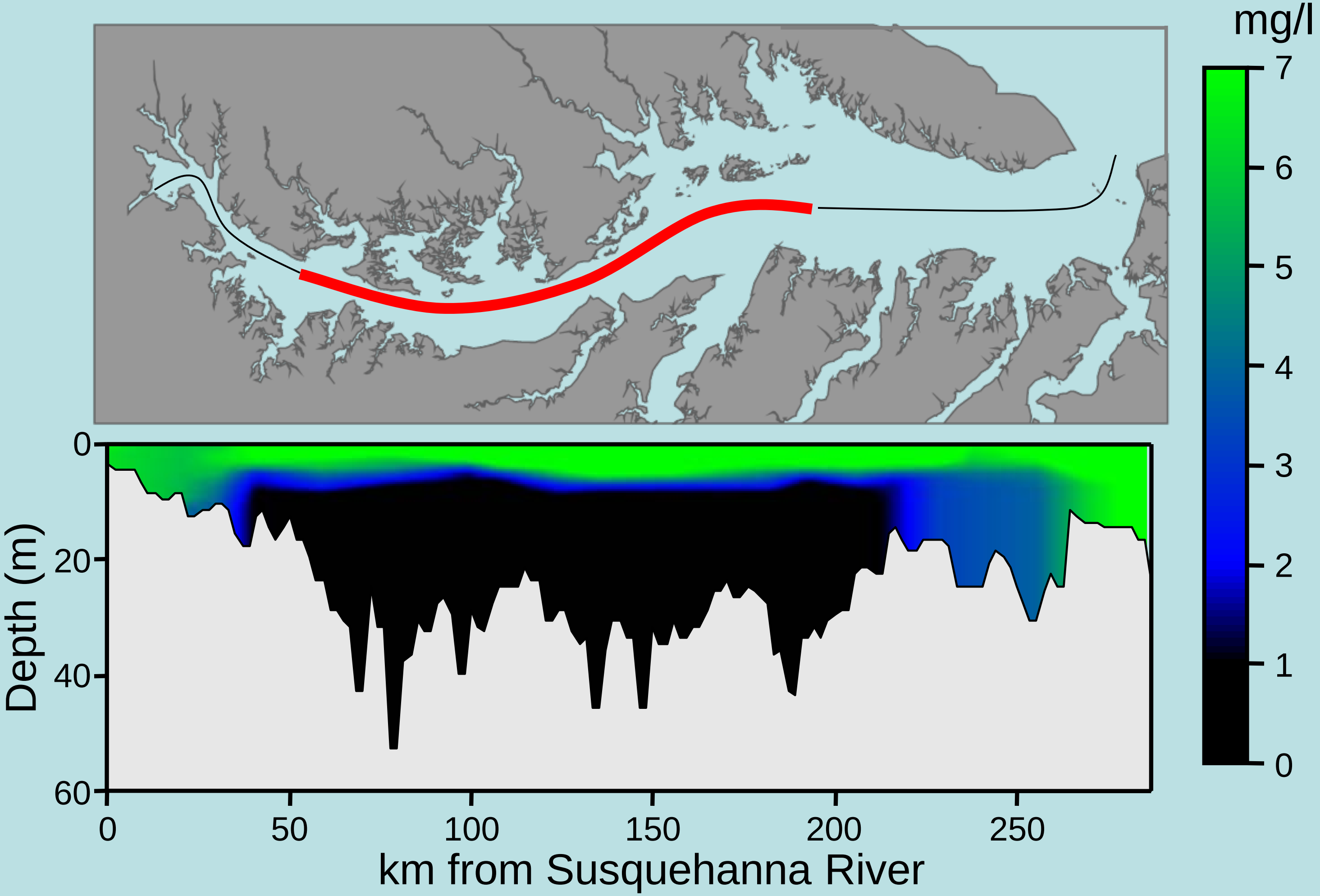
Outline of Talk

- Background on Chesapeake Bay hypoxia
- Long-term trends in Bay hypoxia
  - --Seasonal differences in trends
  - --Linking trends to climate & nutrients
- Hypoxia effects on nitrogen and phosphorus cycling
  - --Low O_2 enhances nutrient recycling
  - --Positive feedback between nutrients & hypoxia
- Implications for nutrient management of hypoxia
  - --Climate can affect hypoxia management
  - --Nutrient-hypoxia feedback can reinforce change

Chesapeake Bay and its Watershed

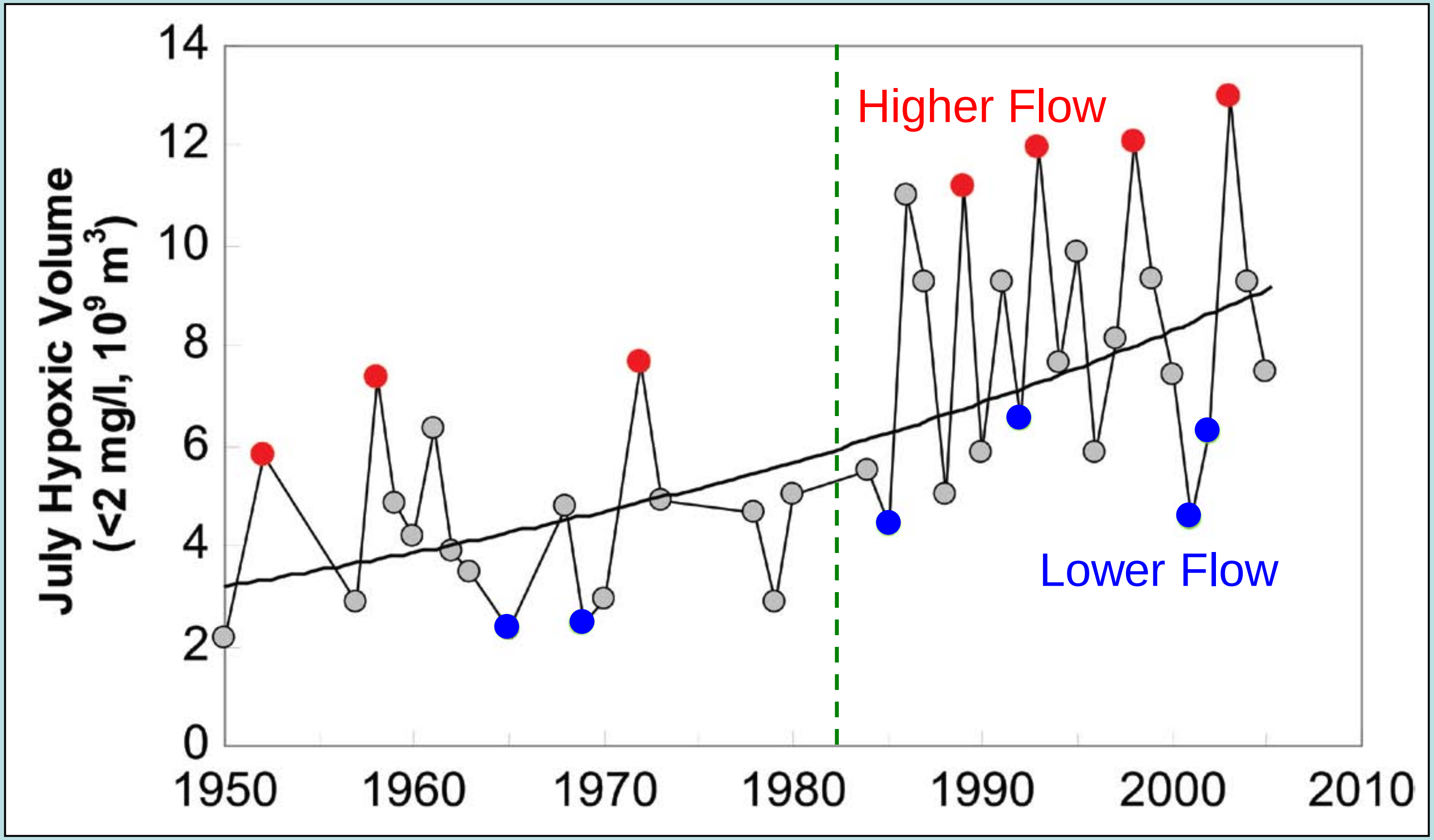


Location of Chesapeake Hypoxic Zone



(Hagy 2002)

Trend in Bay July Hypoxic Volume

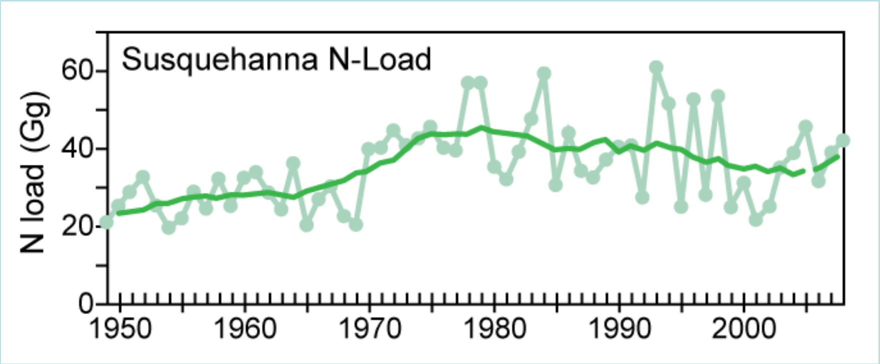


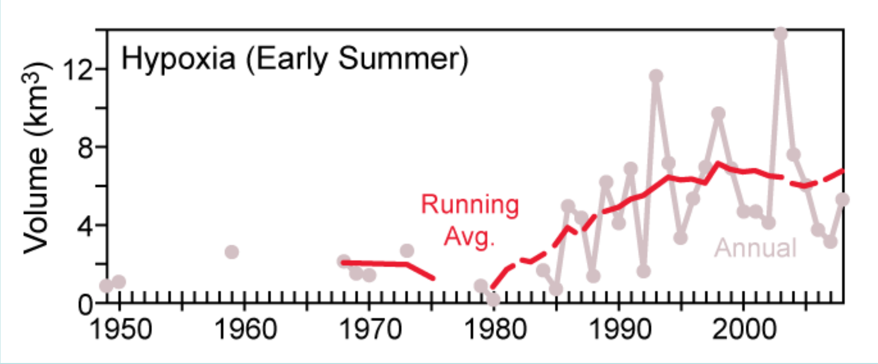
- **Long-Term Trends in Bay Hypoxia**

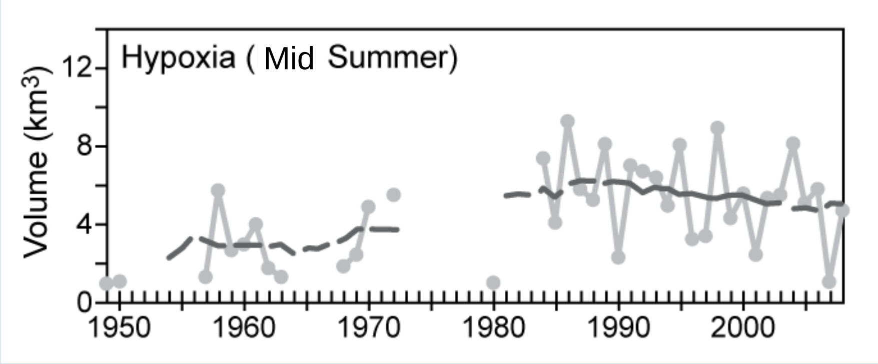
    --Seasonal differences in trends

    --Linking trends to climate & nutrients

Hypoxia Trends in Relation to N-Loading



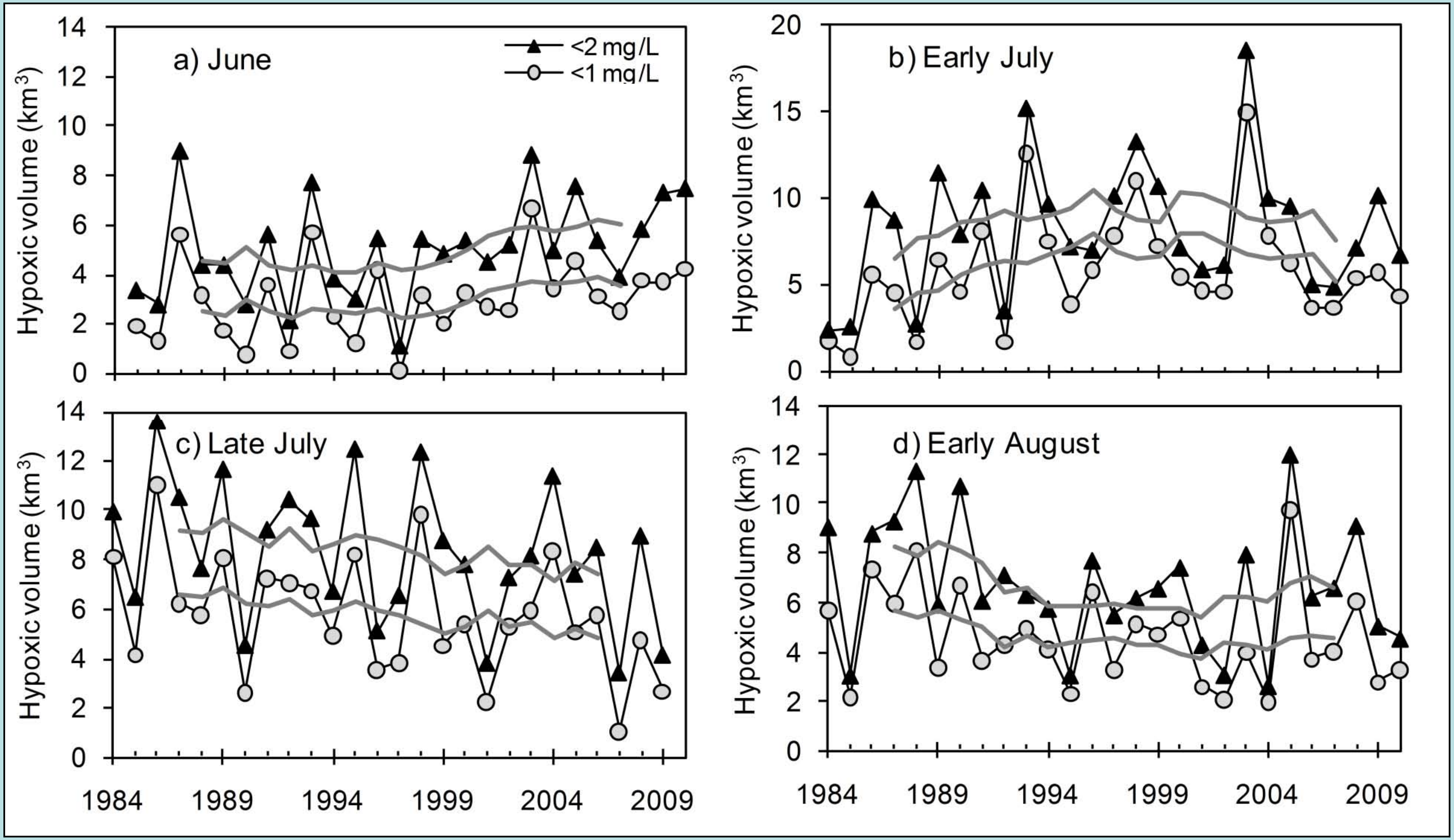




- •N-Loading increased until mid-1980s, then declined gradually into 2000s
- •Inter-annual variations blur long-term trends; clarify with running means
- •Early summer hypoxia shows rapid increase since 1980; not related to N-load
- •Mid-summer hypoxia has actually declined parallel to the decline in N-load
- •Hypoxia & N-Load highly correlated (r^2 = 0.77)

(Murphy et al. 2011. *E&C*)

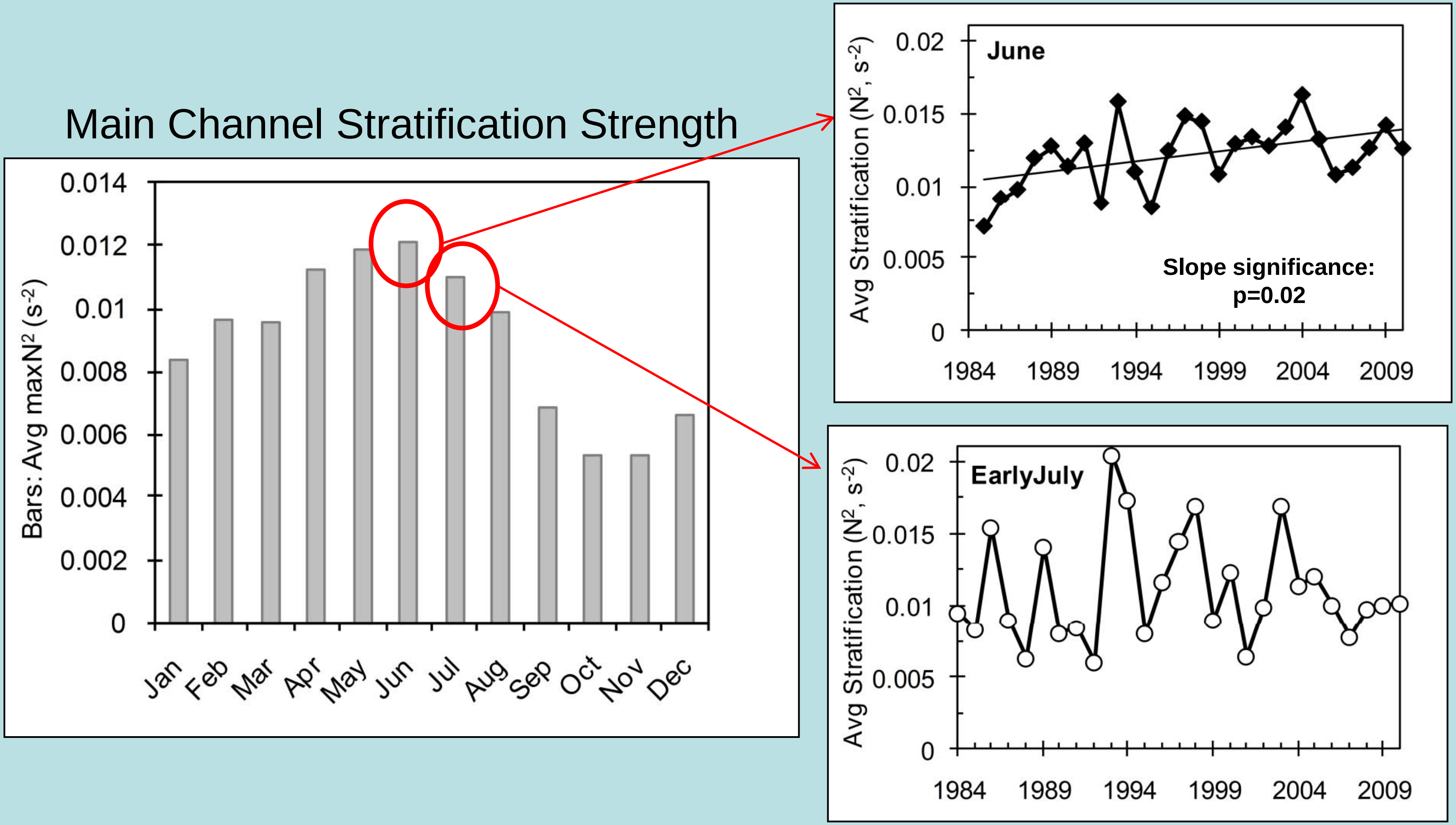
Entire Summer Hypoxic Volume Trends



(Murphy et al. 2011. *E&C*)

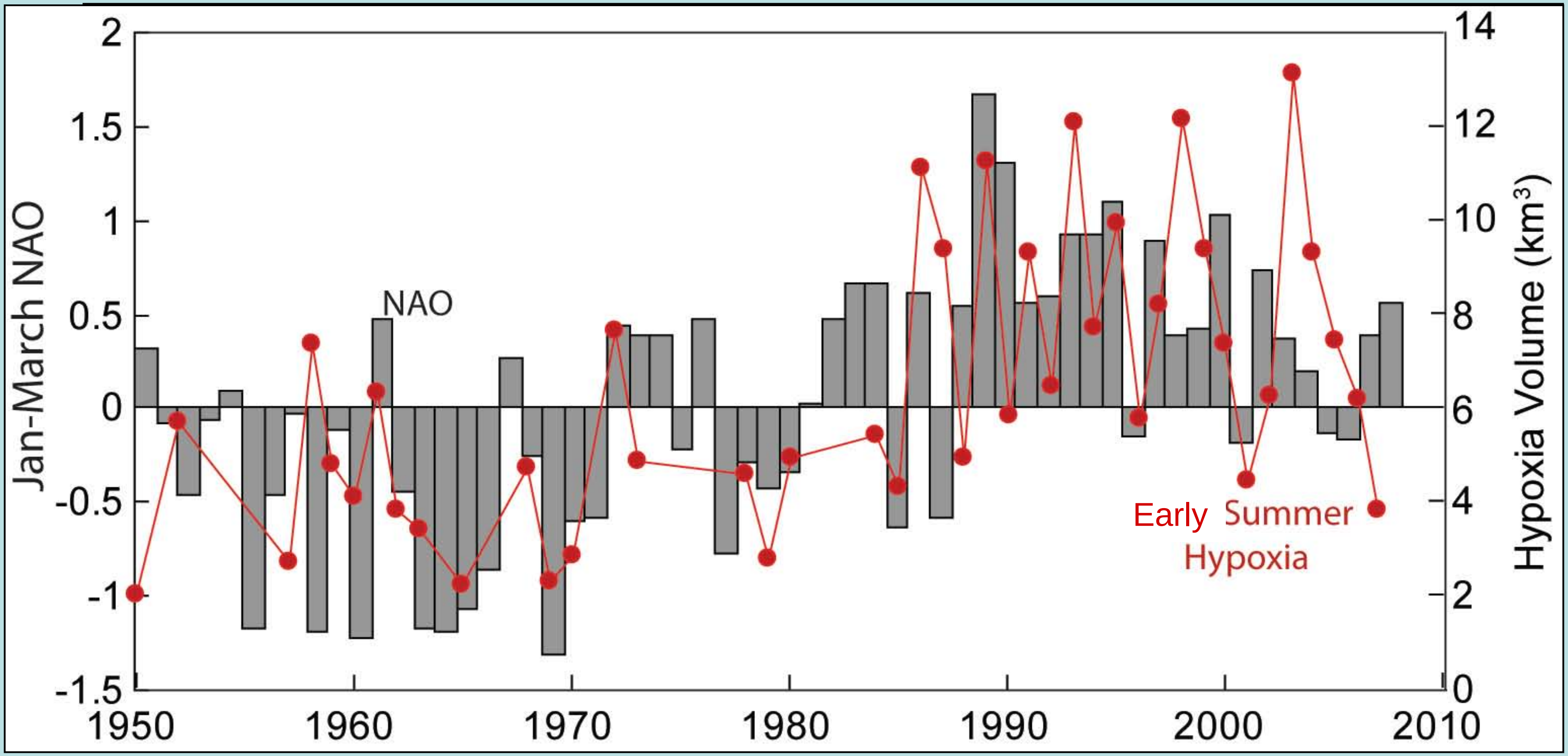
Factors Controlling Hypoxia: Early vs. Late Summer

Main Channel Stratification Strength



(Murphy et al. 2011. *E&C*)

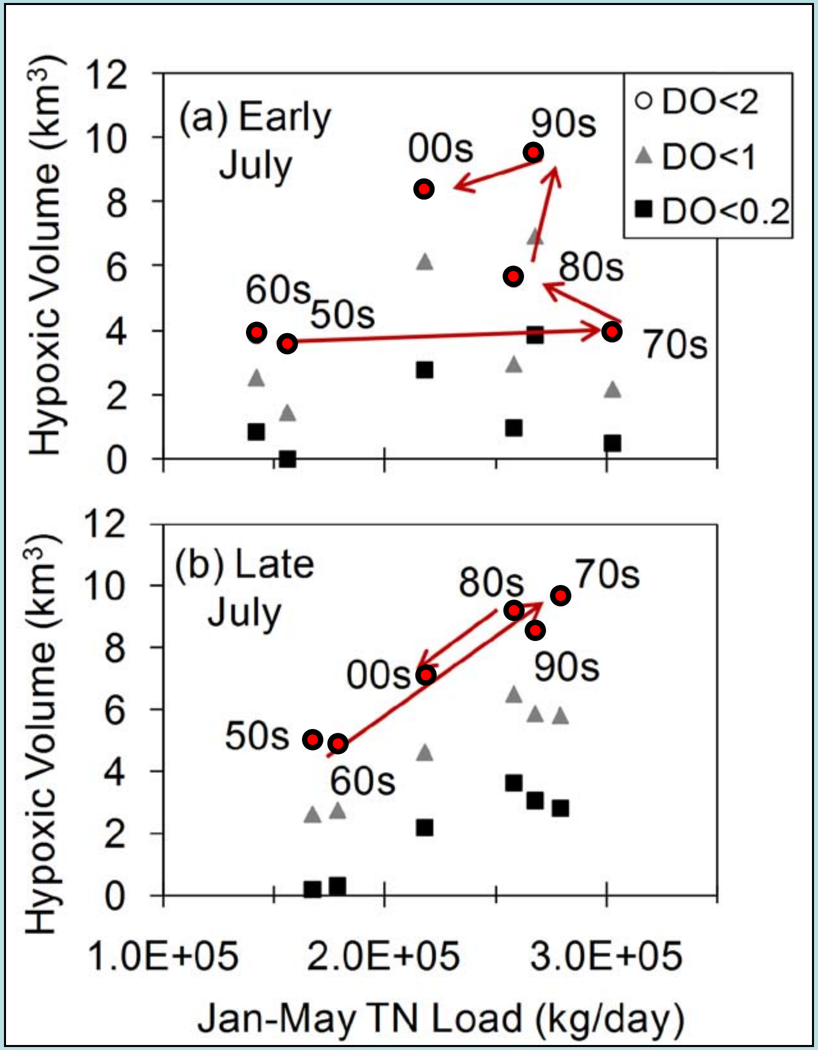
Climate Effects on Mid-Summer Hypoxia:
North Atlantic Oscillation Index



- **Winter NAO Index reflects regional climate and ocean circulation**
- **NAO correlates well ($r^2 = 0.51$, $p < 0.01$) with early summer Bay hypoxia**
- **Negative NAO linked to southerly summer winds (ventilate bottom water)**

(see: Kemp et al. 2009 *BGS*; Scully 2010 *E&C*; Scully 2010 *JPO*)

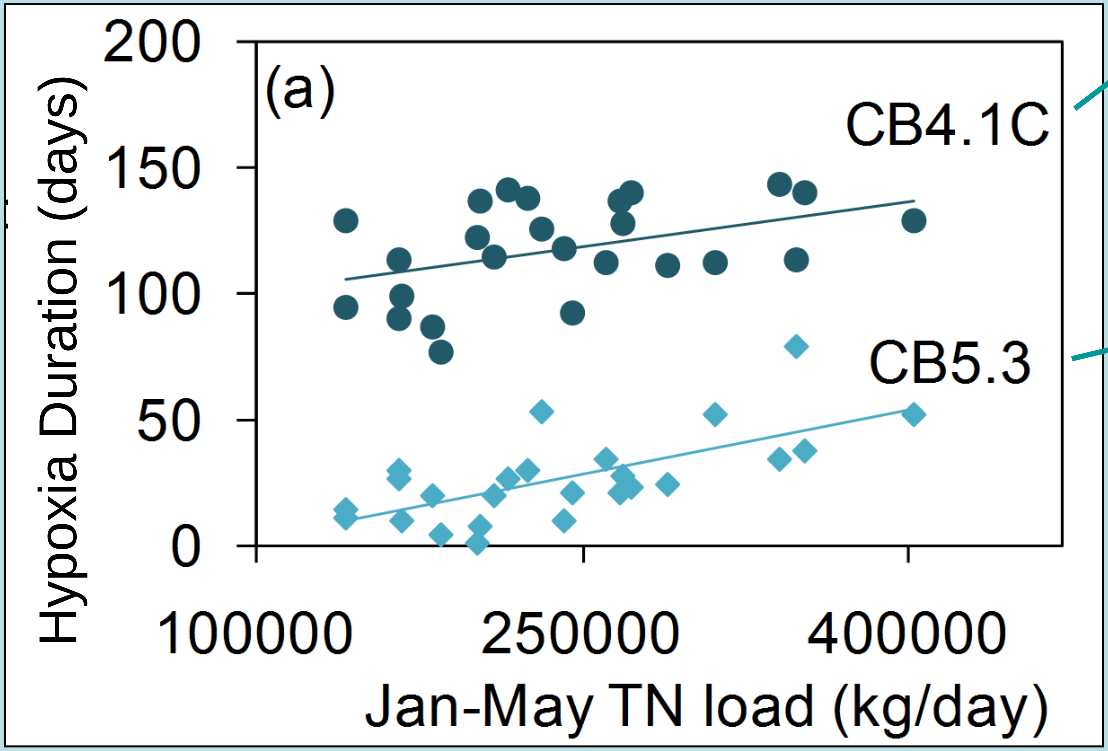
Decadal Average Hypoxic Volume vs. TN

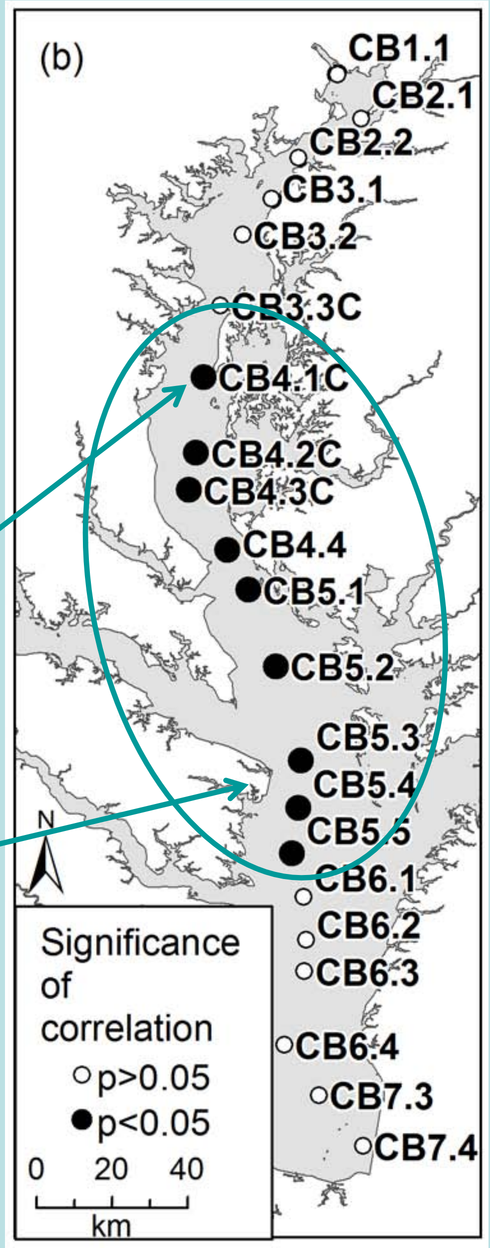


(Murphy et al. 2011. *E&C*)

N-Loading & Hypoxia Duration

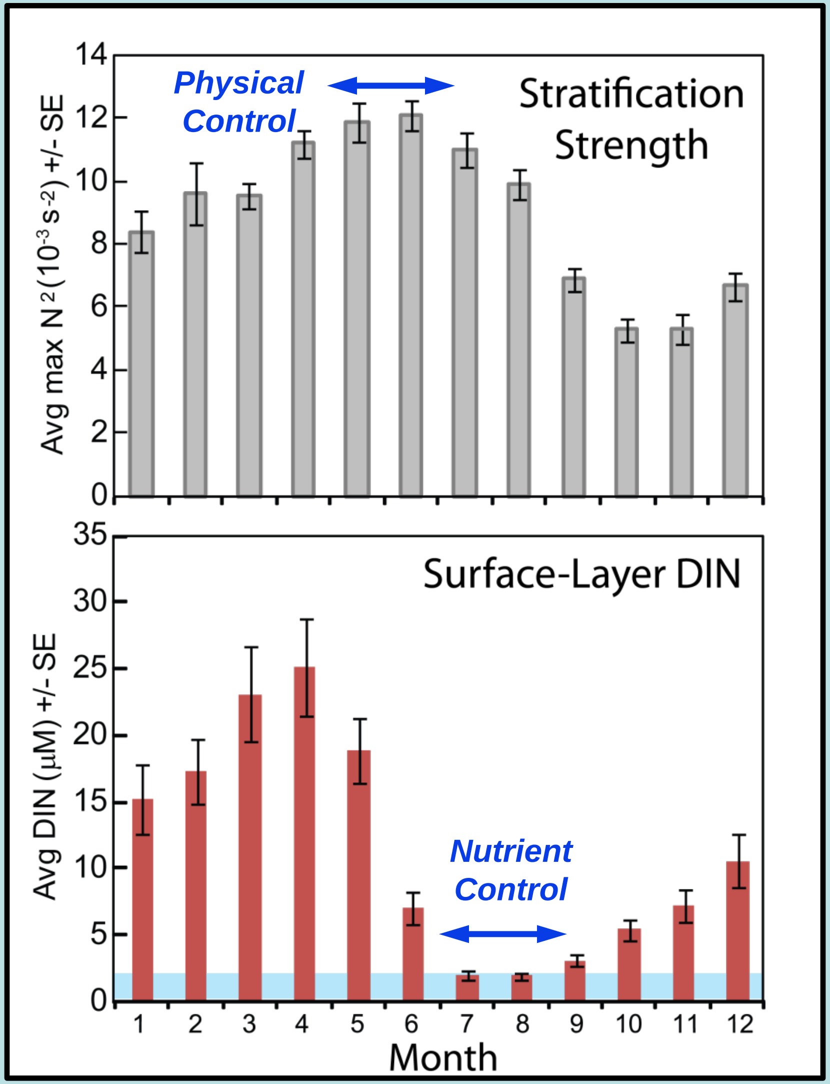
- Number hypoxia days (bottom 5 m water)
- In mid-Bay, hypoxia duration is correlated significantly with Jan-May TN loads





(Murphy et al. 2011. *E&C*)

Controls on Hypoxia: Early vs. Late Summer



- Early summer hypoxia controlled by mixing and stratification

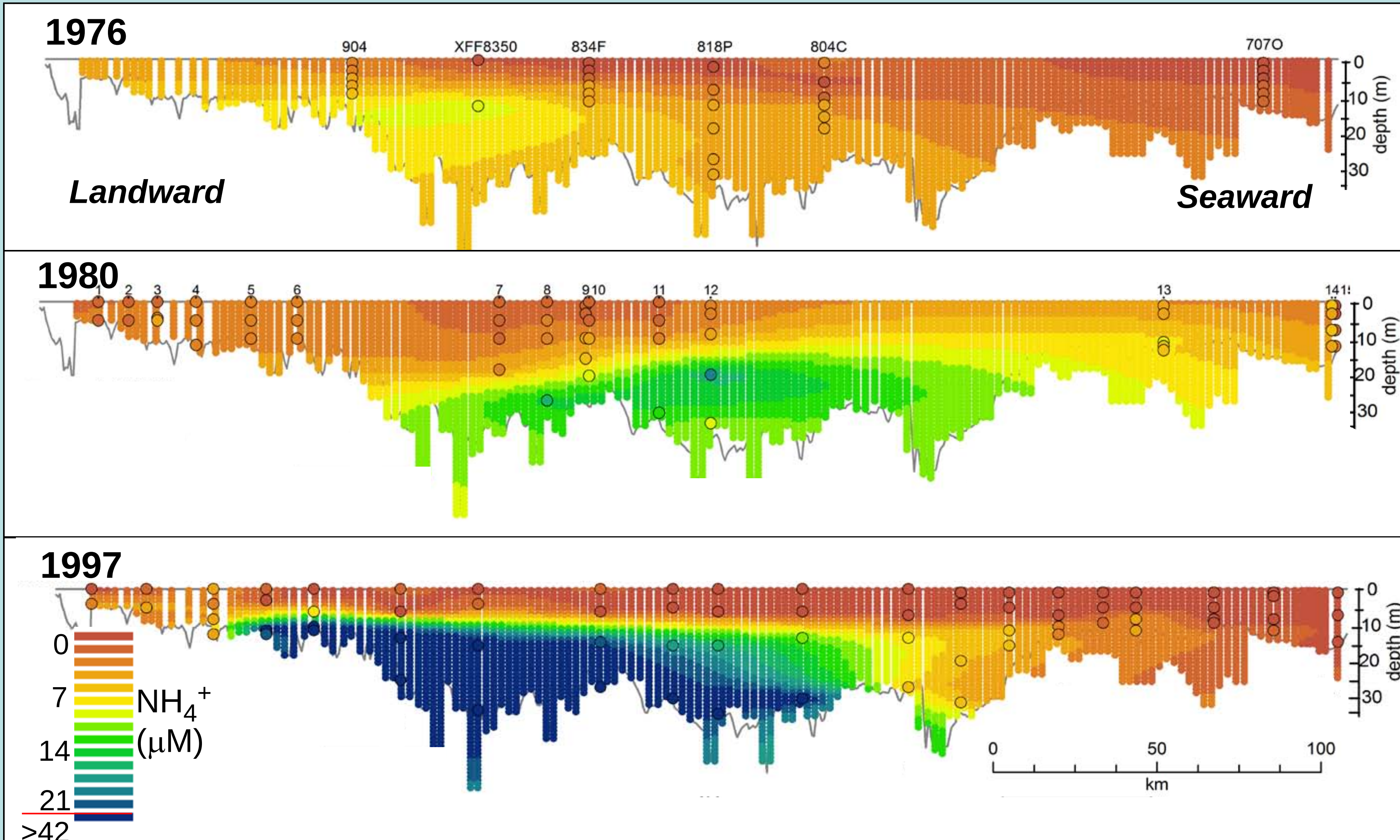
- Mid- to late-summer hypoxia controlled by nutrient availability

- **Hypoxia Effects on Nitrogen and Phosphorus Cycling**

    --Low O_2 effects on nutrient recycling

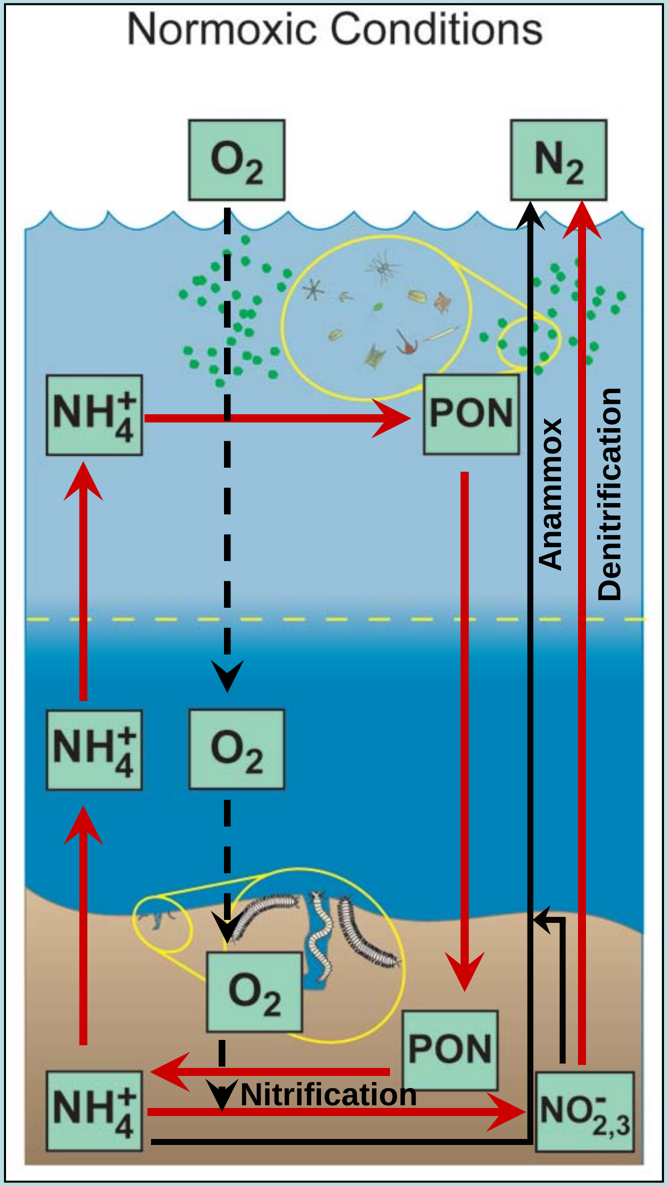
    --Positive feedback effects

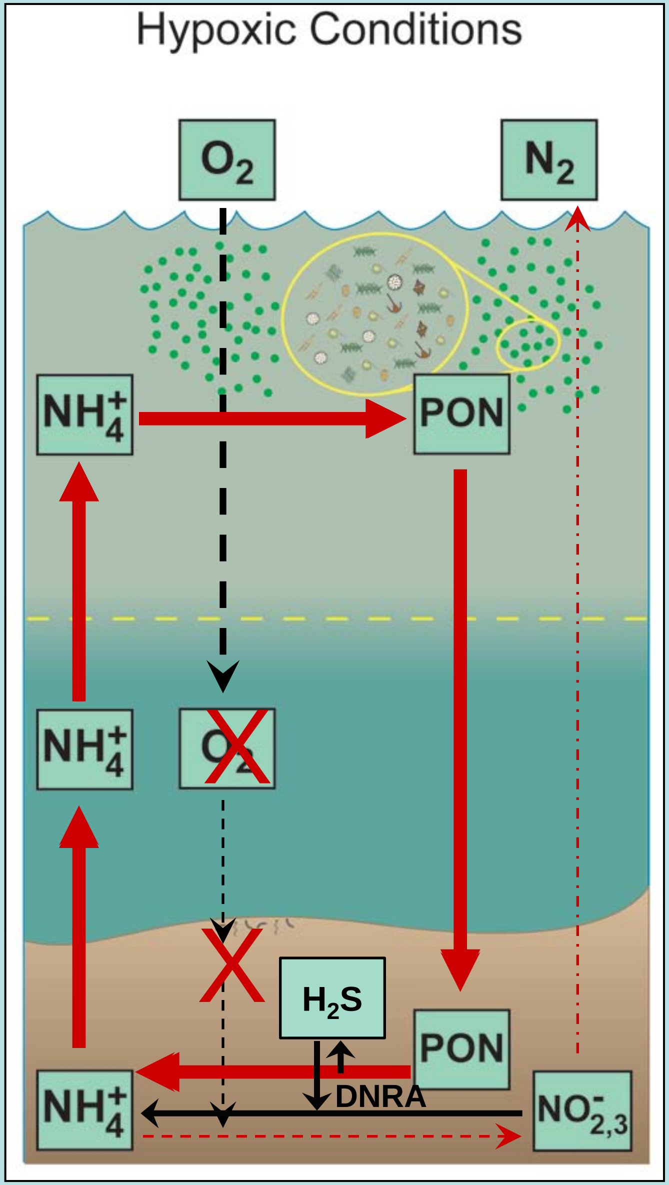
Decadal Change in Bay July [NH_4^+] Distribution



(Rebecca Murphy, JHU. unpublished)

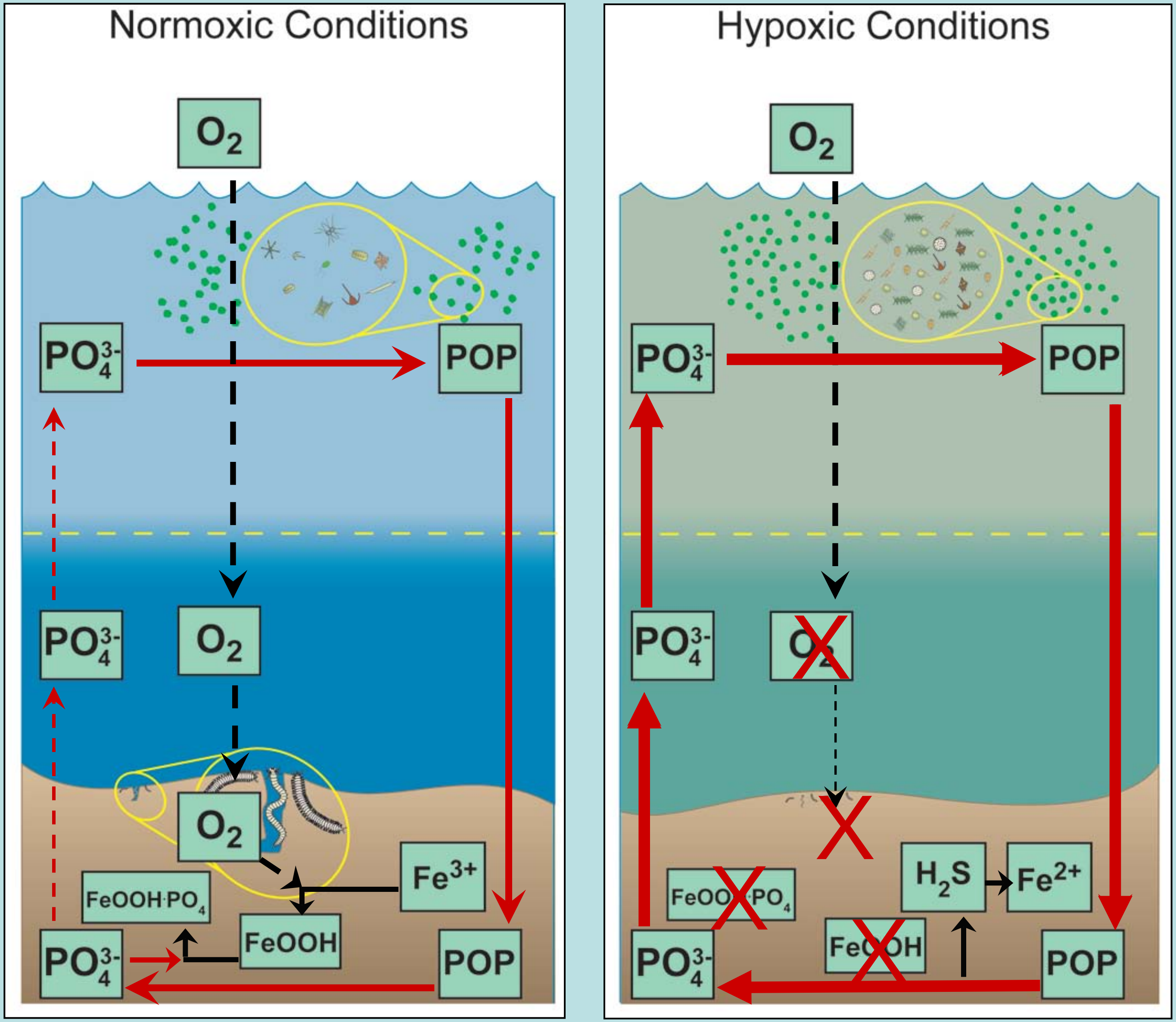
Conceptual Model of O_2 Interactions with N-Cycle





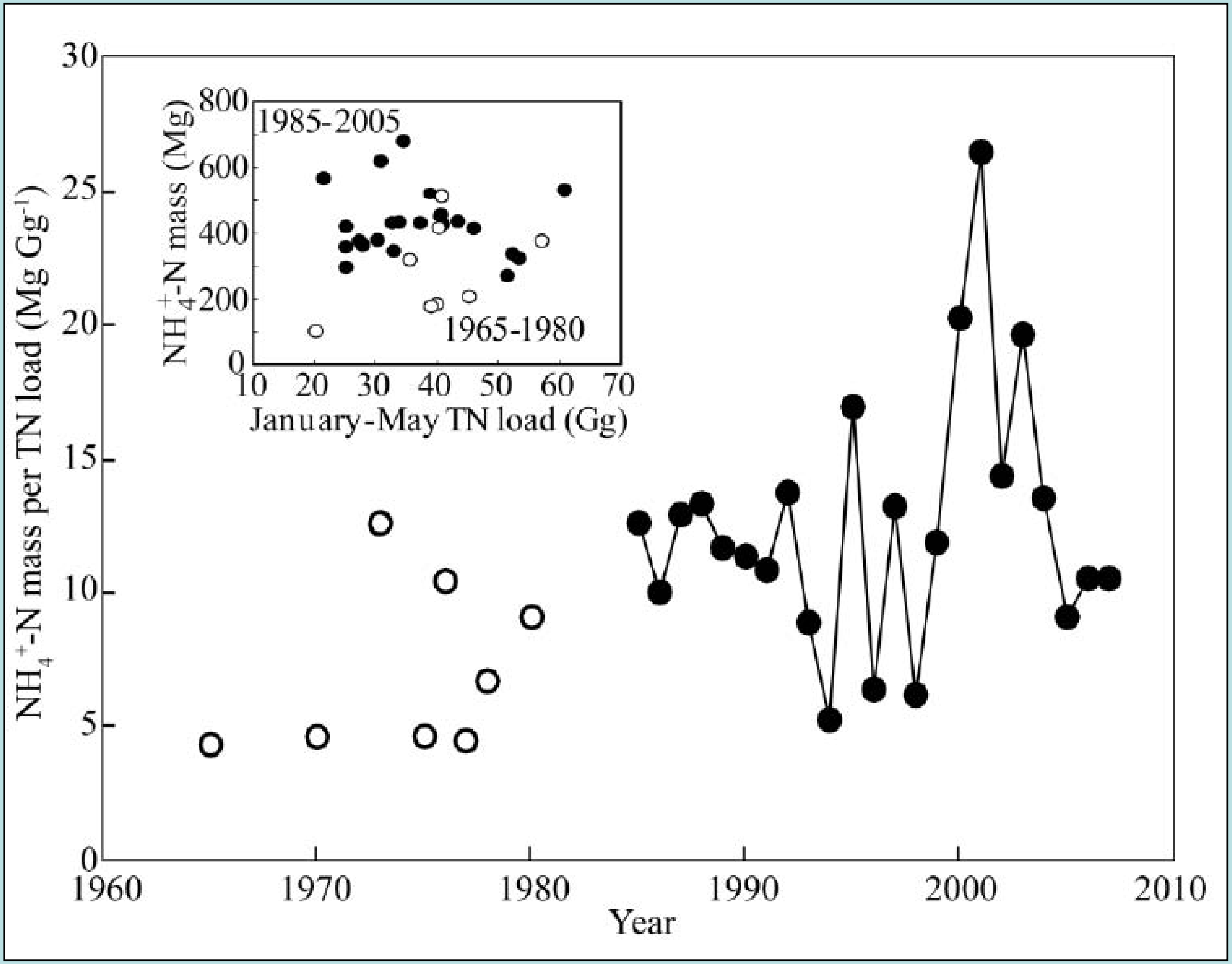
(J. Testa & M. Kemp, Feb ‘11)

Conceptual Model of O_2 Interactions with P-Cycle



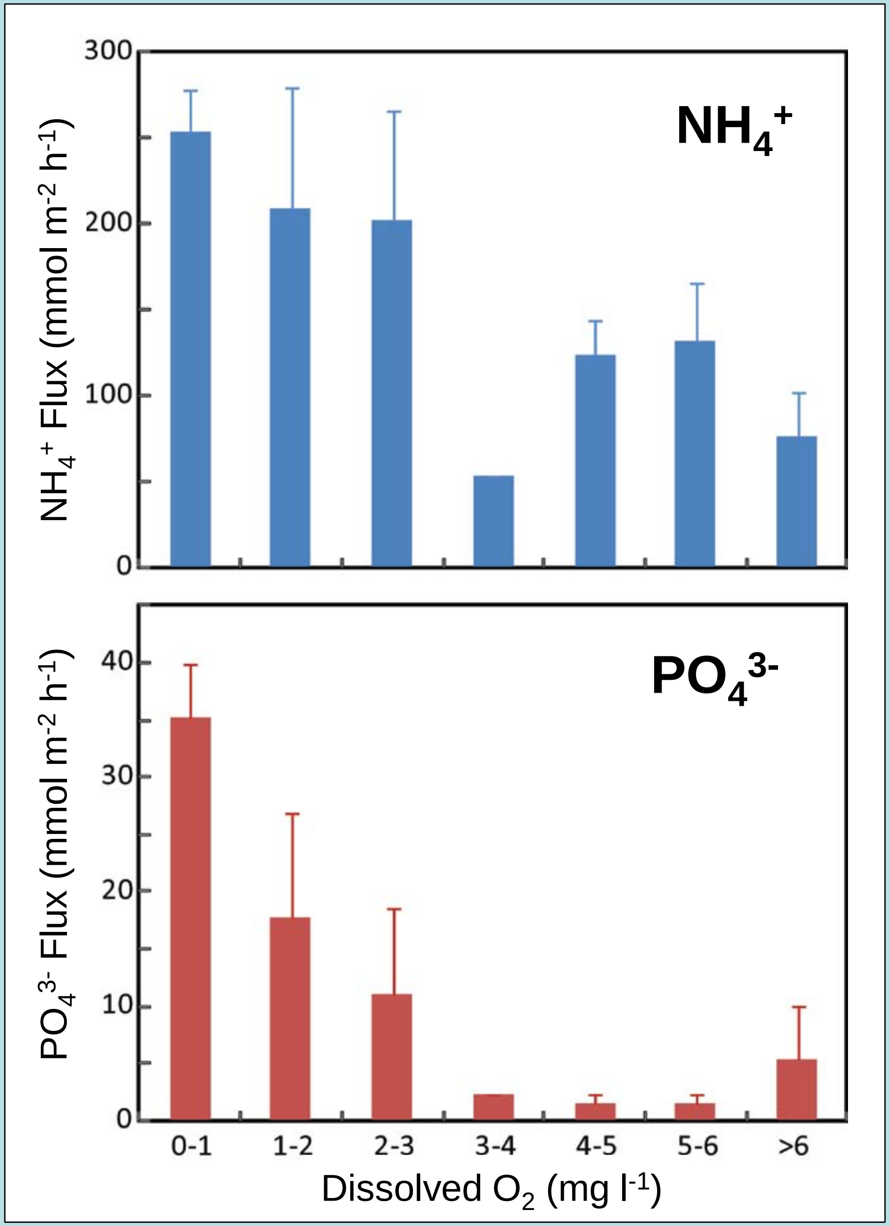
(J. Testa & M. Kemp, Feb '11)

Decadal Change in Bottom Water NH_4^+ Pools



(Testa & Kemp 2012. *L&O)*

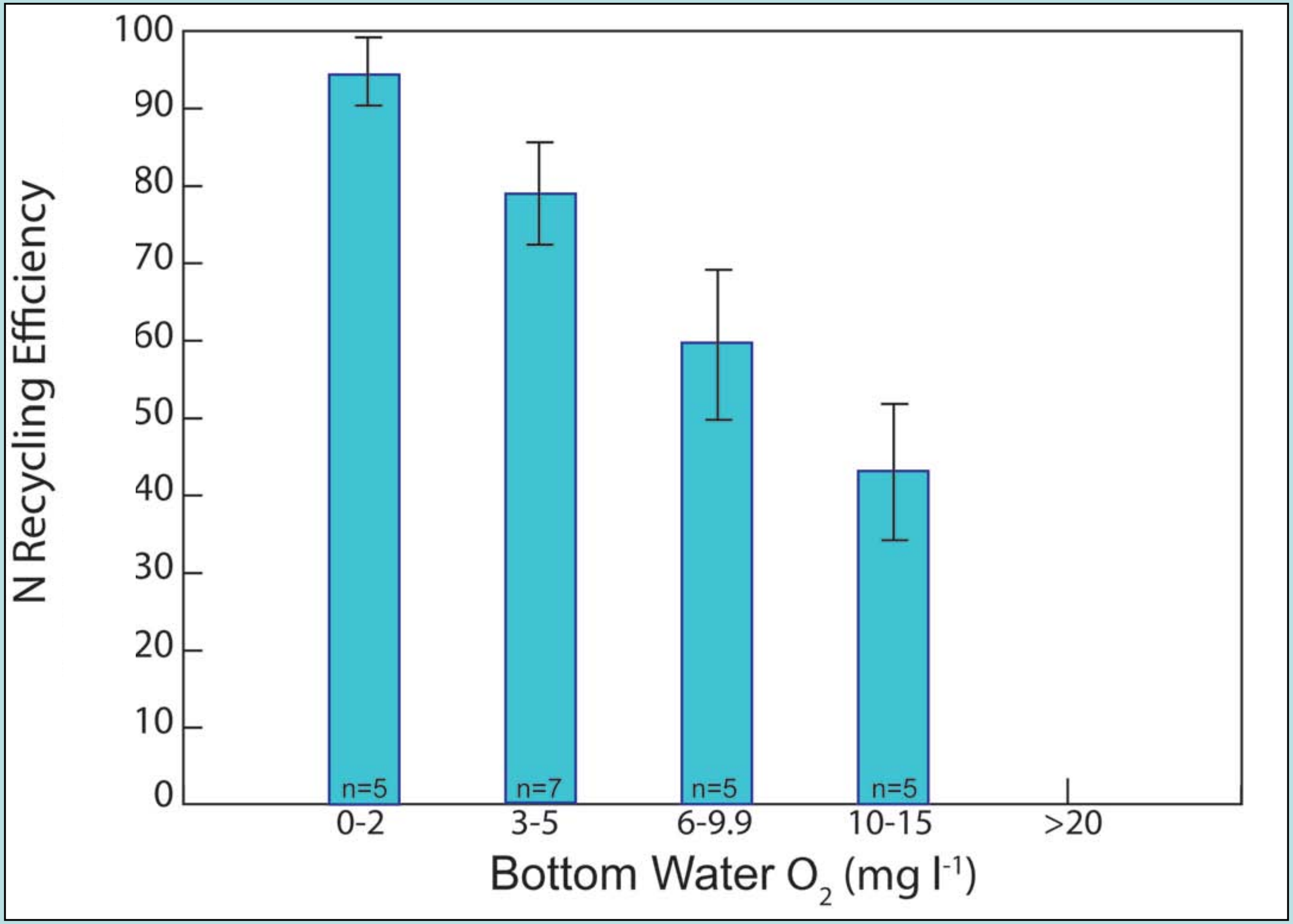
Benthic Fluxes of NH_4^+ & PO_4^{3-} vs. Bottom O_2



(Testa & Kemp 2012. *L&O)*

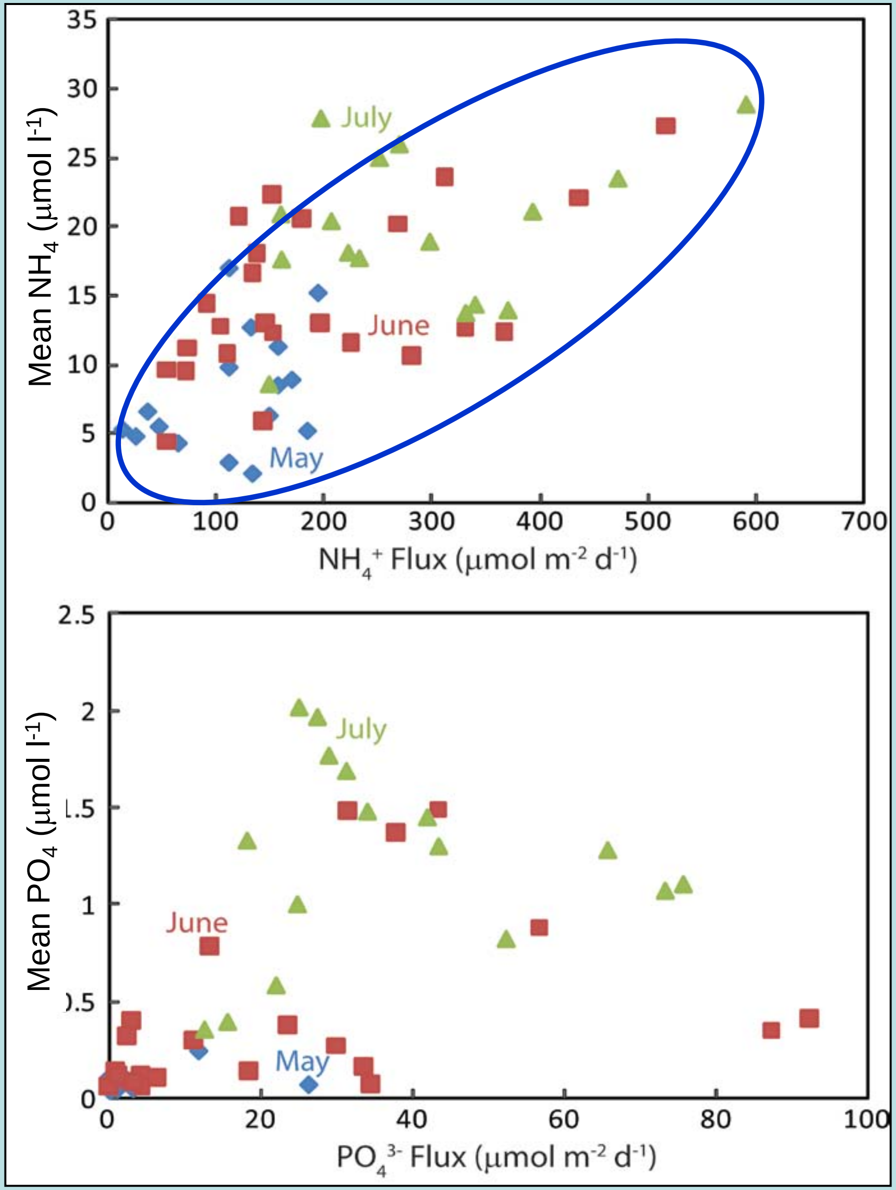
Nitrogen Recycling Efficiency vs. Bottom O_2

$$\text{Efficiency} = [(\text{Flux}_{NH4}) / (\text{Flux}_{N2} + \text{Flux}_{DIN})]$$



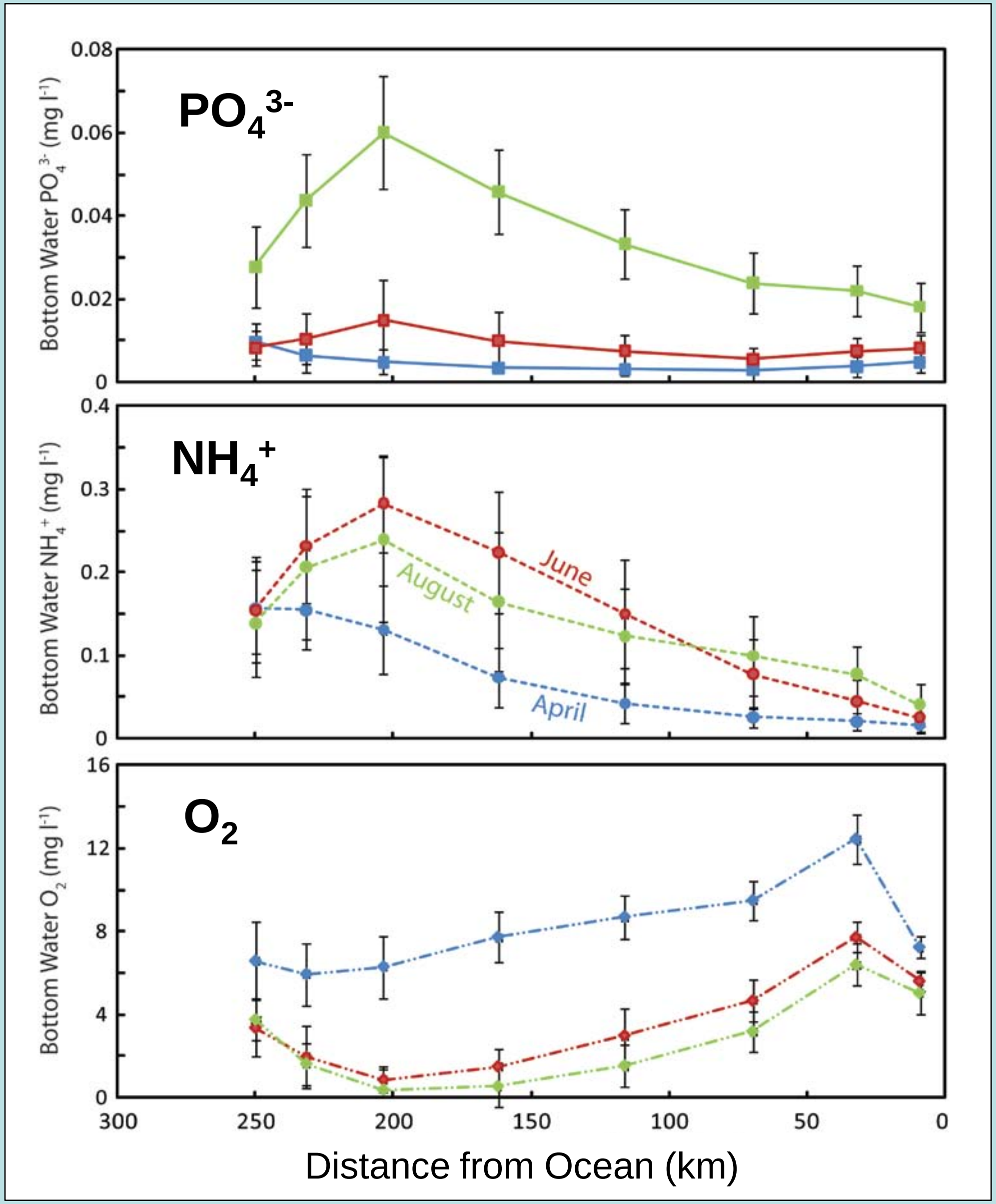
(Boynton and Kemp 2008)

NH_4^+ & PO_4^{3-} Benthic Fluxes vs. Bottom Pools



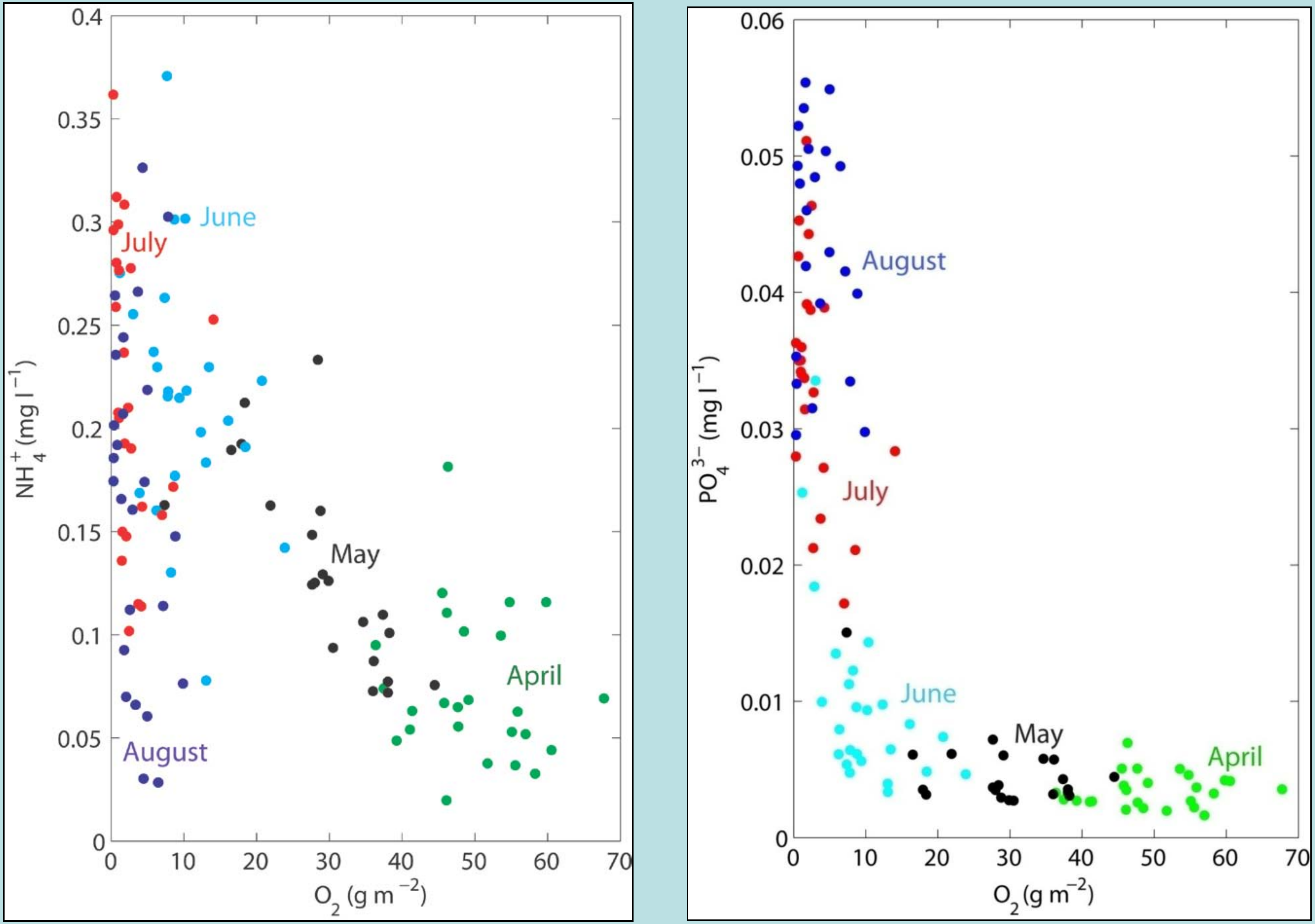
(Testa & Kemp 2012. *L&O)*

Time-Space Distributions of Bottom O_2, NH_4 & PO_4



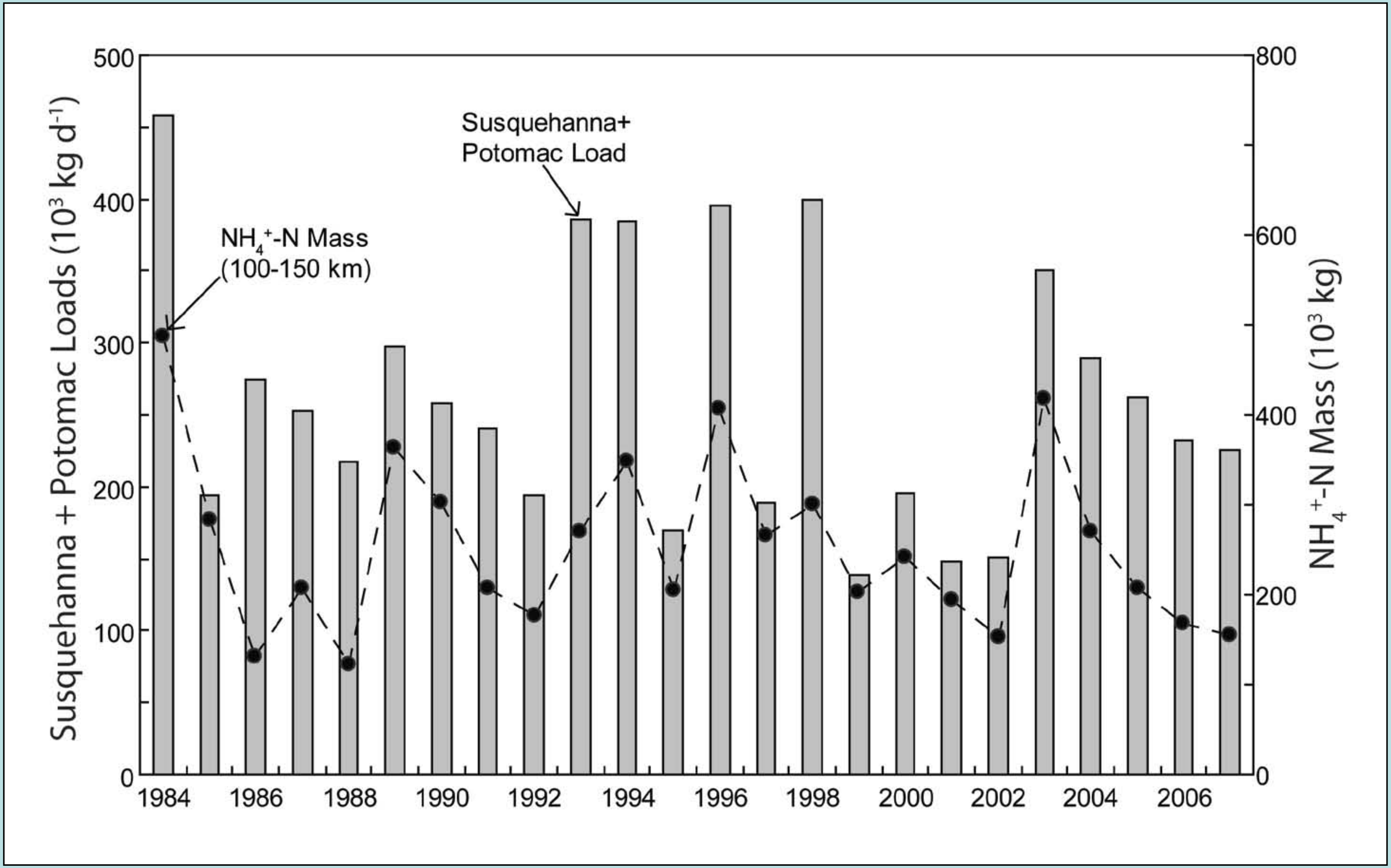
(Testa & Kemp 2012. *L&O)*

Seasonal Trends in Bottom NH_4^+ & PO_4^{3-} vs. O_2



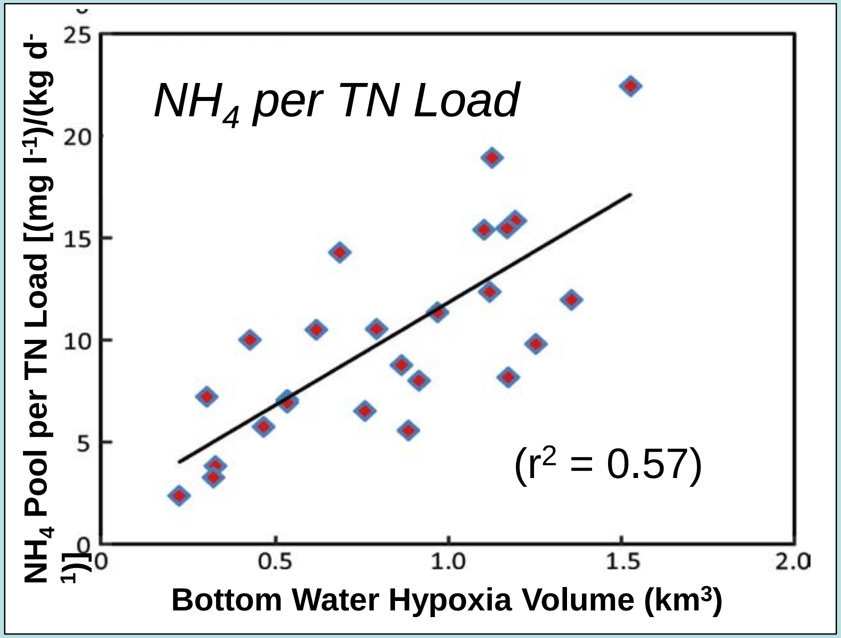
(Testa & Kemp 2012. *L&O)*

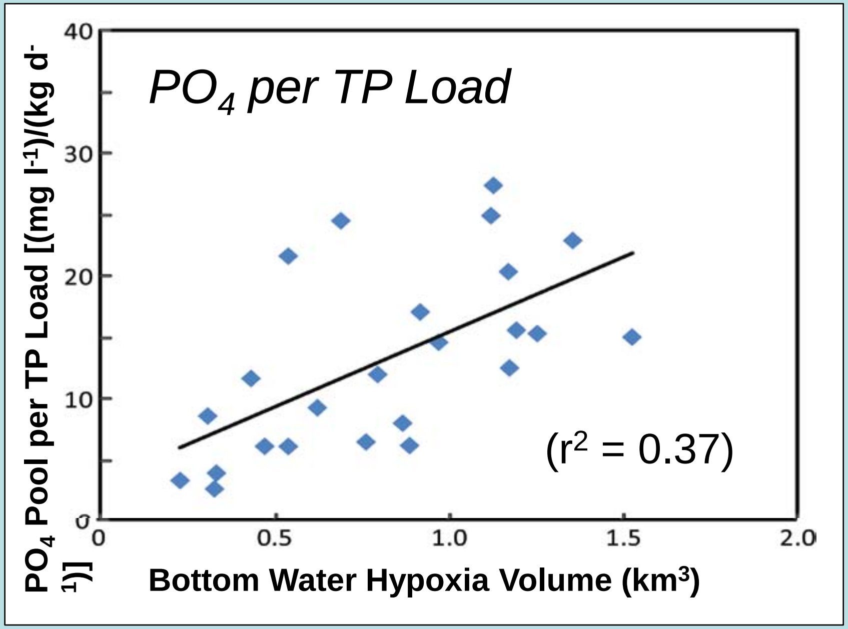
Yearly Variations in N Loading & Bottom N Pools



(Testa & Kemp 2012. *L&O)*

Nutrient Pools per Load vs. Hypoxia Volume





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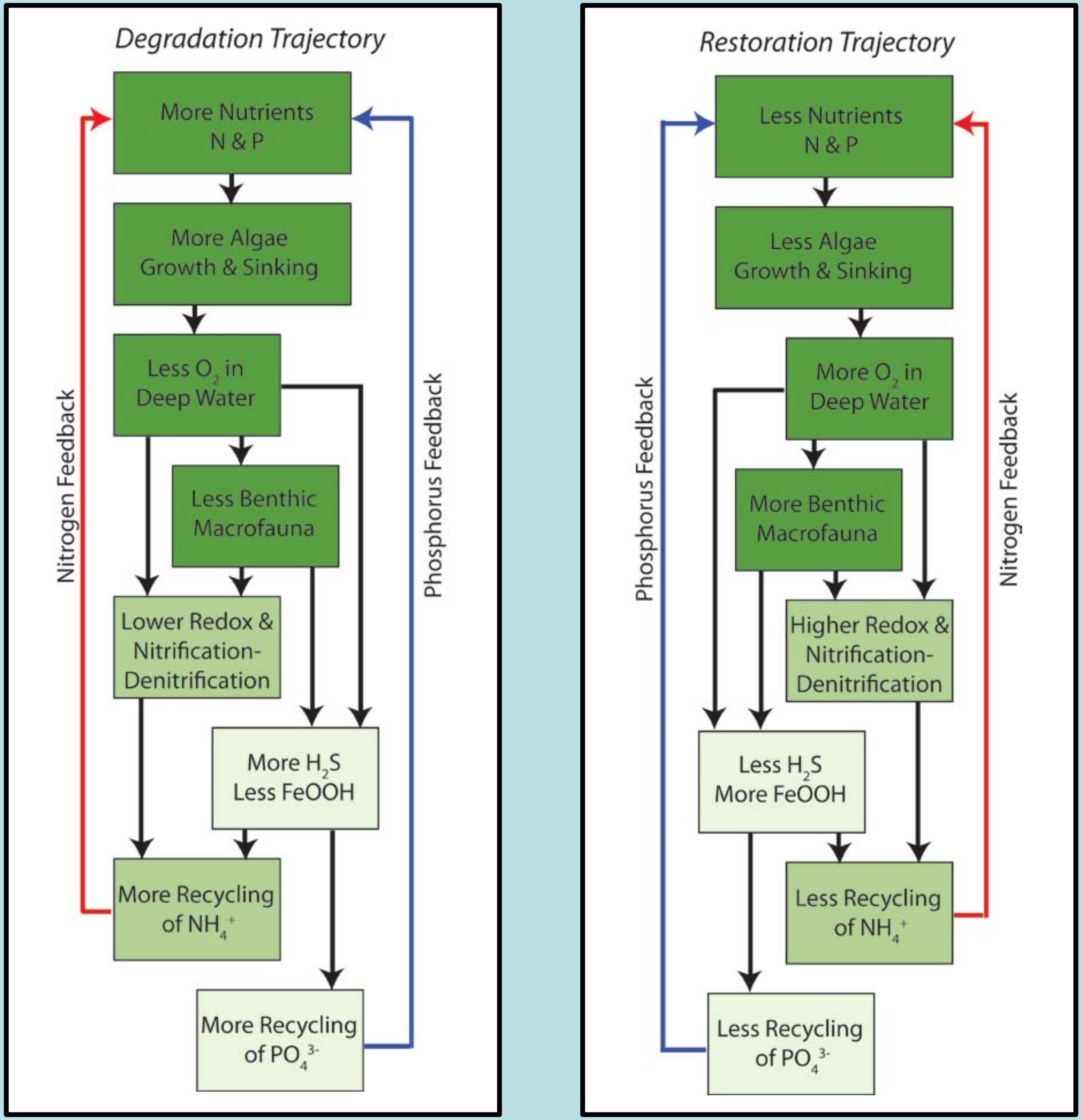
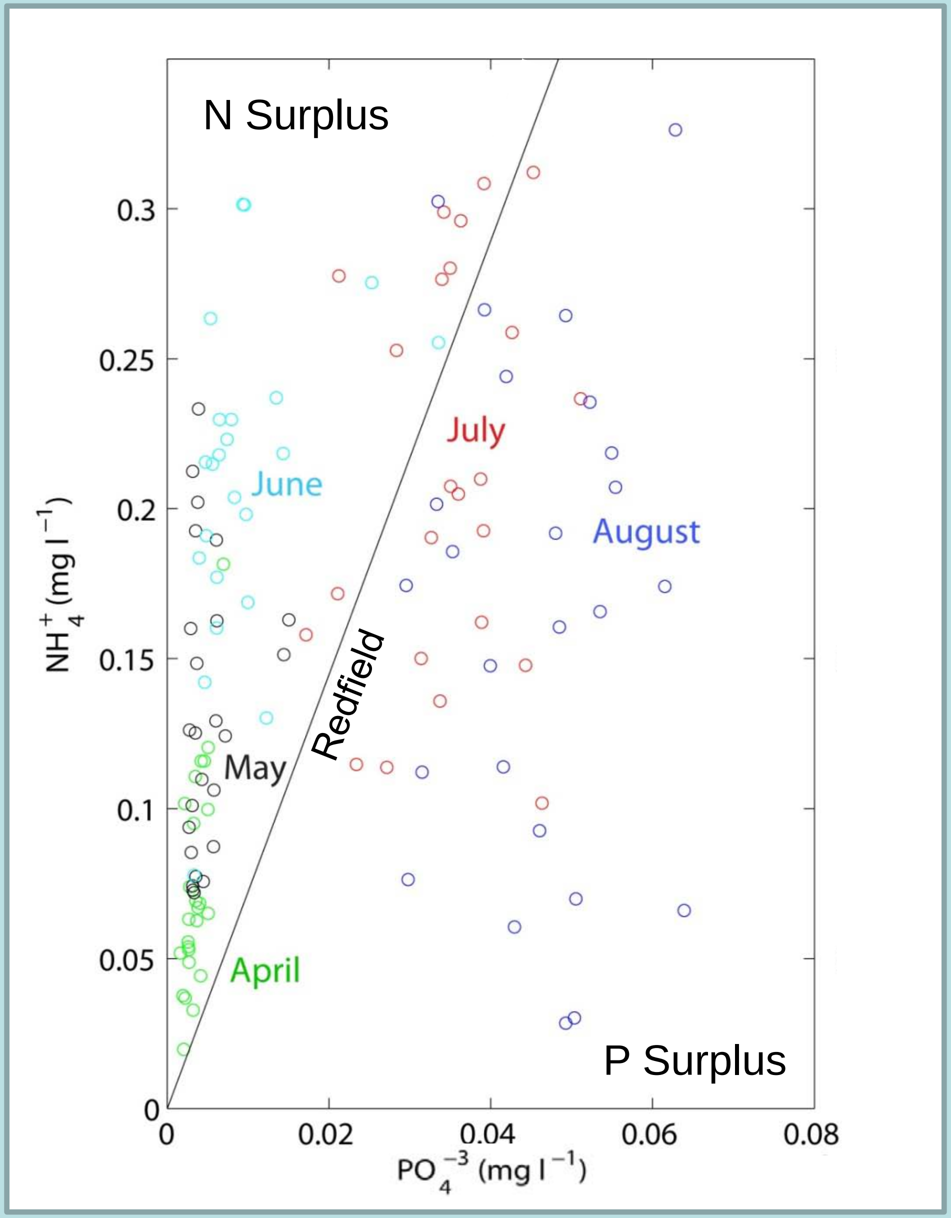
Feedback Effects Linking Hypoxia & Nutrients

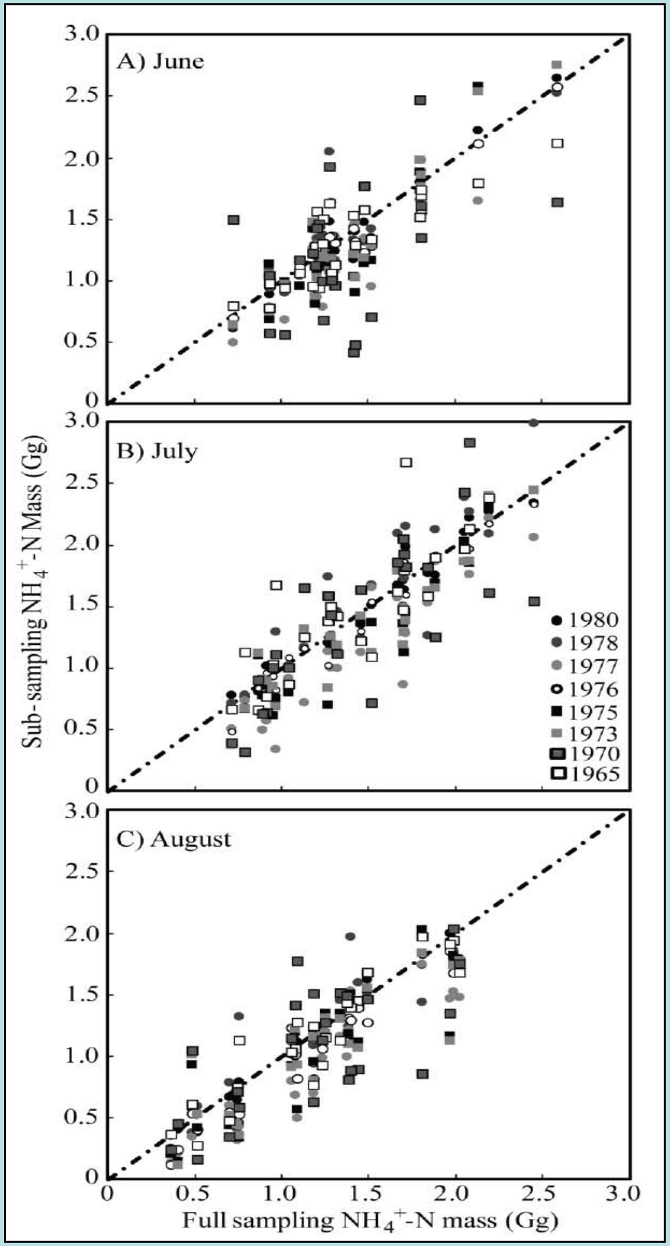


Concluding Comments

- Interannual variations in Chesapeake Bay hypoxia due to river flow
- Decadal increase in early summer hypoxia is controlled by climate
- Decadal decrease in late-summer hypoxia is controlled by nutrient loads
- Hypoxia enhances N & P recycling and creates a positive feedback
- Climate effects can slow or reverse effects of hypoxia management
- Hypoxia-nutrient “feedback link” will enhance both degradation & recovery

Temporal Mismatch in Fluxes Drives N:P Ratios




A) June
B) July
C) August
Sub-sampling NH4+-N Mass (Gg)
Full sampling NH4+-N mass (Gg)
1980
1978
1977
1976
1975
1973
1970
1965
0
0.5
1.0
1.5
2.0
2.5
3.0