Recalcitrance and Tipping Points in Recovery from Hypoxia in Chesapeake Bay

W. M. Kemp[1], J. Testa[1],
J. Hagy[2] , W. R. Boynton[3]

[1]University of Maryland CES, HPL
[2]US EPA, GED, Gulf Breeze, FL, USA
[3]University of Maryland CES, CBL

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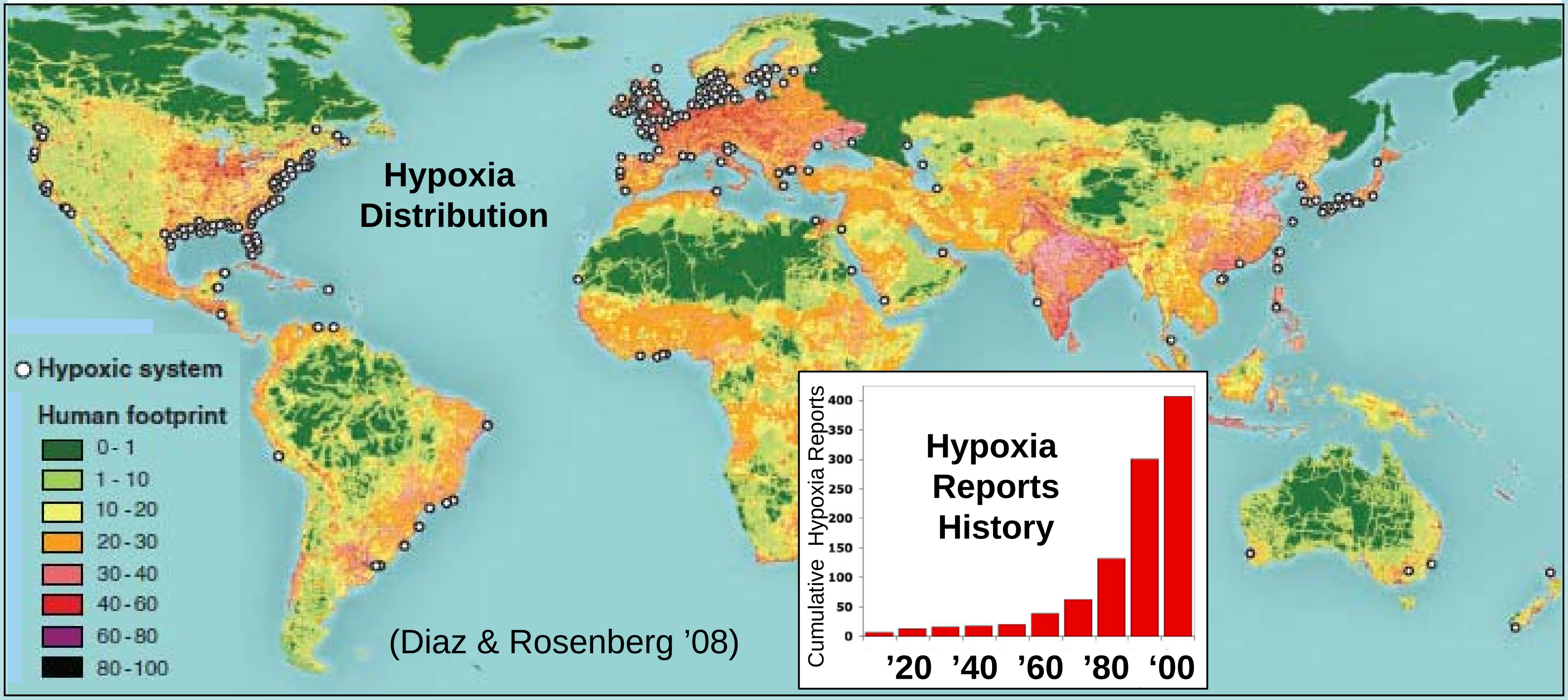
Outline

- **Background & Motivation**
  - -Hypoxia linked to eutrophication
  - -Understand hypoxia response to nutrients
- **Chesapeake Bay Hypoxia Trends & Controls**
  - -Chesapeake Bay Background
  - -Hypoxia & Nutrient Trends
- **Hypoxia-Nutrient "Regime shift" in Chesapeake Bay?**
  - -Response trajectories
  - -Possible explanation: Enhanced N-Recycling
- **Concluding Comments**

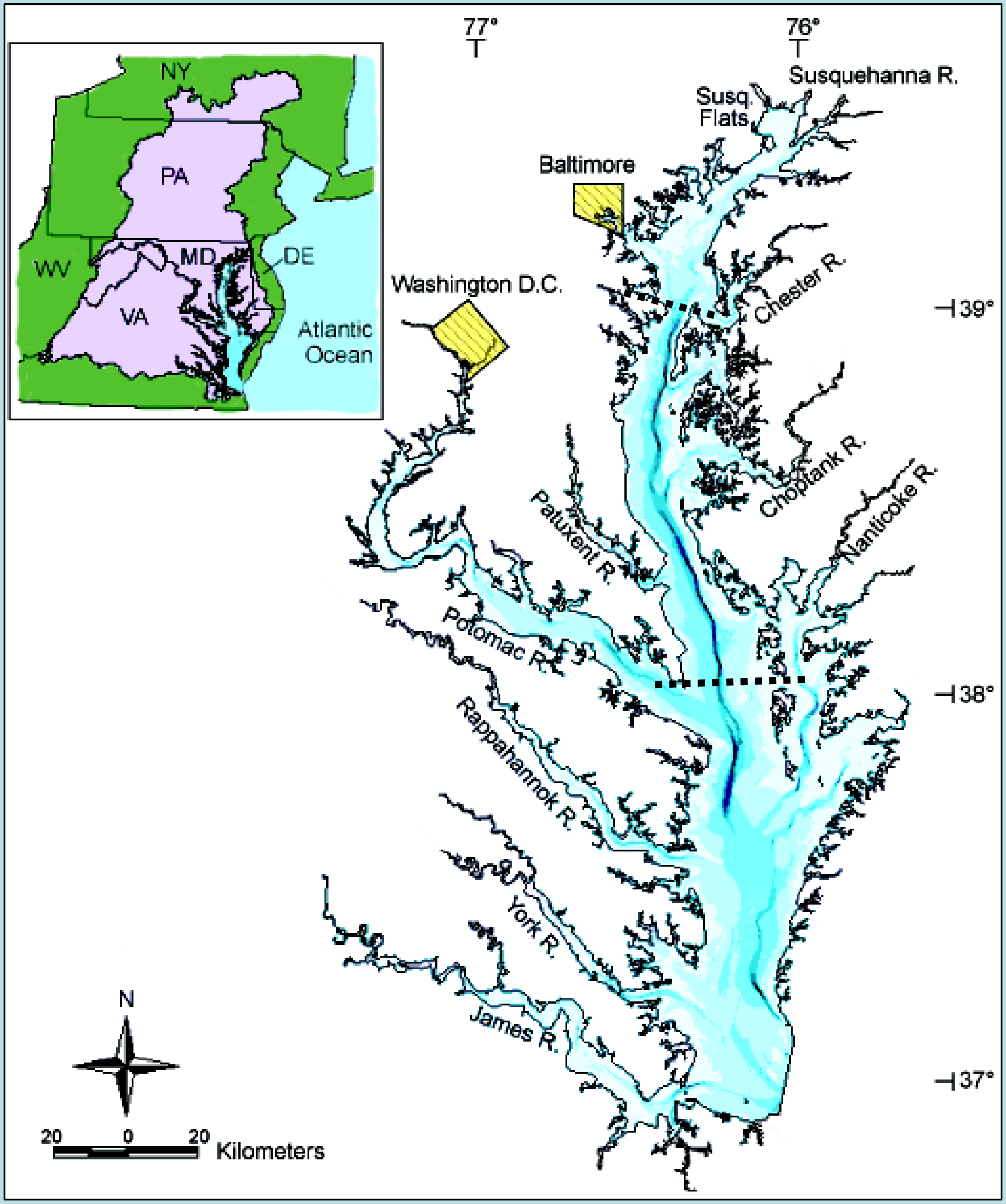
Global-Scale Spread of Coastal Hypoxia



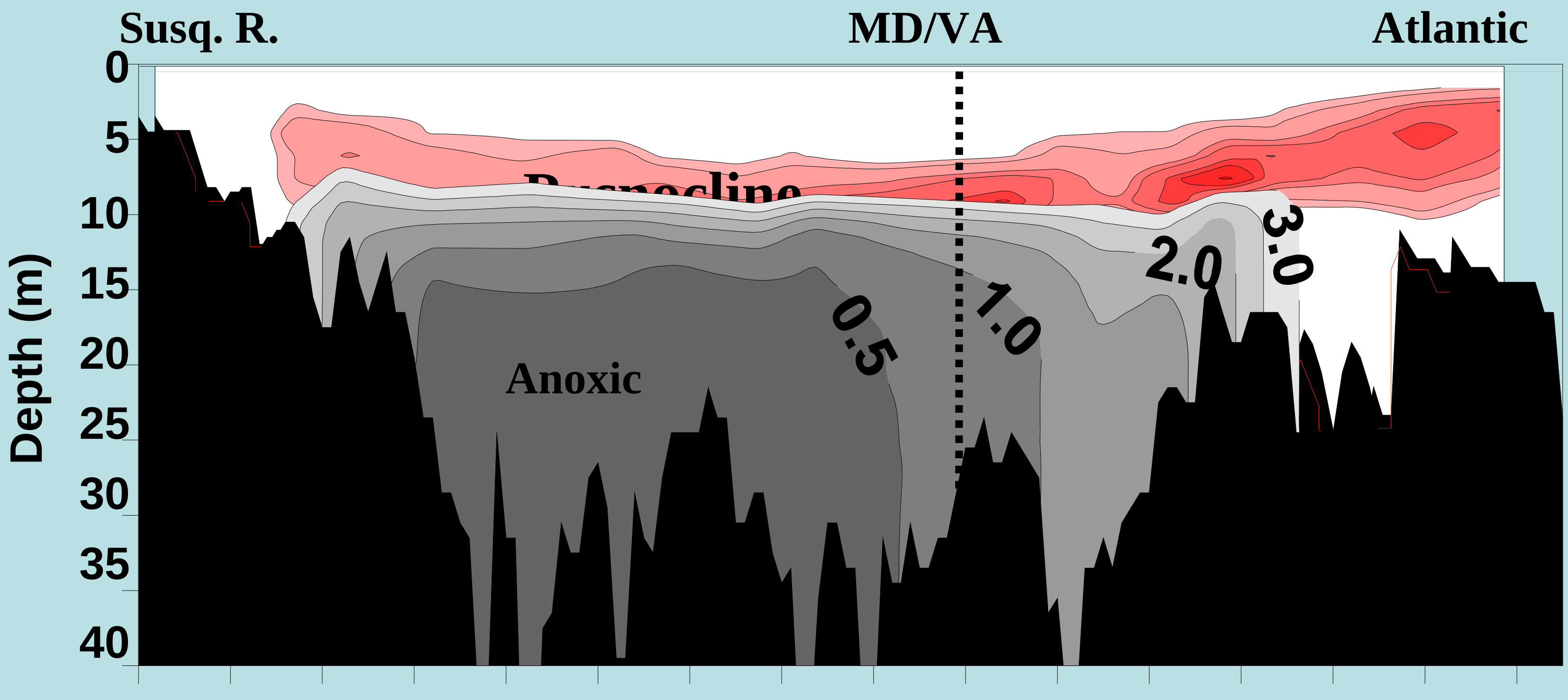
- **Global distribution of coastal hypoxia**
- **Hypoxia concentrated near intense human activities**
- **Global spread of hypoxia related to eutrophication**
- **Other processes (e.g., climate change) also important**

Chesapeake Bay Physical Features

- **Large ratio of watershed to estuarine area (~ 14:1)**
- **Deep channel is seasonally *stratified***
- **Broad shallows flank channel (mean Z = 6.5m)**
- **Relatively long water residence time (~ 6 mo)**



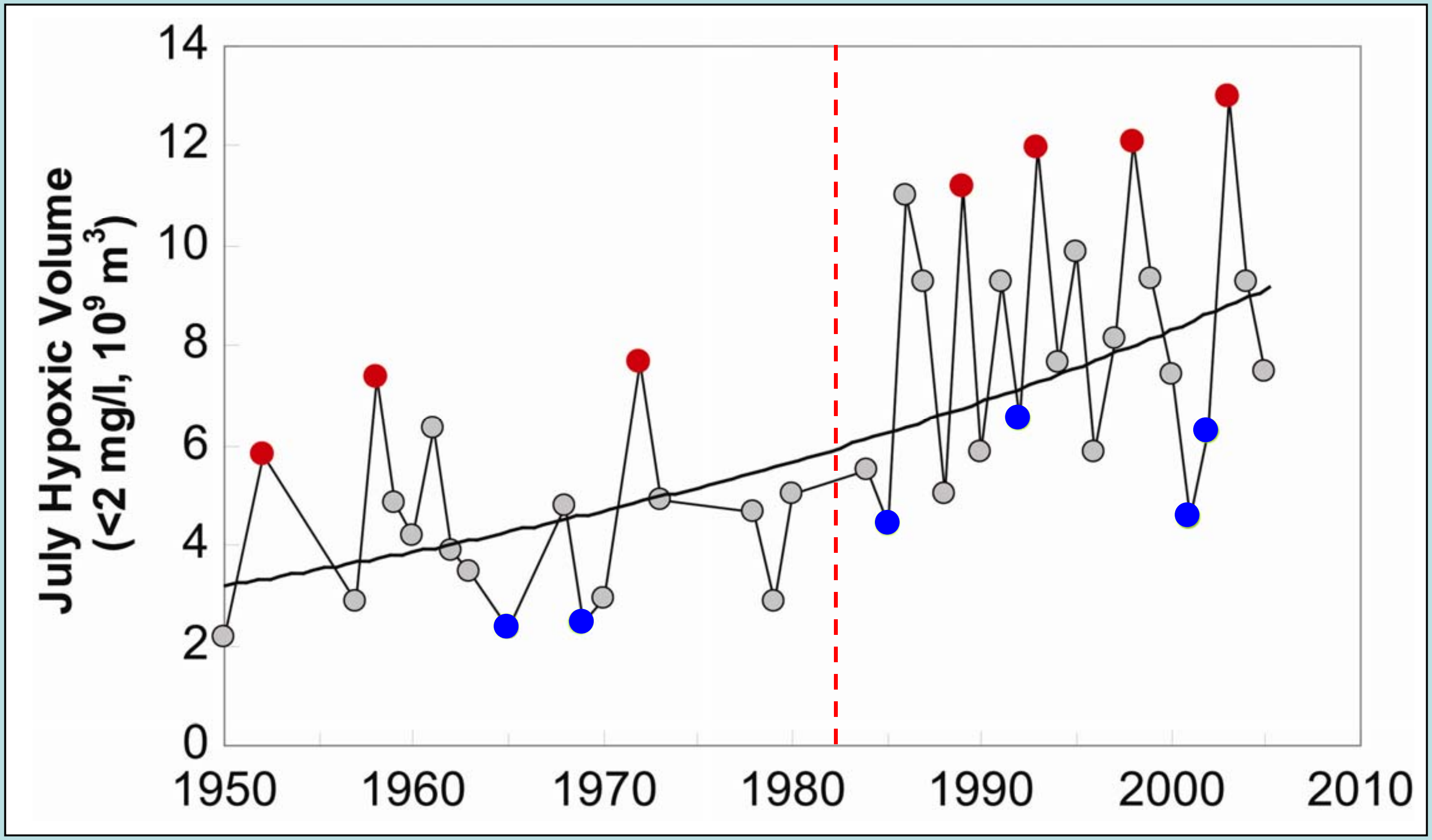
Stratification Control of Hypoxia



- Pynocline controls position & intensity of low O_2 water.
- Landward transport replenishes deep O_2 pools.

(Hagy 2002)

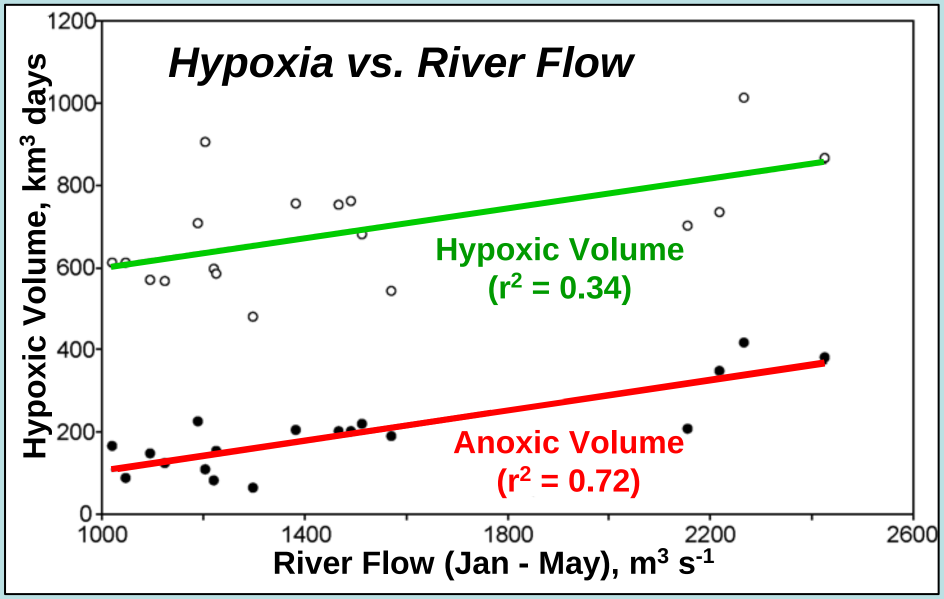
Trend in Bay Summer Hypoxia Volume (1950-2004)



- Exponential increase, w/ strongest change since 1980
- Interannual variability driven by **high** and **low** river flow

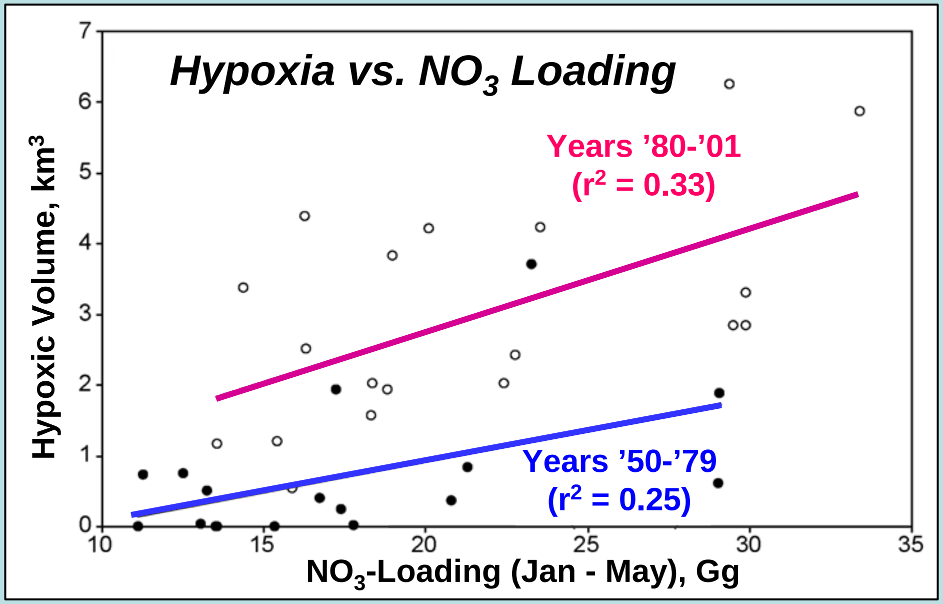
Volume of Summer Hypoxia Related to River Flow and N Loading: Regime Shift in Early 1980s

- **Volumes of summer hypoxia (< 1 mg/L) and anoxia (< 0.5 mg/L) related to winter-spring river flow.**



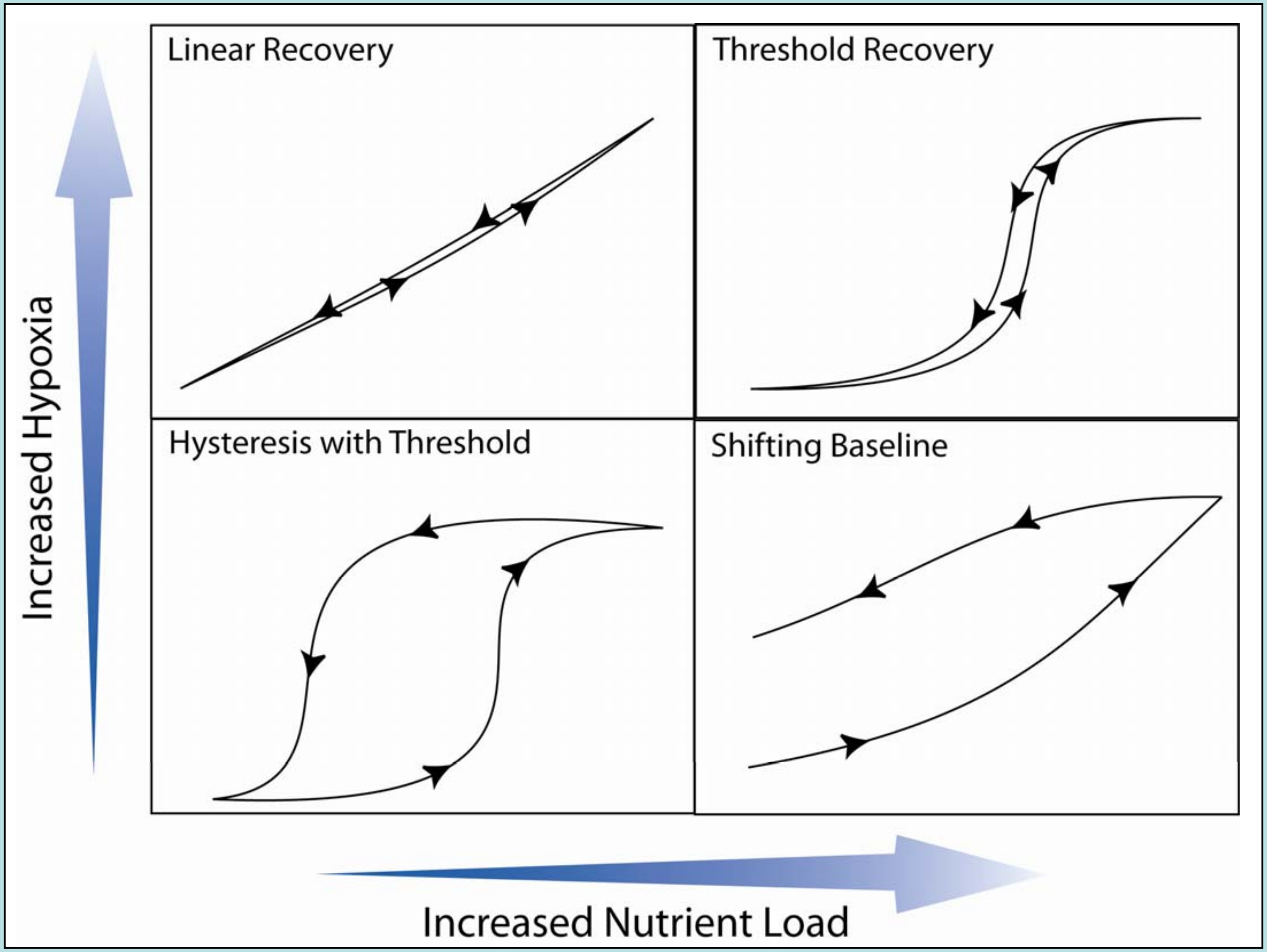
- **Abrupt increase in slope of hypoxia-nitrate relation for 1950-1980 and 1980-2003 (hypoxia per NO_3 Load)**

- **What factors drive this abrupt regime shift?**



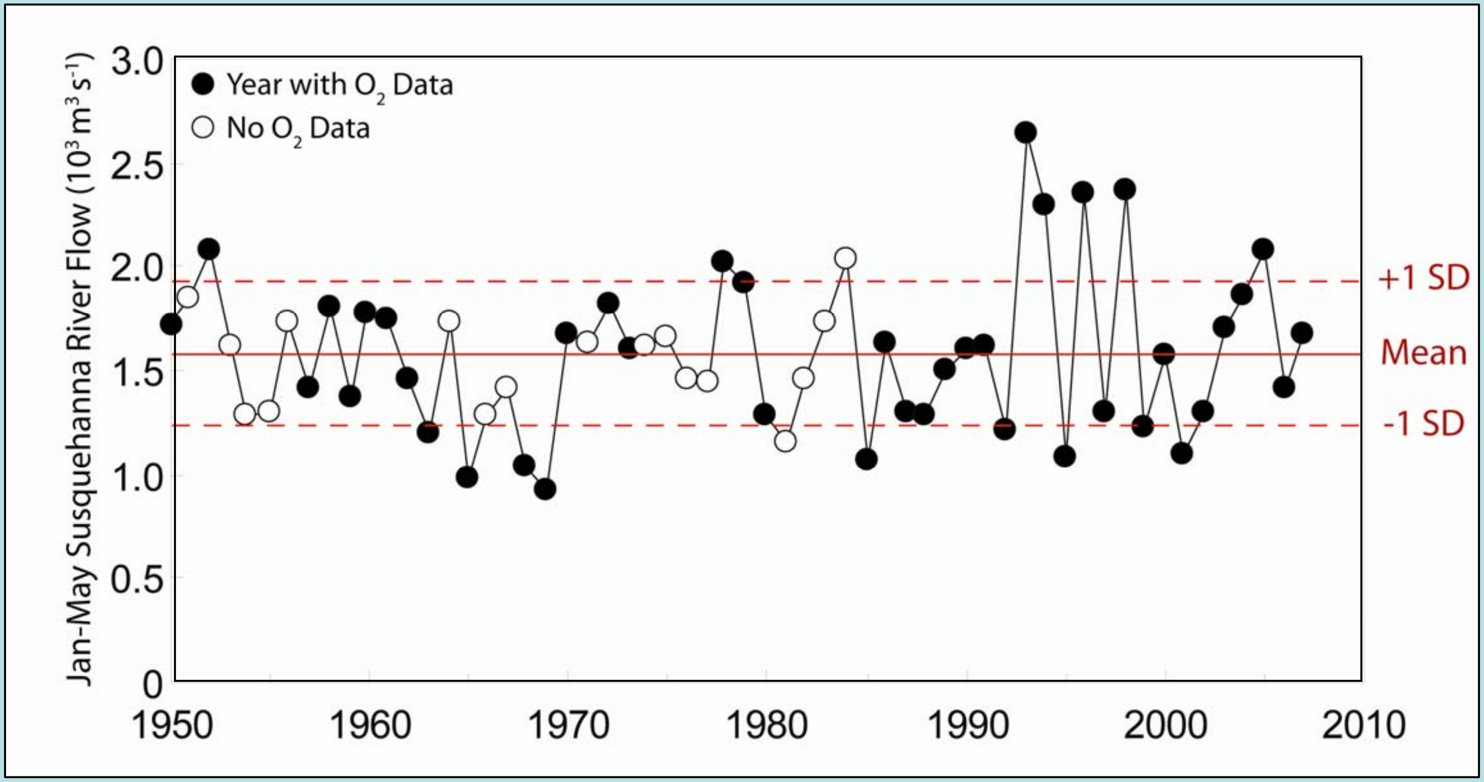
(Hagy et al. Estuar. & Coast. 2004, Kemp et al. MEPS. 2005)

Response of Hypoxia to Nutrient Remediation?

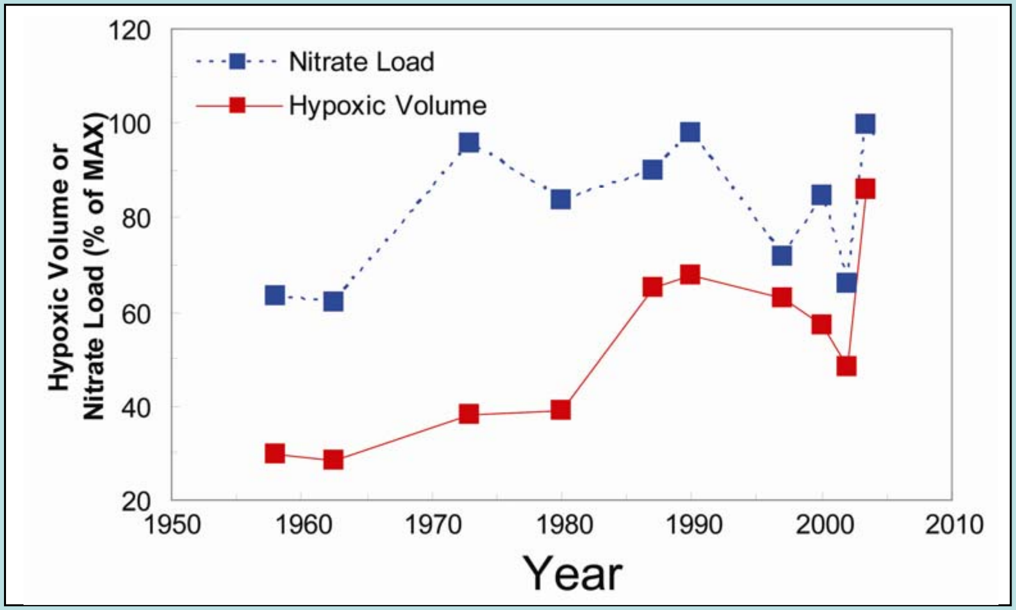


(modified after Duarte et al. 2008)

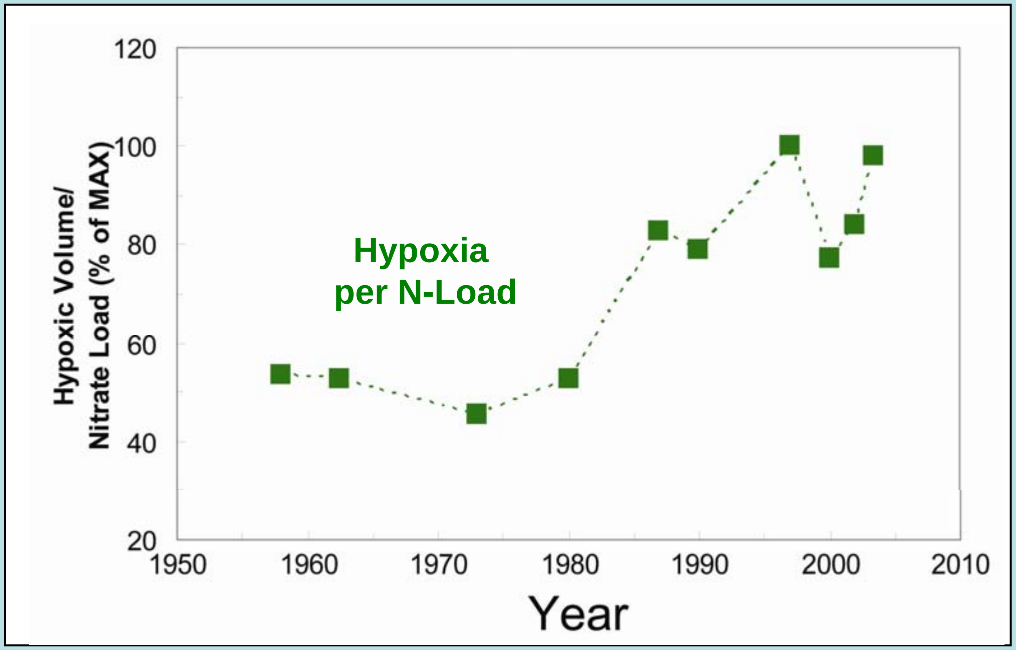
Interannual Variations in River Flow: Selecting Years within 1 SD



Focusing on Years of Intermediate River Flow

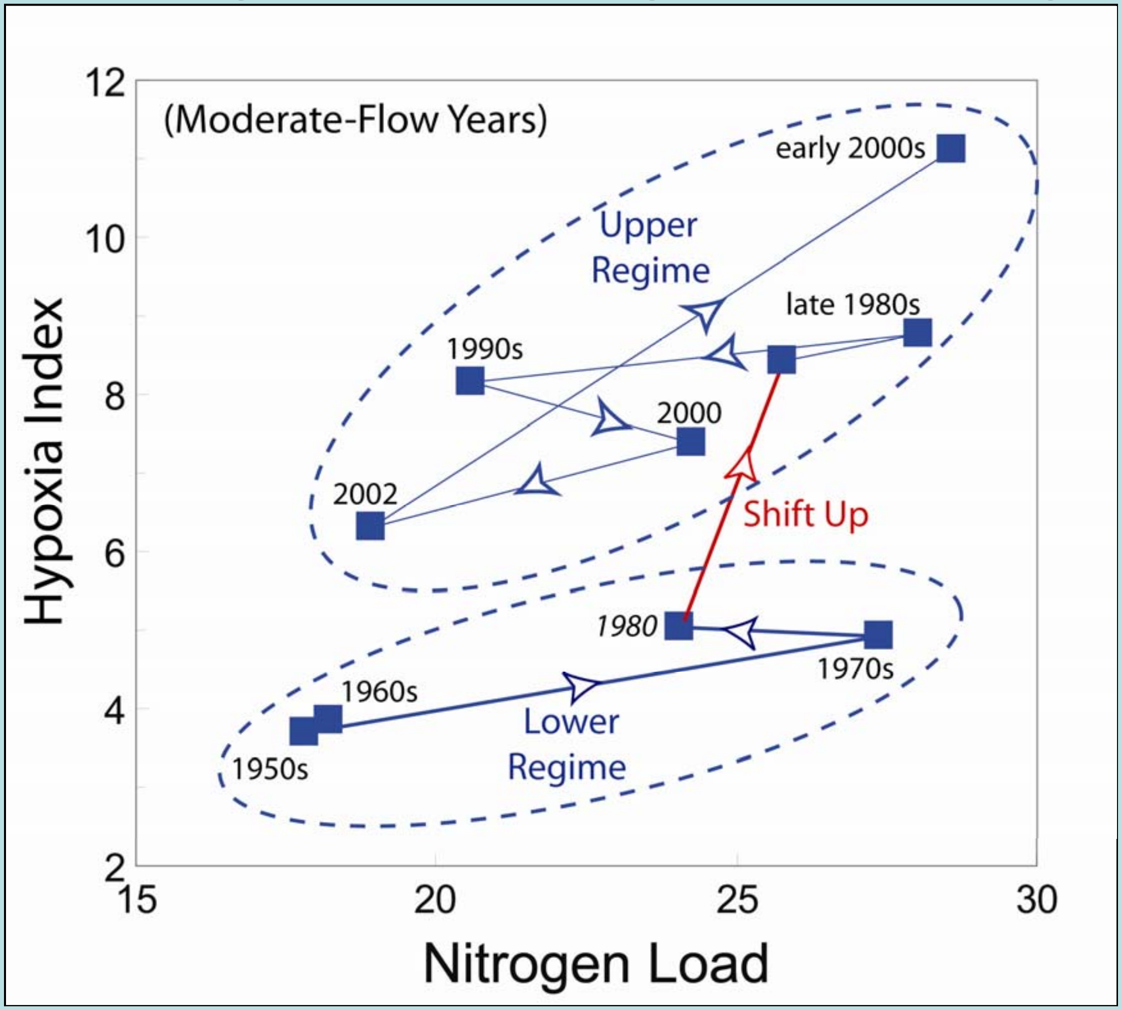


- **To reduce inter-annual variance, we analyzed only years with intermediate flow (mean ± SE).**
- **From 1960–2006, both NO_3-Load and Hypoxia increase steadily**
- **Hypoxia increases more rapidly than NO_3-Loading**



- **Hypoxia volume per NO_3-Load relatively constant until 1980.**
- **Shifts-up in mid-1980's and remains high through early 2000s**

Bay Hypoxia Response Trajectories for Changes in Nitrogen Loading

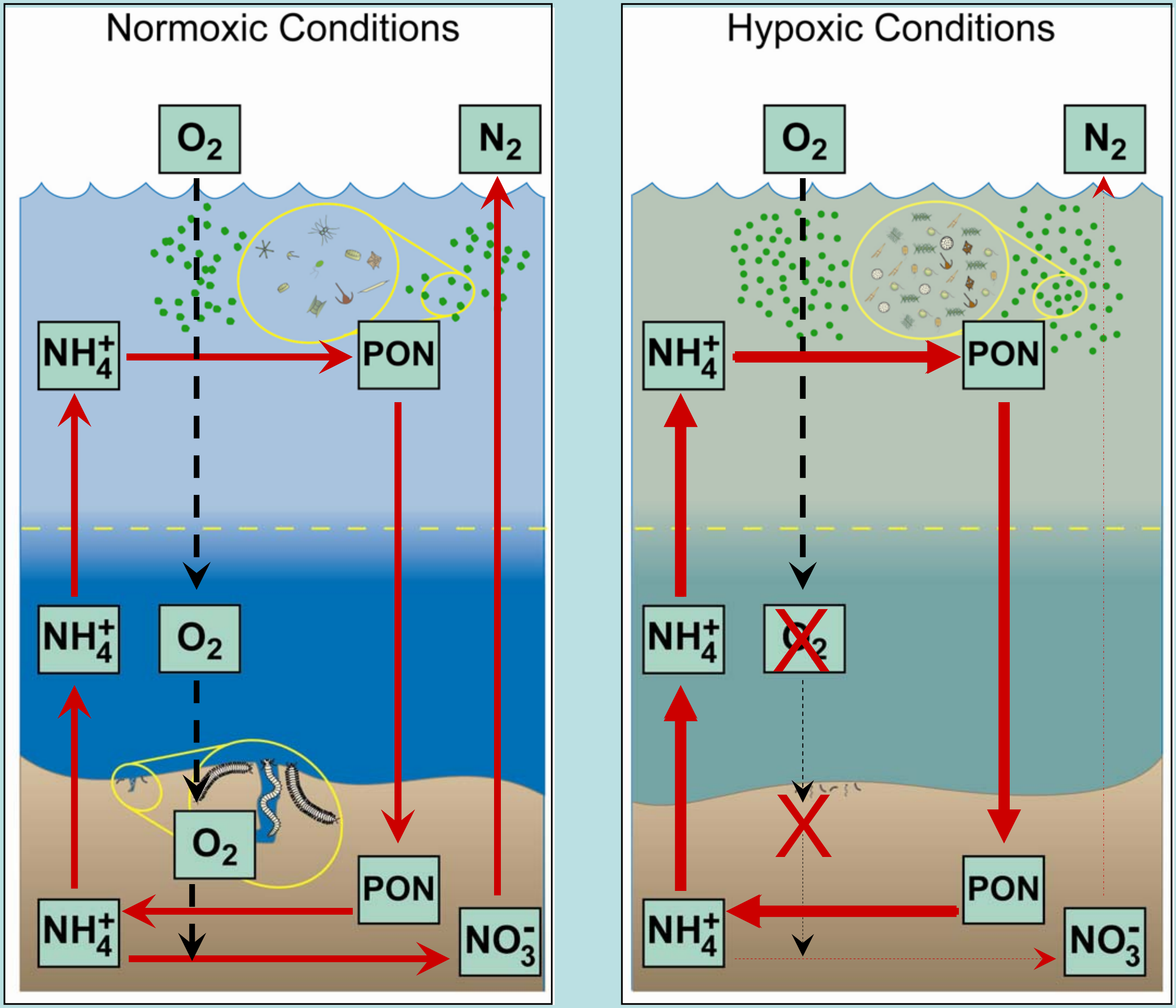


- **Visualize response trajectories and regime shifts**
- **Shift-up to new *Upper Regime* in 1980 with more Hypoxia per N-Load**
- **Recent apparent down-shift to *Lower Regime* (initial recovery?)**

Potential Explanations for Observed Shift in Relationship between Hypoxia & N-Loading

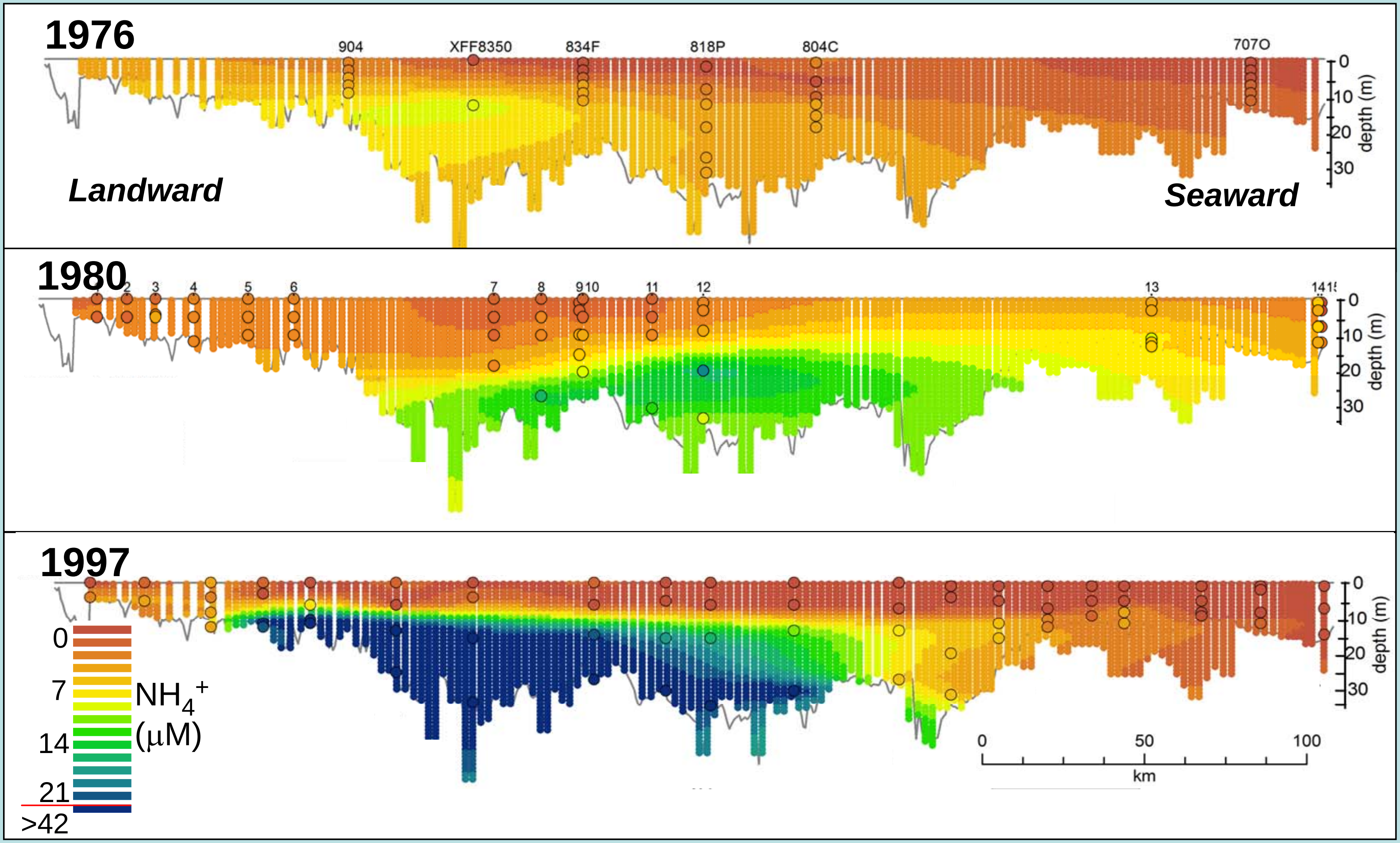
- Loss of oyster grazing on phytoplankton
- Loss of seagrass & marsh “nutrient trapping”
- Climate-induced changes (temperature, circulation)
- Enhanced nutrient recycling efficiency under low O_2

Conceptual Model of O_2 Interactions with N-Cycle



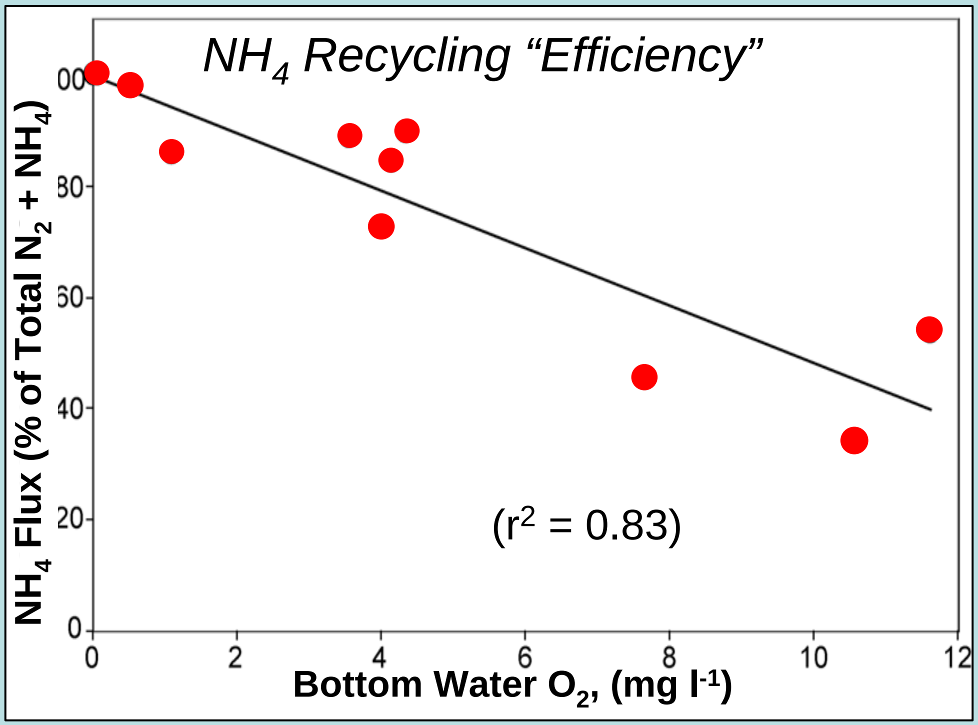
(J. Testa & M. Kemp 2009)

Decadal Change in July Distribution of [NH_4^+]



(Rebecca Murphy, JHU. unpublished)

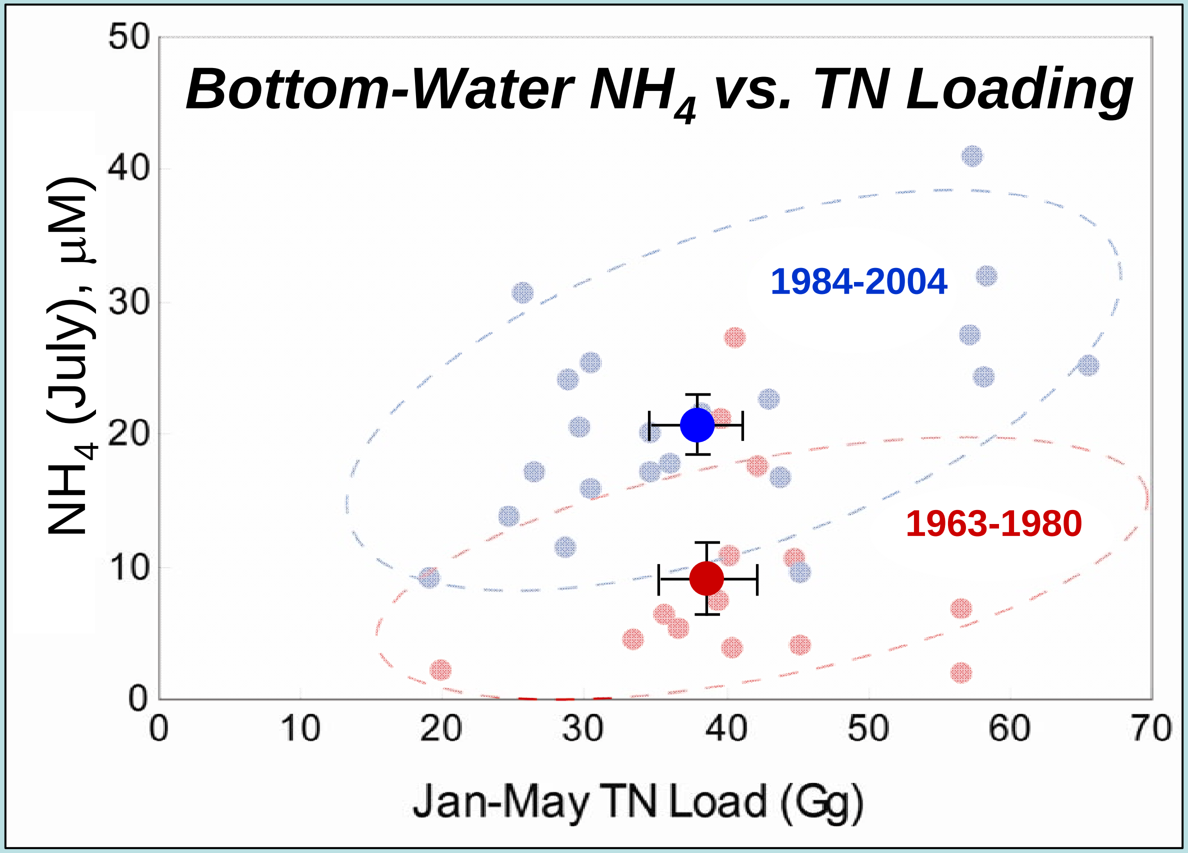
Hypoxia Enhancement of Benthic Nutrient (NH_4^+) Recycling Efficiency



- **DIN 'Recycling Efficiency' (NRE) is flux ratio (DIN/(DIN + N_2)**
- **NRE increases w/ decreasing O_2 because of nitrification inhibition**
- **Thus, DIN recycling higher under hypoxic conditions.**

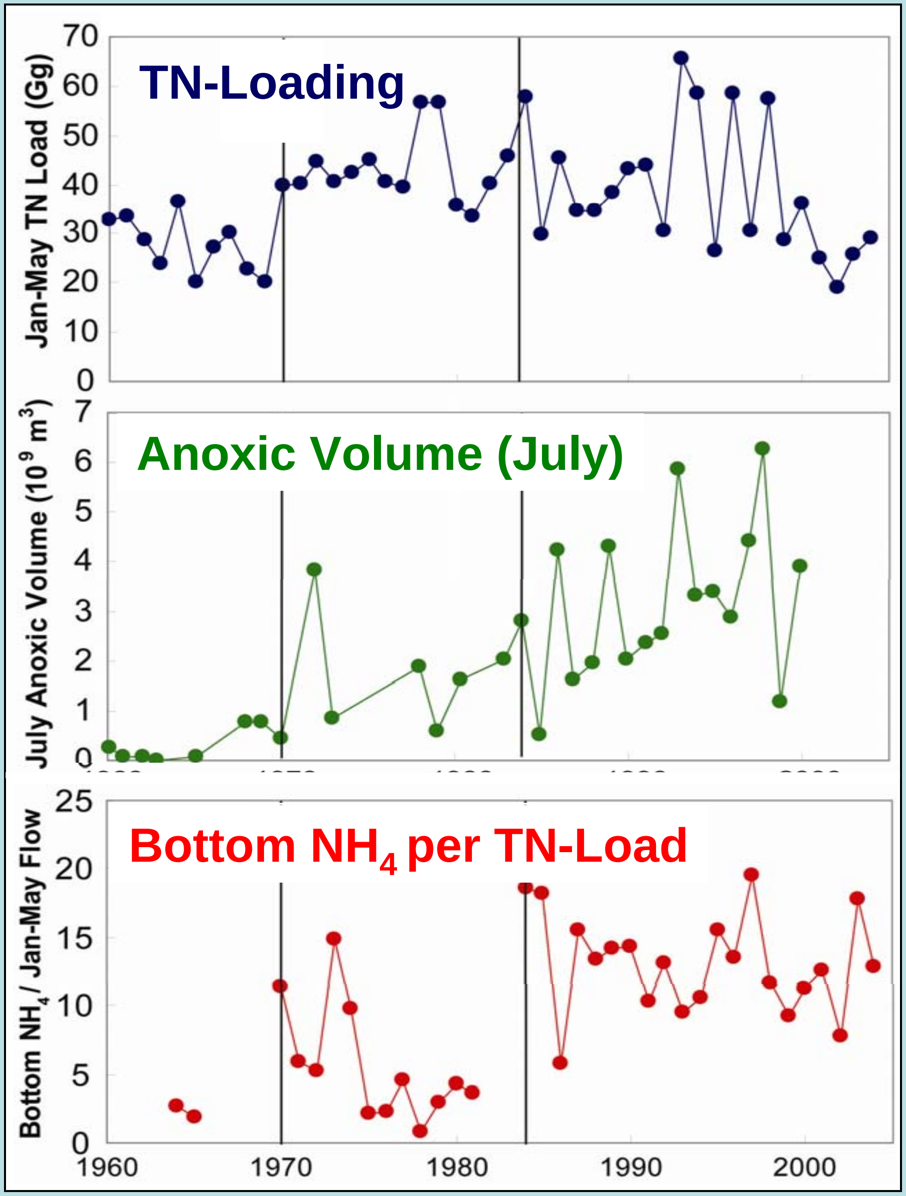
(J. Cornwell data from Kemp et al. MEPS. 2005)

Significant Shift in Bottom Water NH_4 Pools Since Early 1980s



- Bottom-water NH_4 pools generally increase with TN loading.
- In early 1980s the size of the bottom NH_4 pools increased (>2x) abruptly
- Biogeochemical change (hypoxia, macrofauna?)

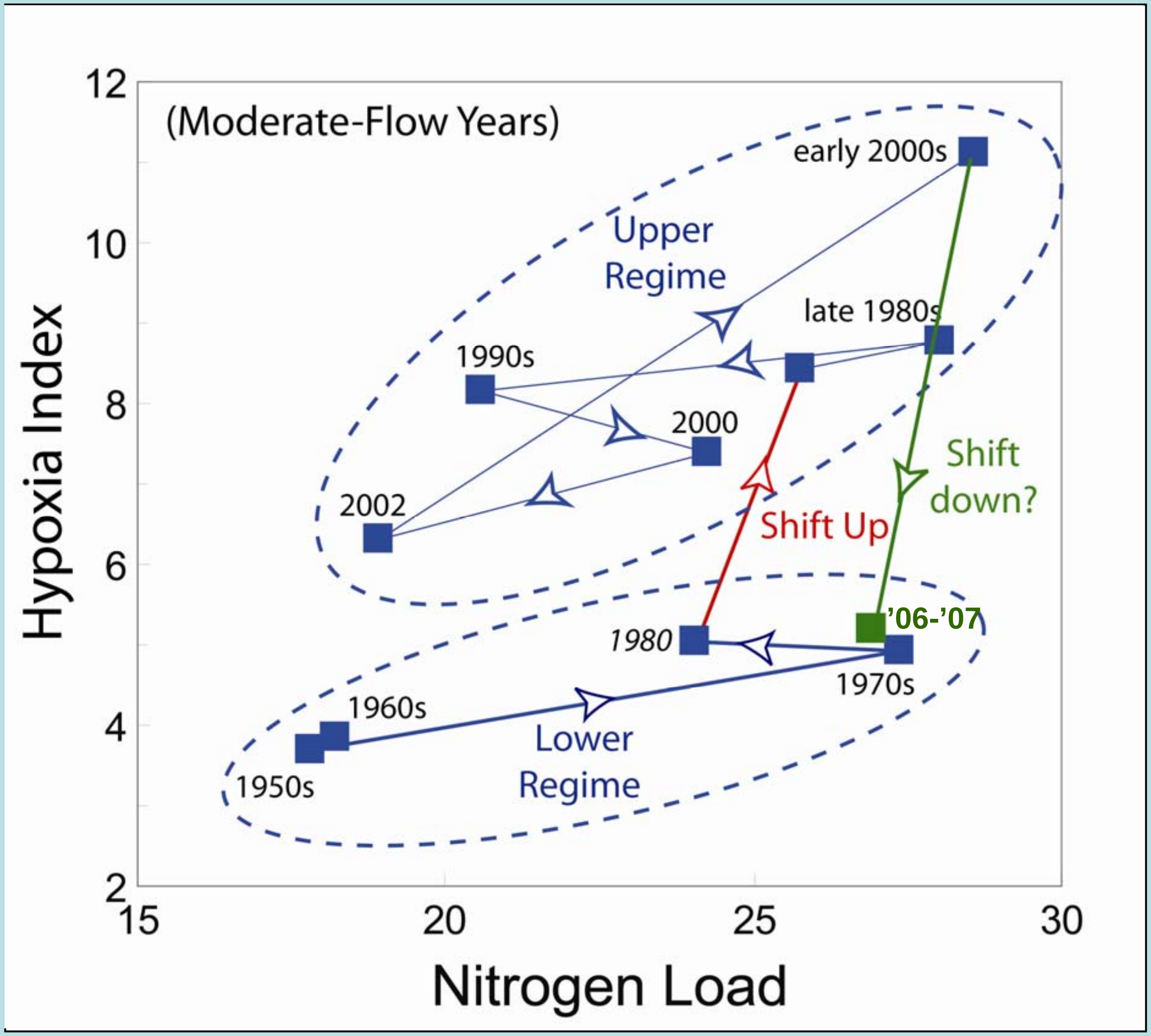
Changes in Bay's Bottom Water NH_4 with Nutrient Loading and Hypoxia



- **TN-loading increases until mid-1980s, then fluctuates & declines**
- **Anoxia volume fluctuates, but increases steadily into 2000s.**

•Bottom-water NH_4 pool per N-load fluctuations & jumps up in 1980s

Hypoxia Response to Changes in N-Load



Concluding Comments

- Coastal Hypoxia is Global Problem Associated with Eutrophication
- Chesapeake Bay may be Particularly Susceptible to Hypoxia
- Chesapeake Hypoxia has Grown with Increasing Nutrient Loading; an abrupt Increase occurred in Hypoxia/N-load in early 1980s
- It appears that Hypoxia-Enhanced N-recycling has Contributed to this "Regime Shift" and/or the Recalcitrance for Restoration
- There may be Reason for "Cautious Optimism" for Hypoxia Recovery; possibly, a "Shift-Down" to Lower Regime with Less Hypoxia per N-Load