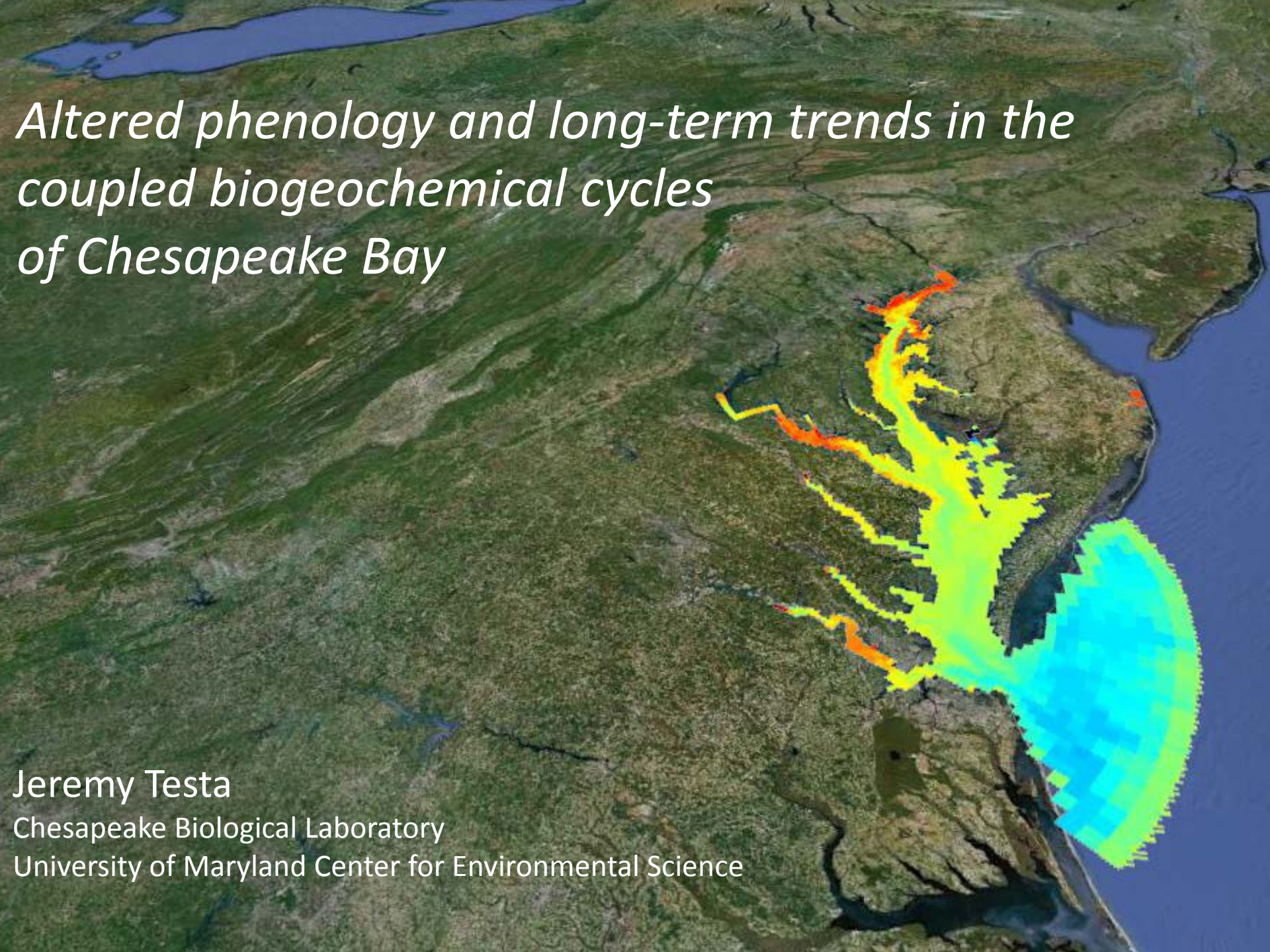


*Altered phenology and long-term trends in the
coupled biogeochemical cycles
of Chesapeake Bay*

Jeremy Testa
Chesapeake Biological Laboratory
University of Maryland Center for Environmental Science



Context:

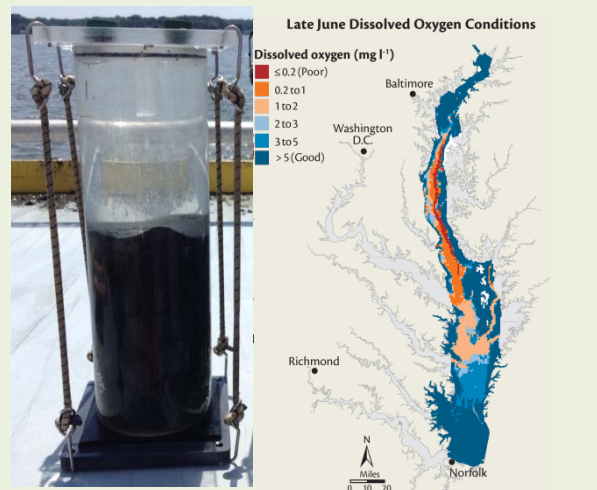
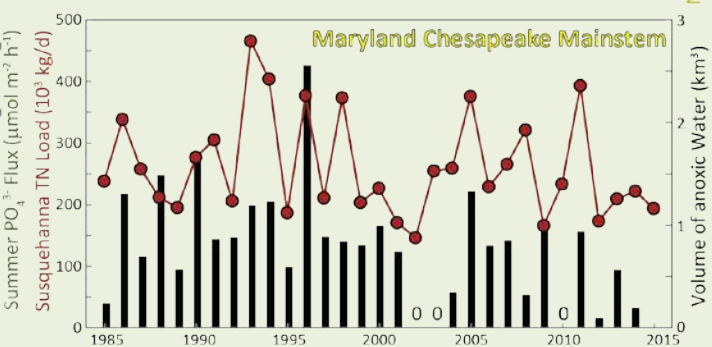
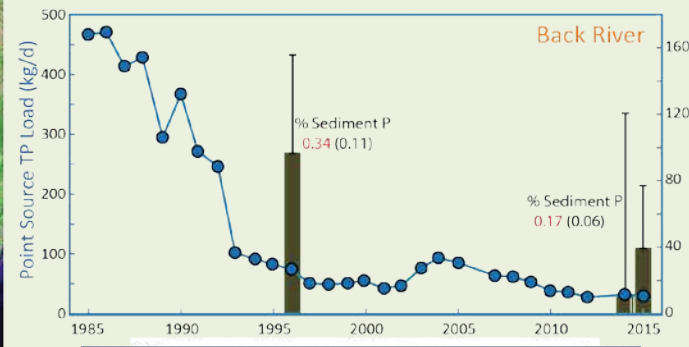
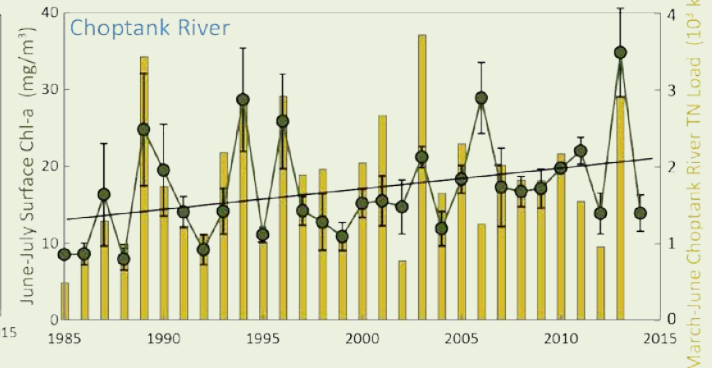
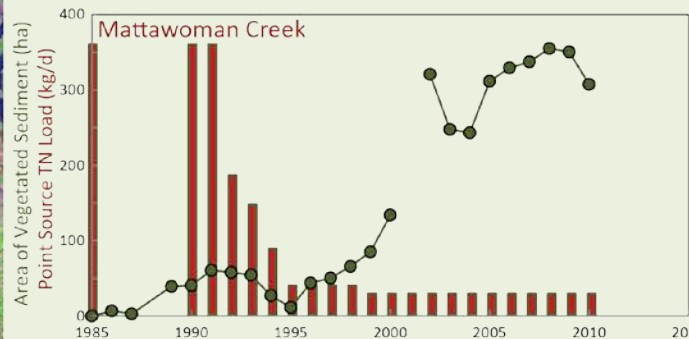
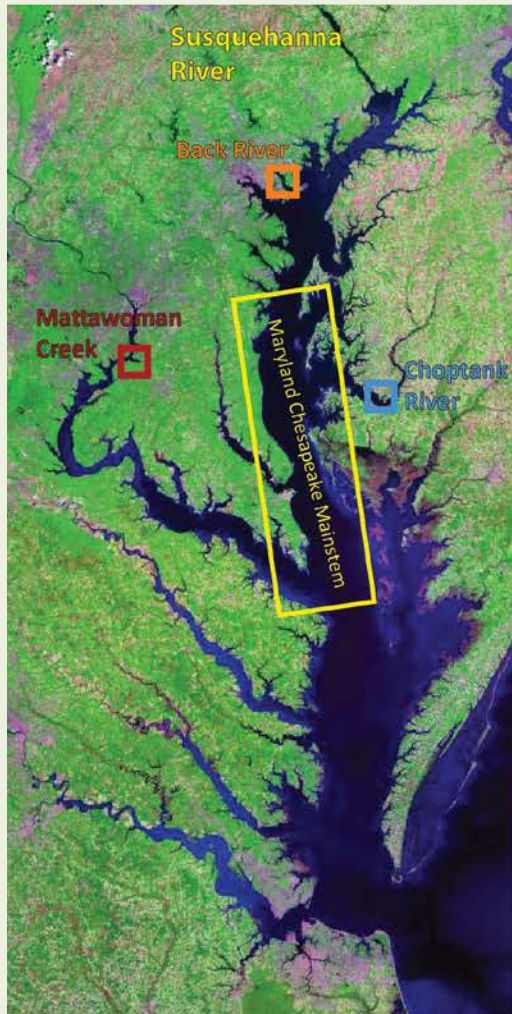
There are a variety of changes in water-quality that have occurred over the past 30 years in Chesapeake Bay

For the mainstem Bay, these changes are spatially-specific

Many of the analyses of changes in water quality have focused on annual-scale patterns

But many variables have regular seasonal variability, and changes in the seasonality of key variables will help explain long-term change in Chesapeake Bay

A Variety of Changes in a Variety of Places

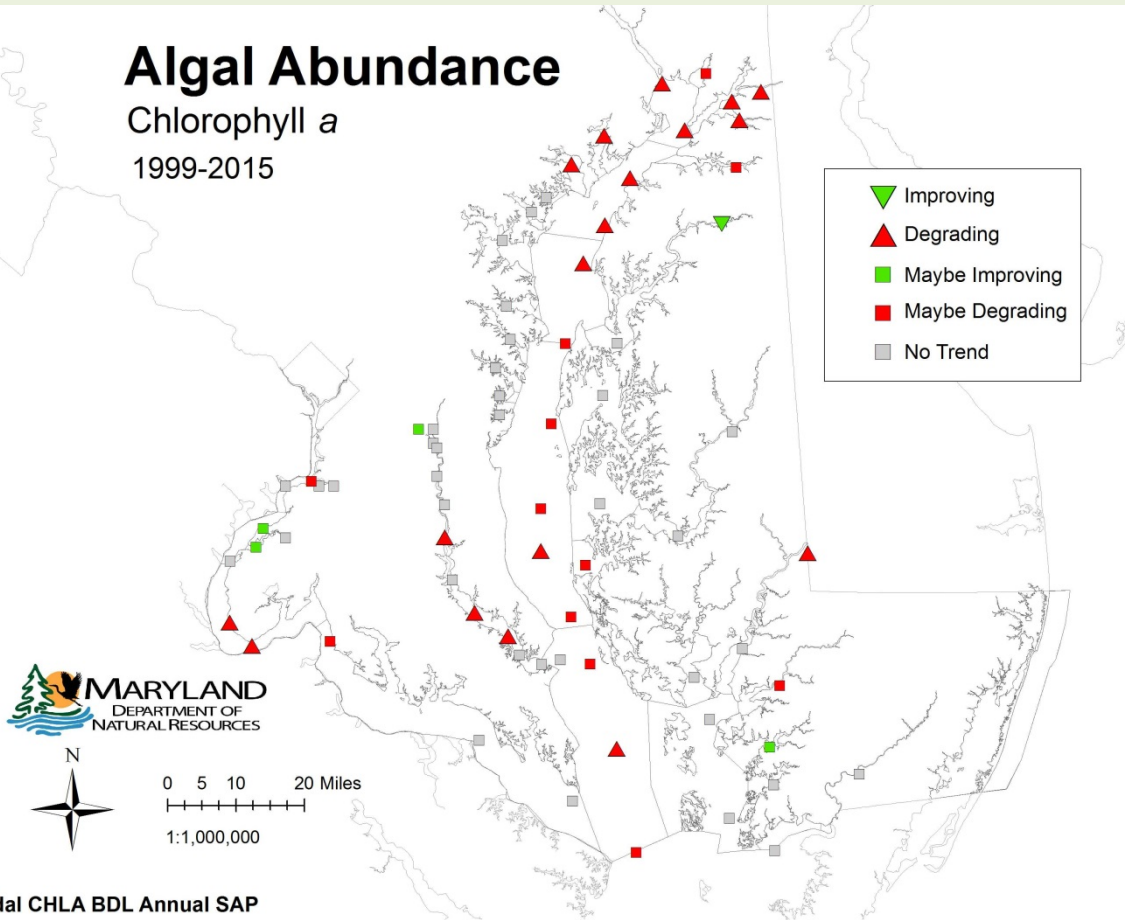


Source: Boynton et al. (2014)
 Testa, Boynton, in prep
 Fisher et al. (2006)
 Testa et al., in prep

Spatial Patterns in Trends Capture Annual Patterns

Algal Abundance

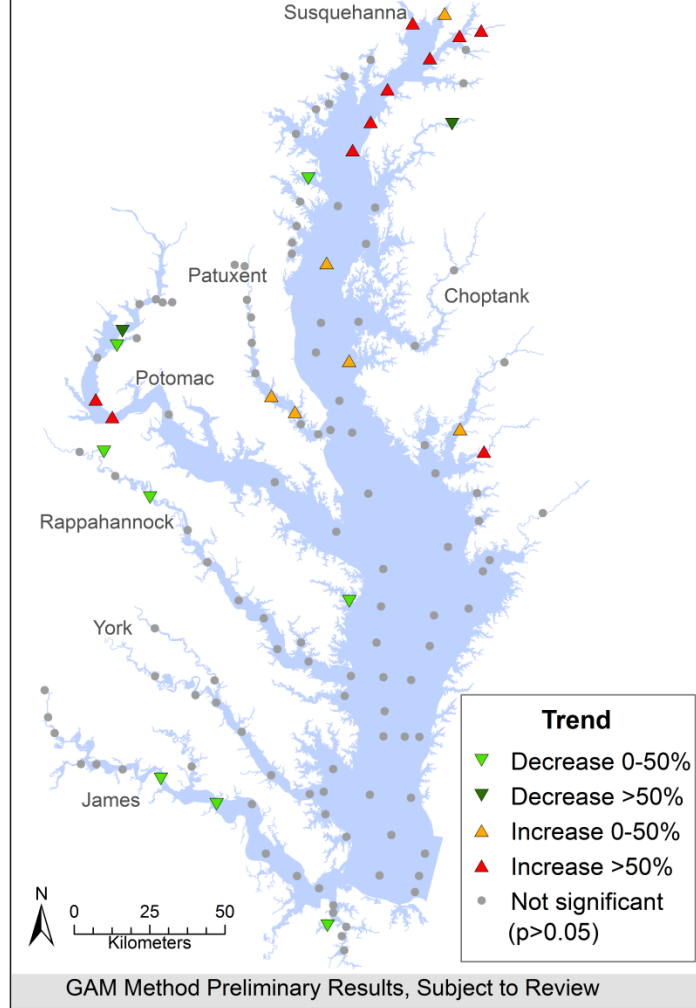
Chlorophyll *a*
1999-2015



Tidal CHLA BDL Annual SAP

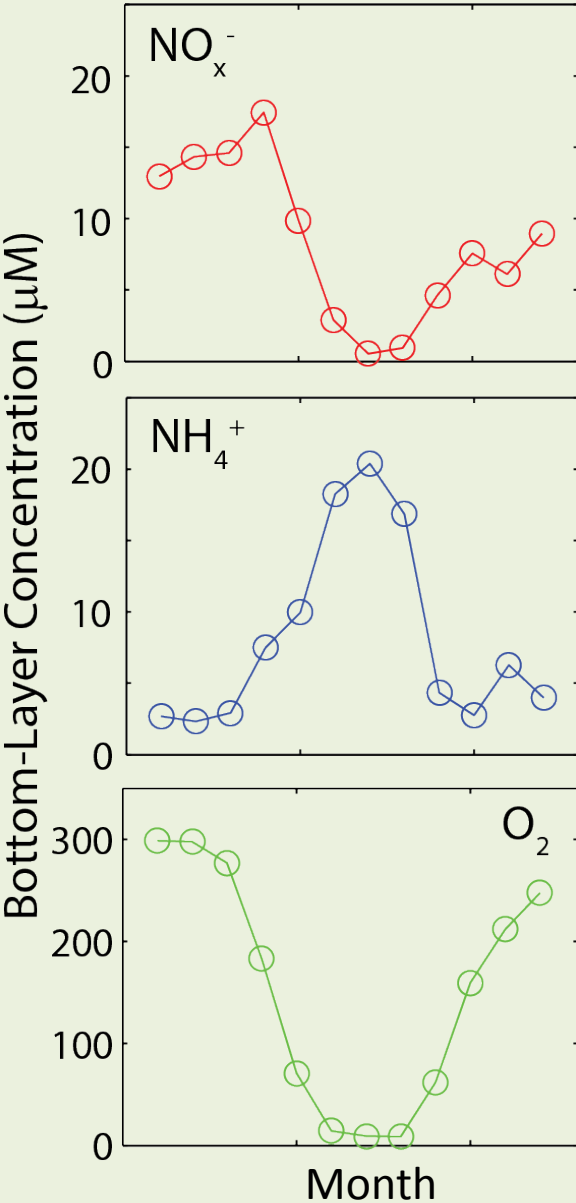
Compiled by Renee Karhhr, MDDNR

Trends for Surface Chlorophyll-*a* in the Chesapeake Bay: 1999-2015

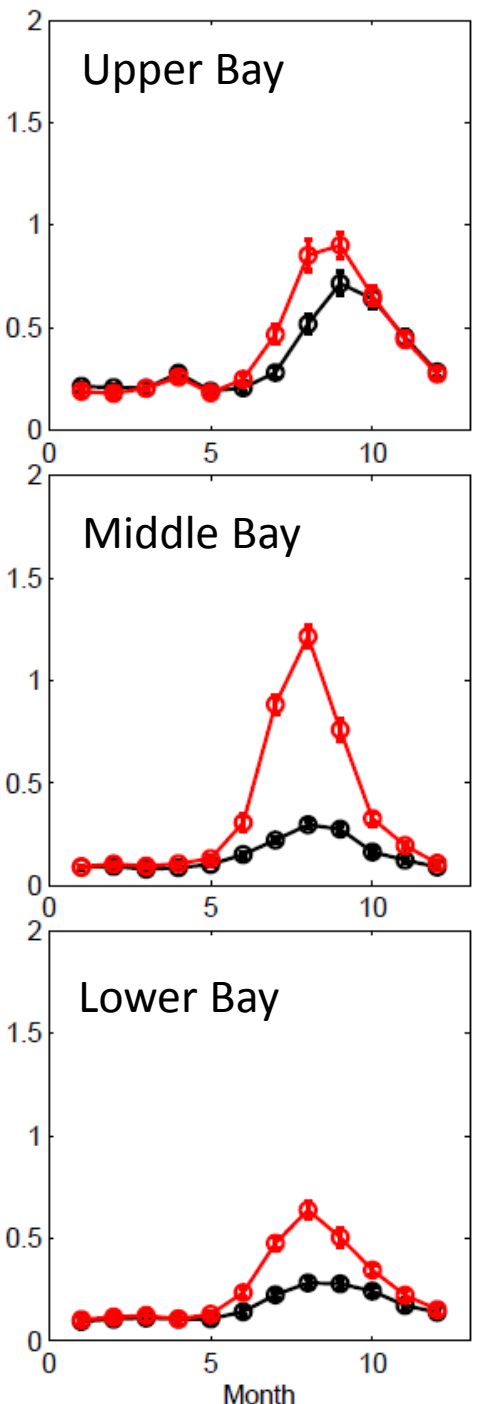


compiled by R Murphy (UMCES/CBPO)
with results from MDDNR and VADEQ

Many Variables Have Dependable Seasonal Cycles



PO₄³⁻ Solute Concentration (μM)



phe·nol·o·gy

fi' näləjē/

Noun

the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life.

(from Google)

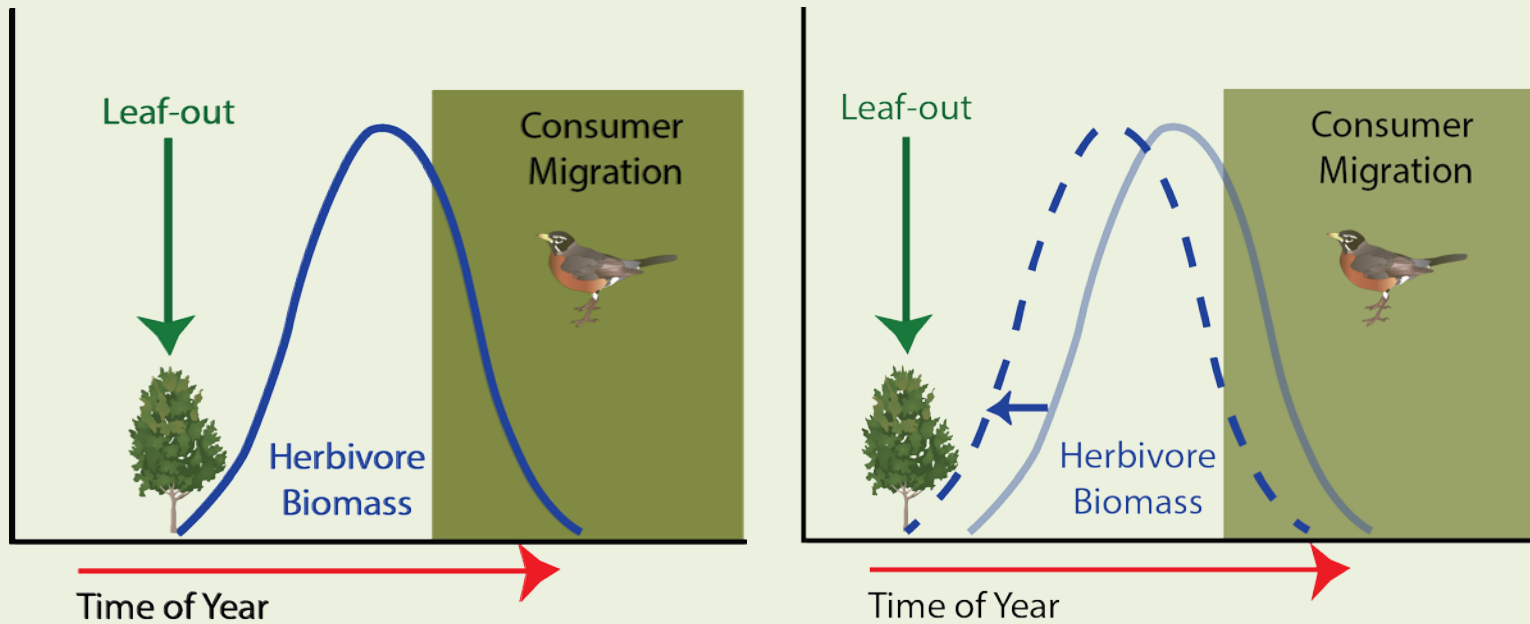
Phenology refers to key seasonal changes in plants and animals from year to year – such as flowering, emergence of insects and migration of birds – especially their timing and relationship with weather and climate.

[USA National Phenology Network](#)

Phenology in Terrestrial Ecosystems

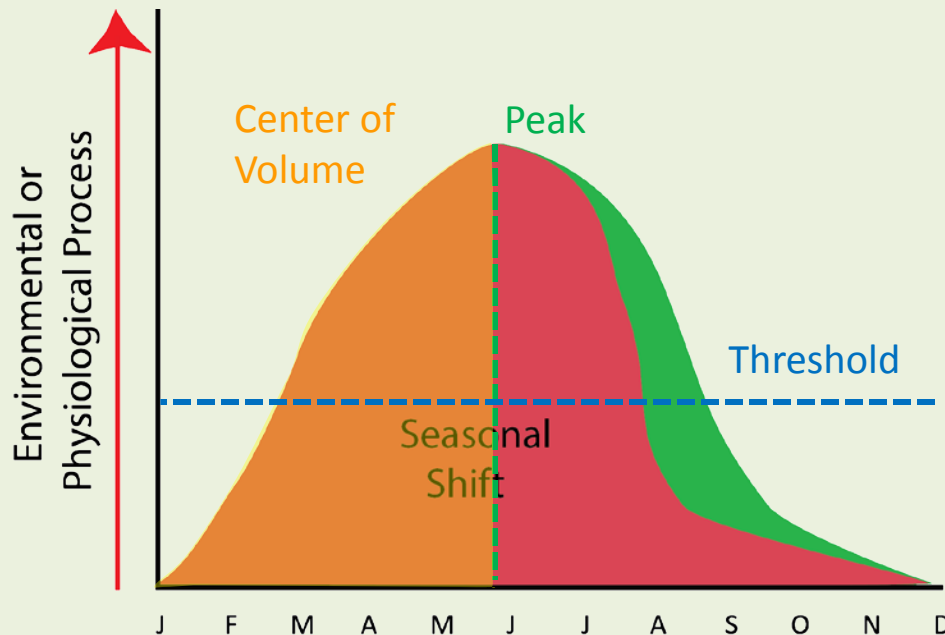
Phenology a well-established concept in terrestrial ecology describing natural cycles related to annual solar cycle (light, temperature) and potential responses to climate change

Inherent in the phenology concept is the linked timing of primary producers and consumer migrations and/or reproduction

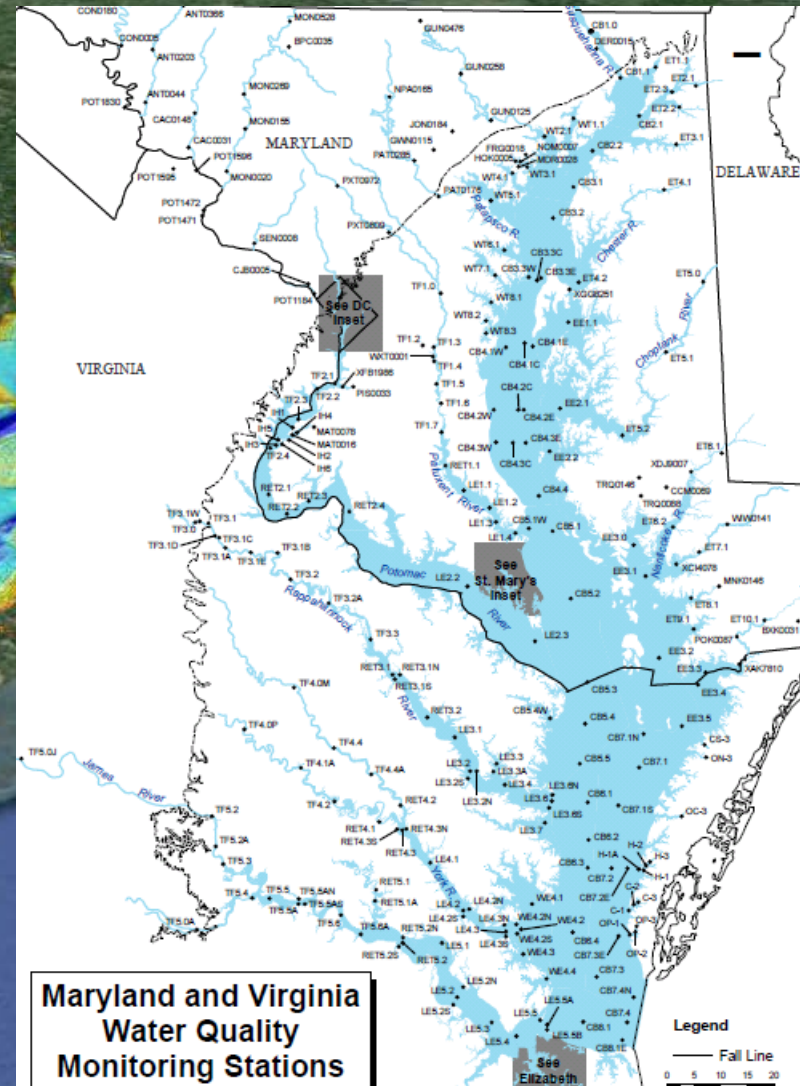
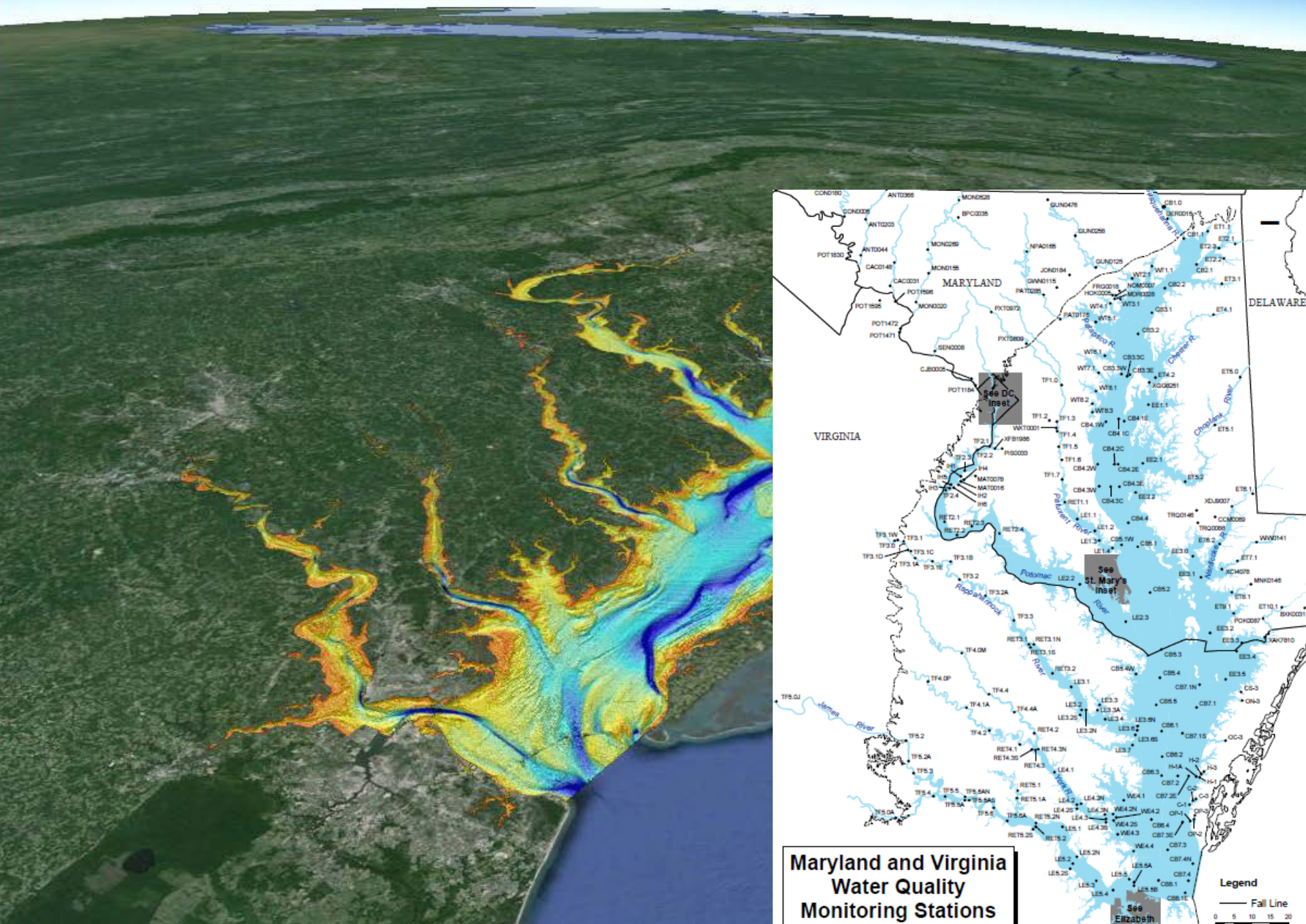


Challenges to Understanding Phenology in Coastal Ecosystems

- (1) Estuaries are highly dynamic systems
 - freshwater input can be the dominant driver *seasonally* and *inter-annually*
- (2) Phenological changes occurring in watersheds will be transferred to estuary
 - timing of watershed hydrology drives timing of estuarine response
- (3) Time scales of turnover for small organisms (e.g., phytoplankton) too short?
 - only larger animals accumulate long periods of climatological change
- (4) Spatial variability/gradients in seasonal timing

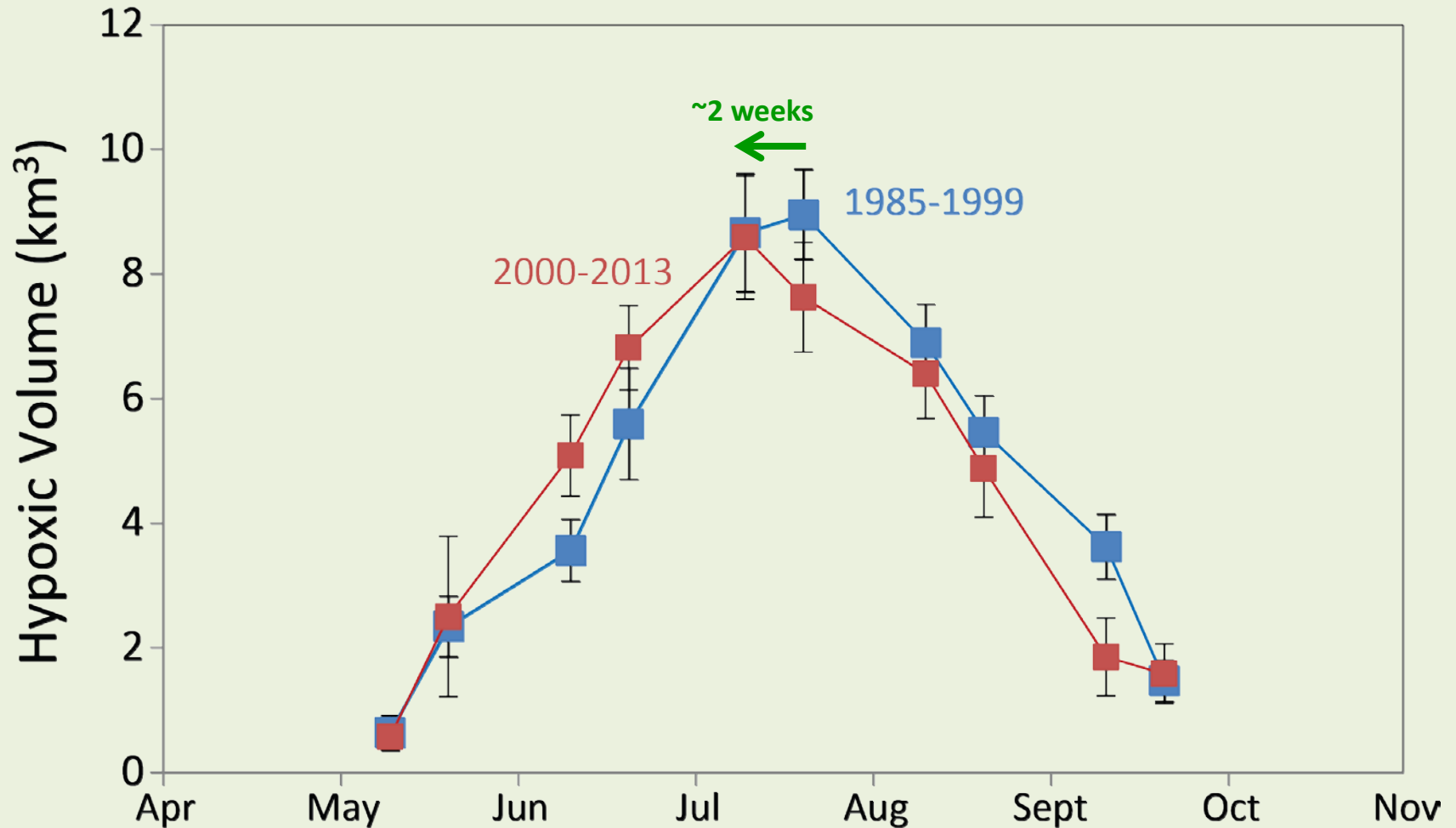


Chesapeake Bay as an Experimental Ecosystem



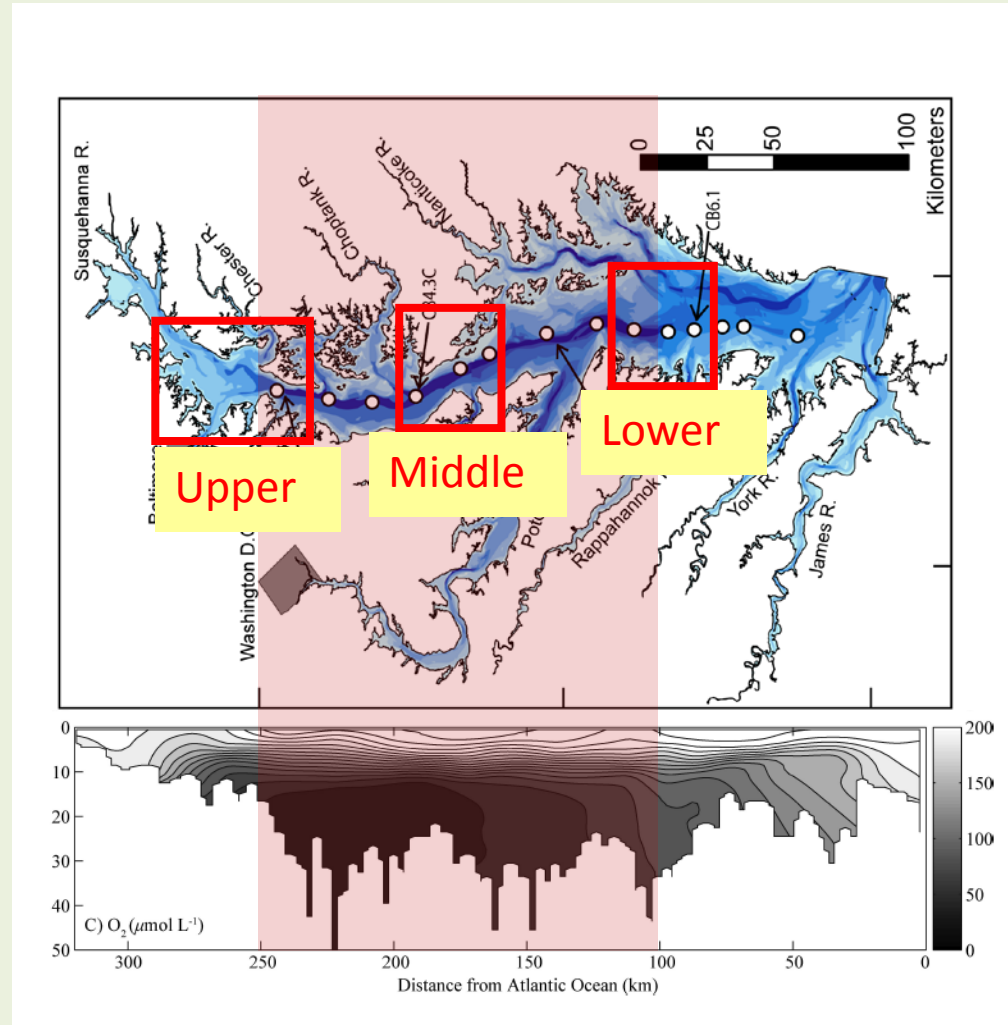
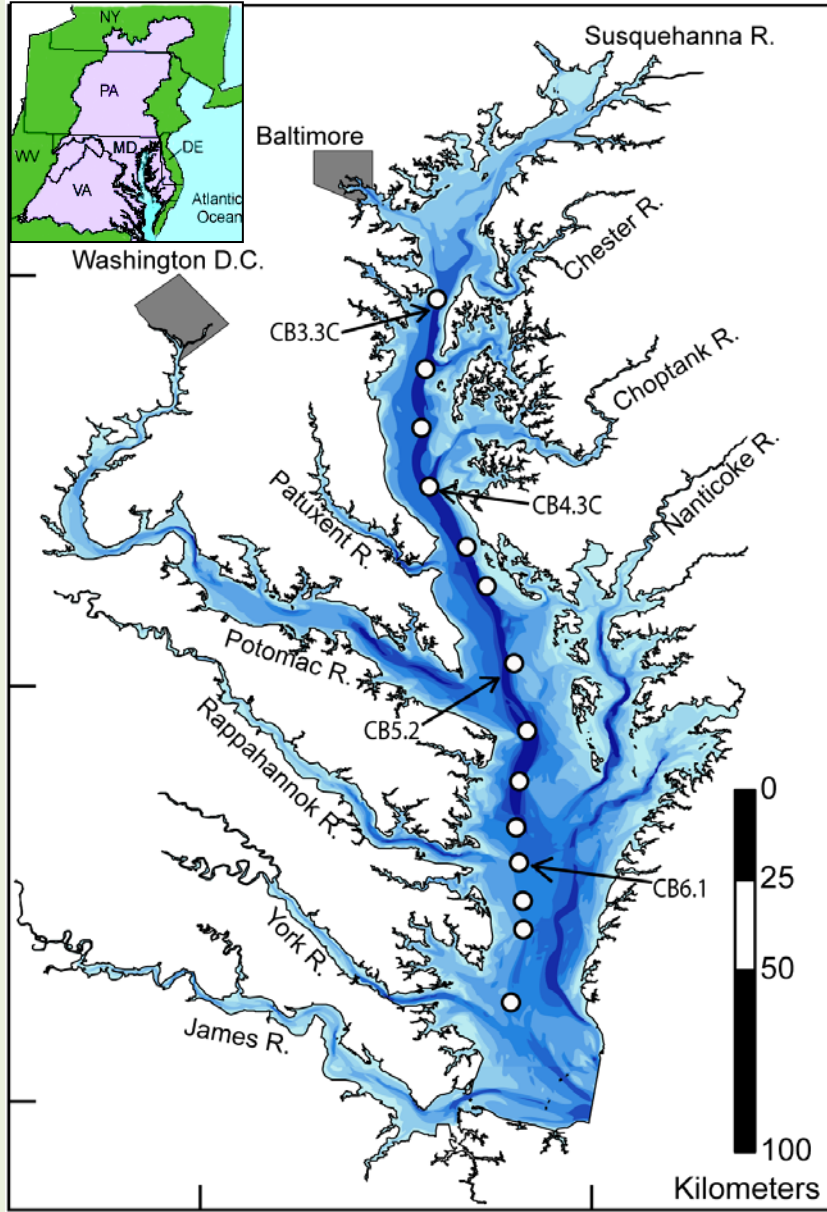
Maryland and Virginia
Water Quality
Monitoring Stations

Shifted Seasonality in Hypoxic Volume

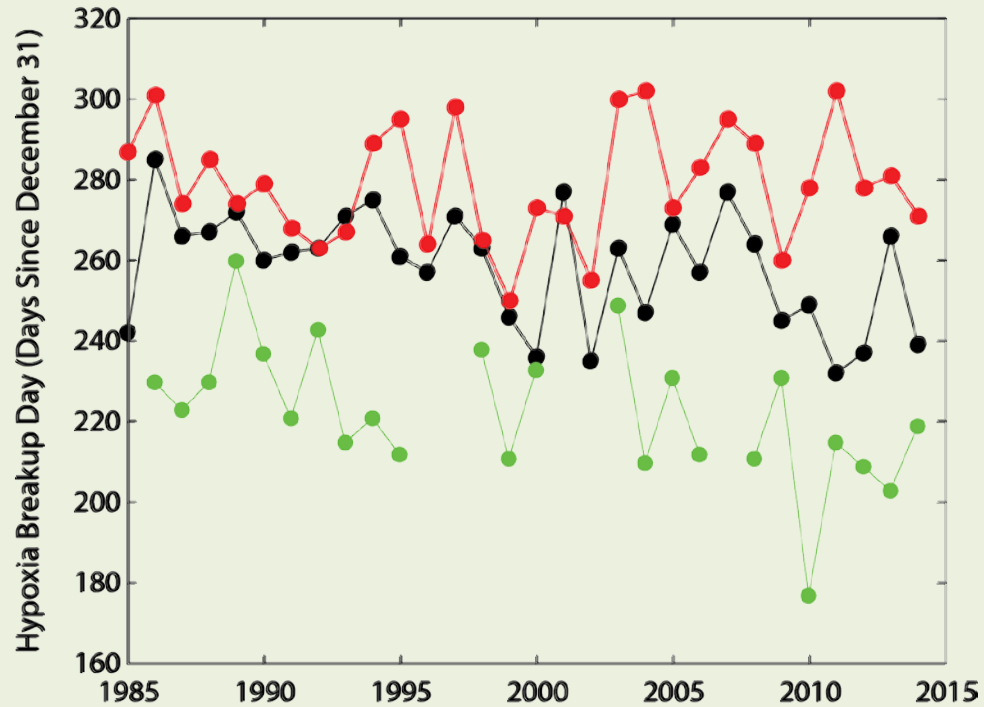
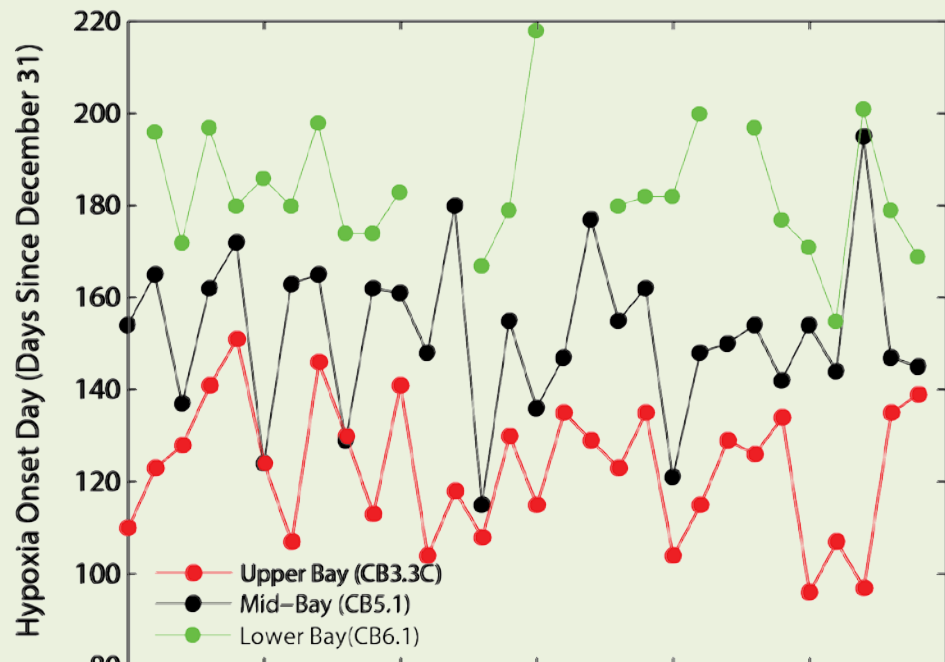
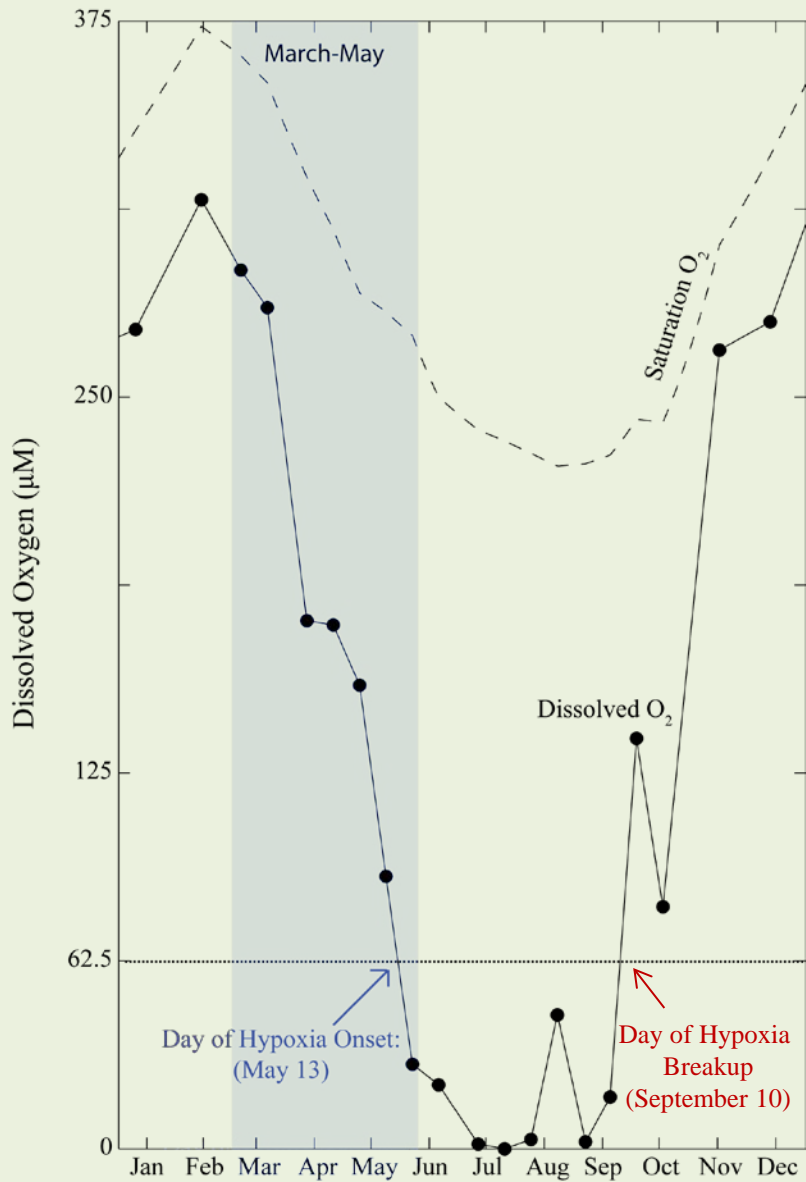


- **Inter**-annual variability realized via **intra**-annual shift in timing (phenology)
- What is driving this intra-annual change in hypoxic volume?

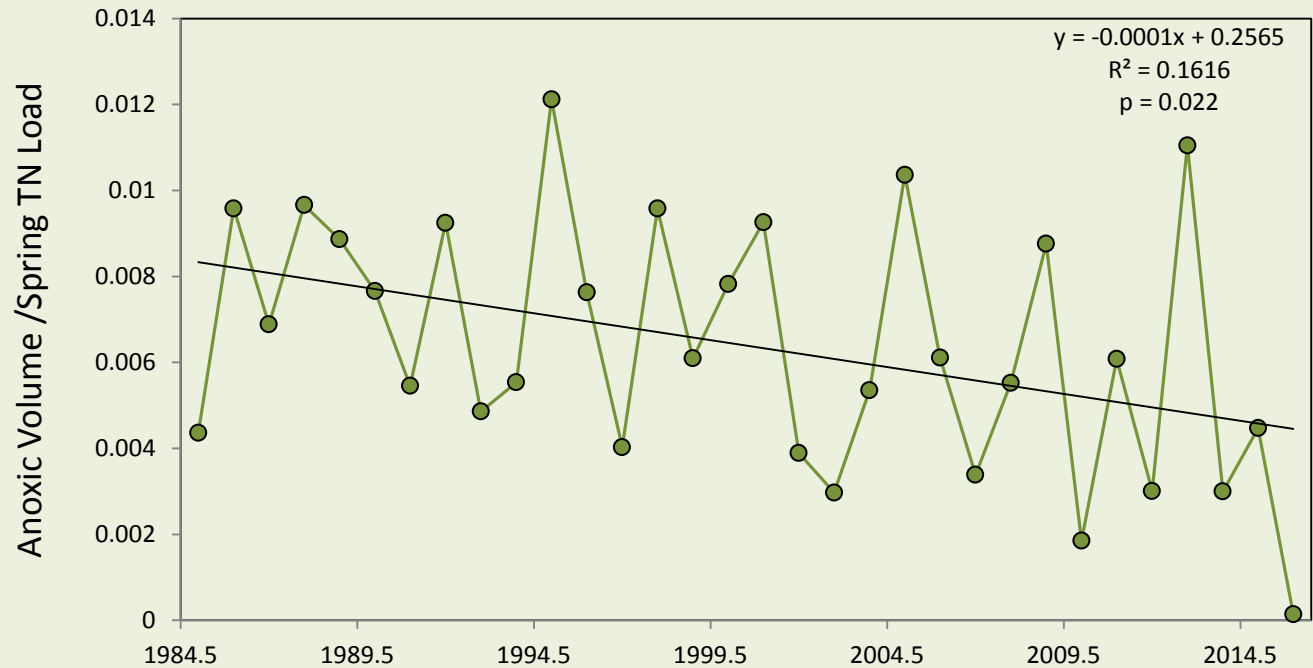
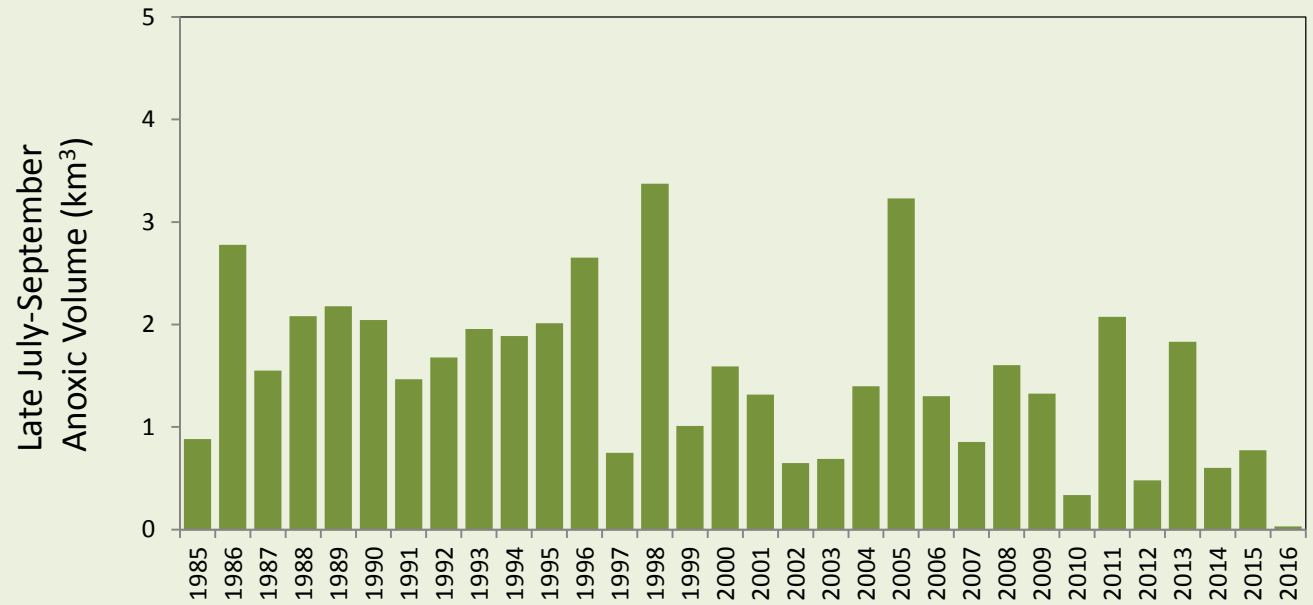
Chesapeake Bay Regions



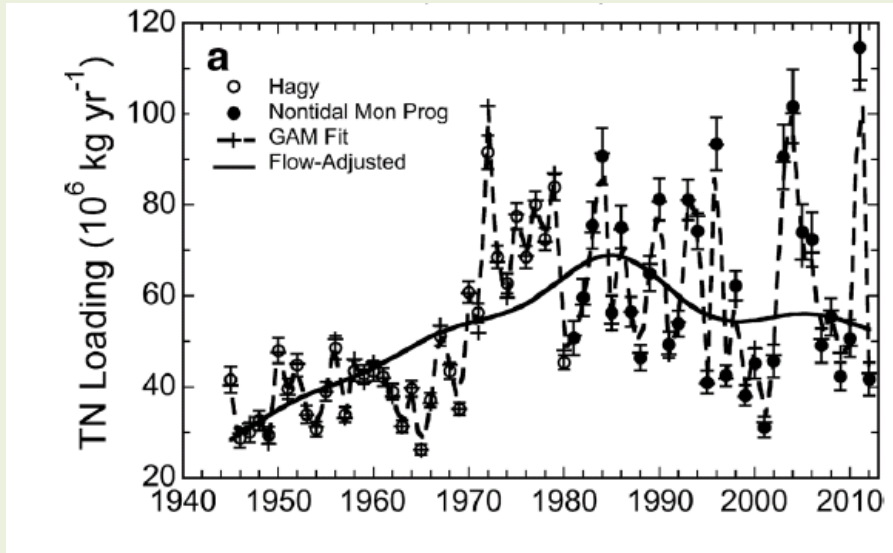
Hypoxia Timing



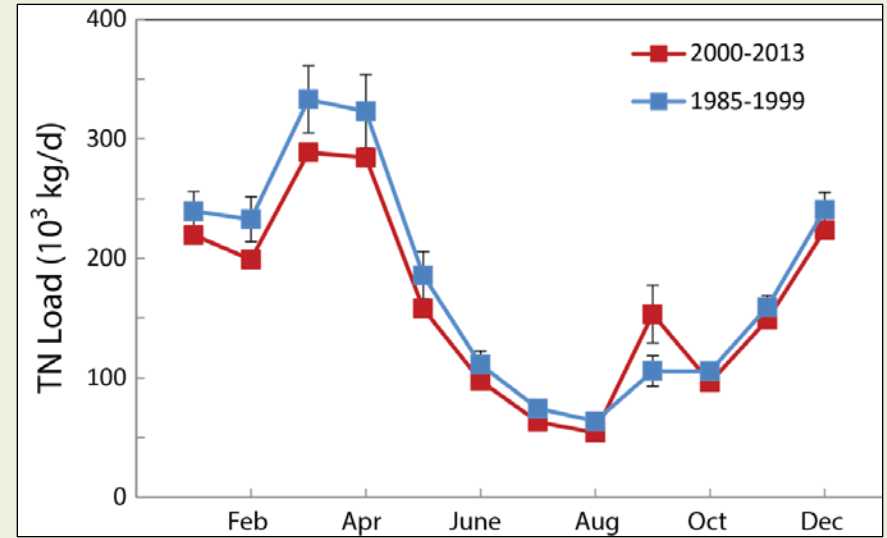
Late Summer Anoxia in Decline



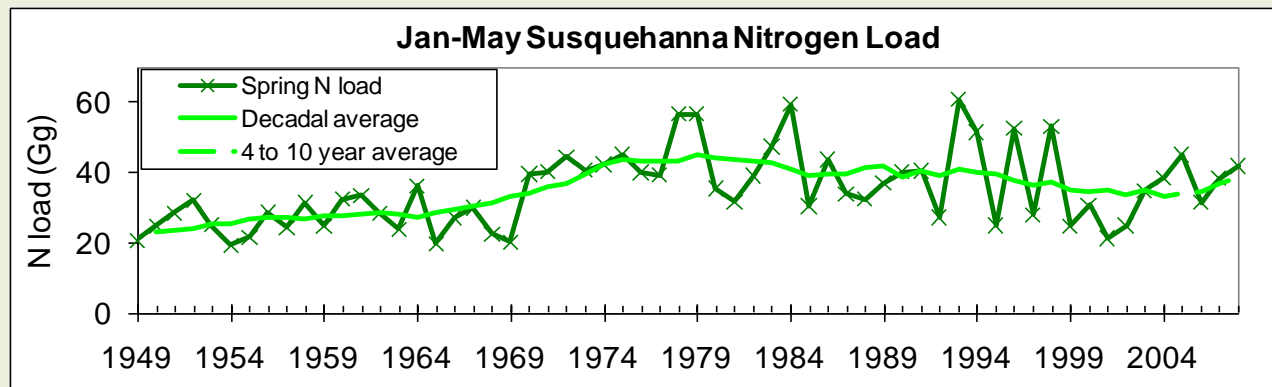
Modest Declines in Susquehanna N Load



Annual Loads - Harding et al. (2015)

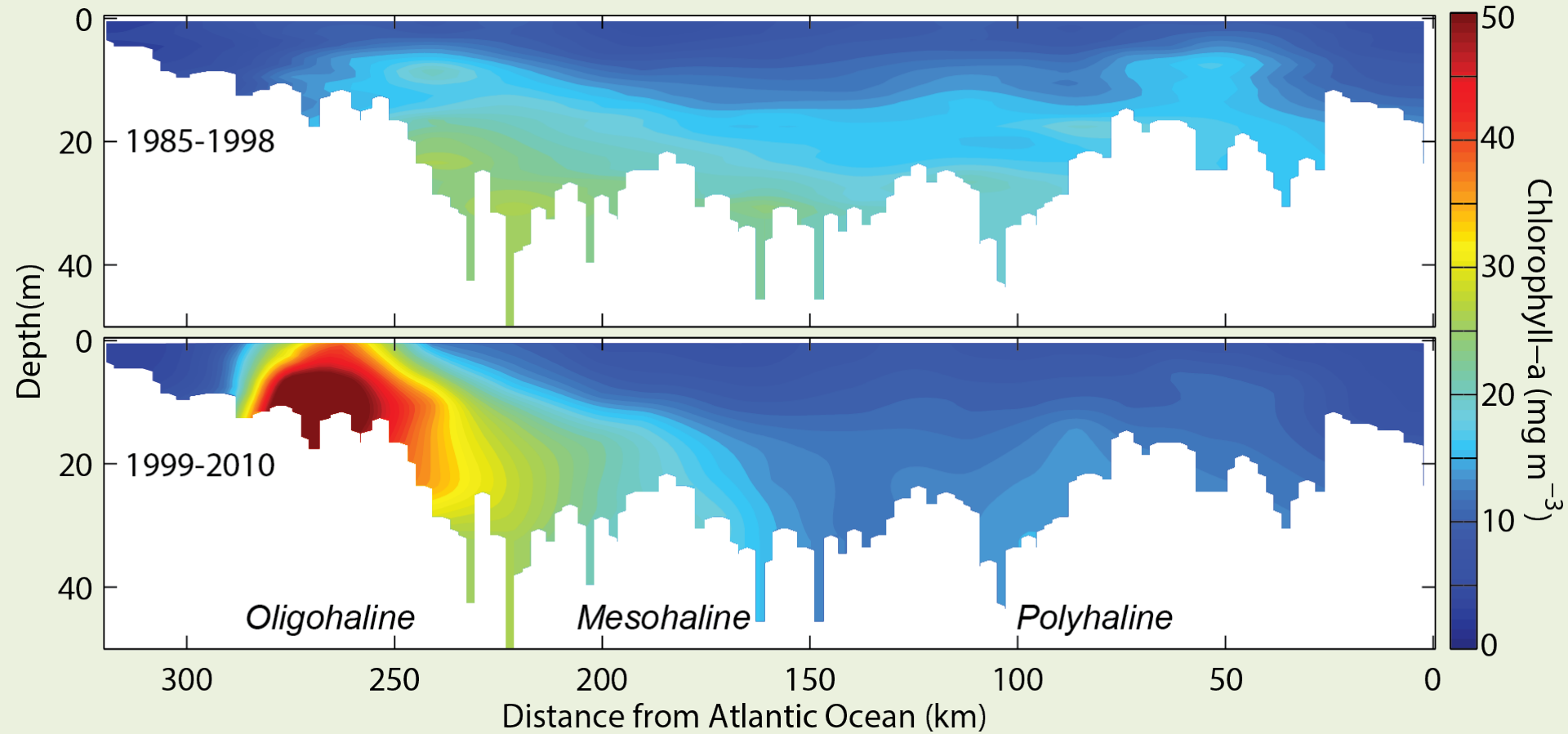


Testa (unpublished) using USGS data

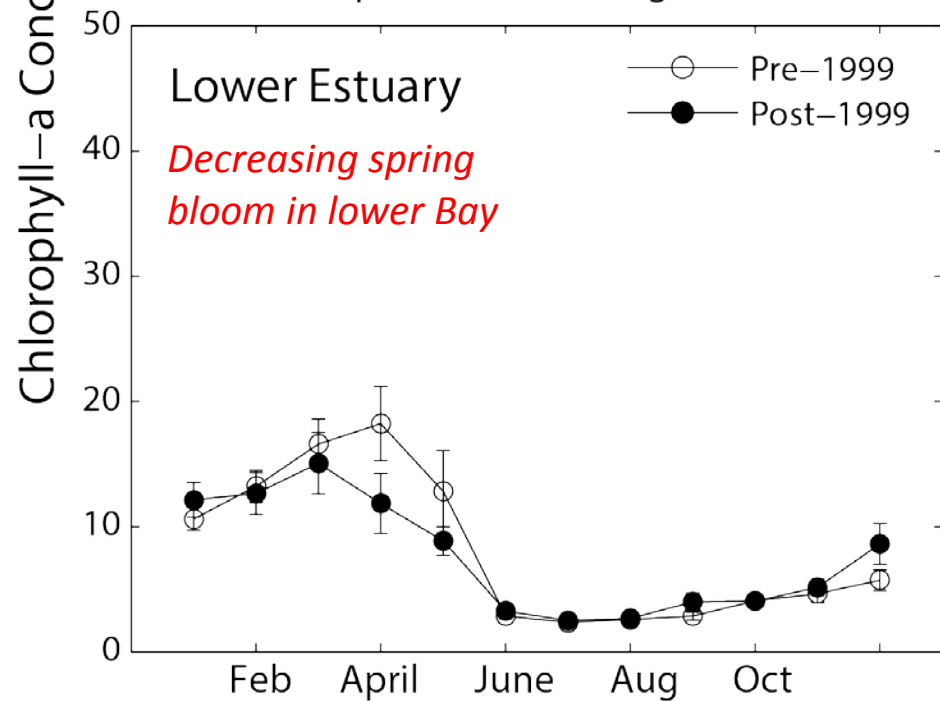
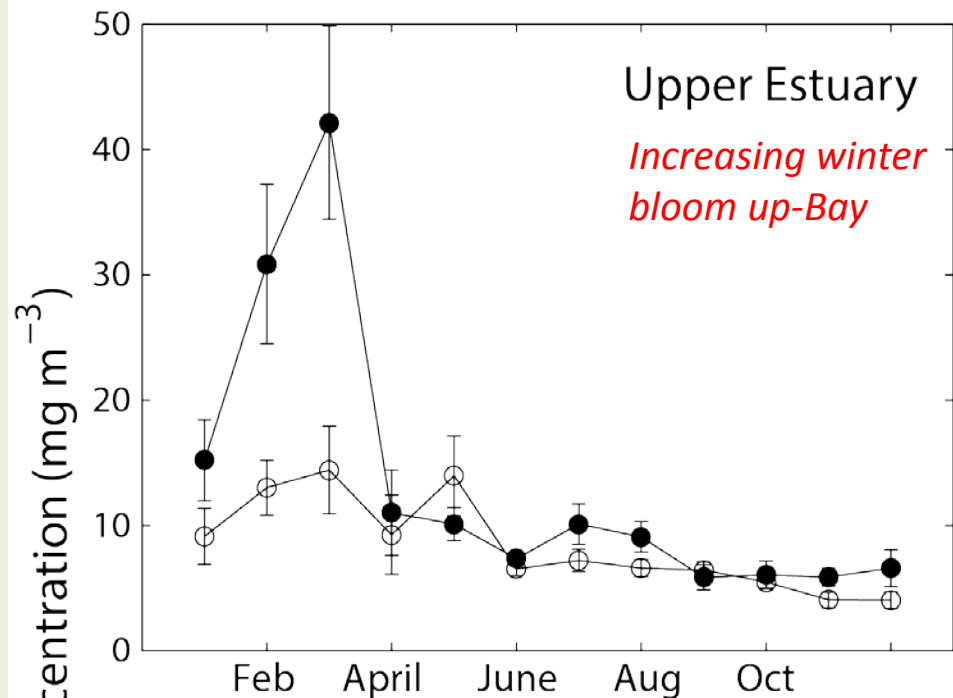
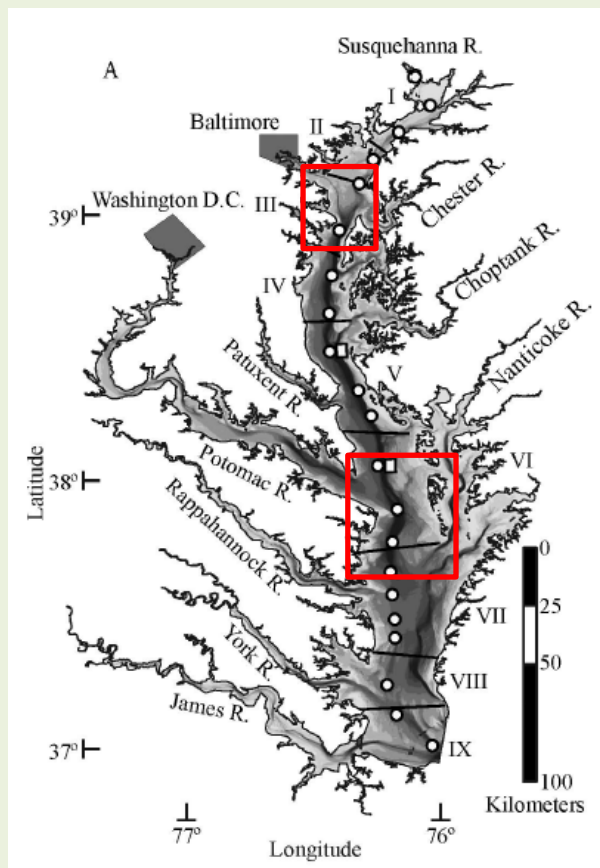


Murphy et al. (2011)

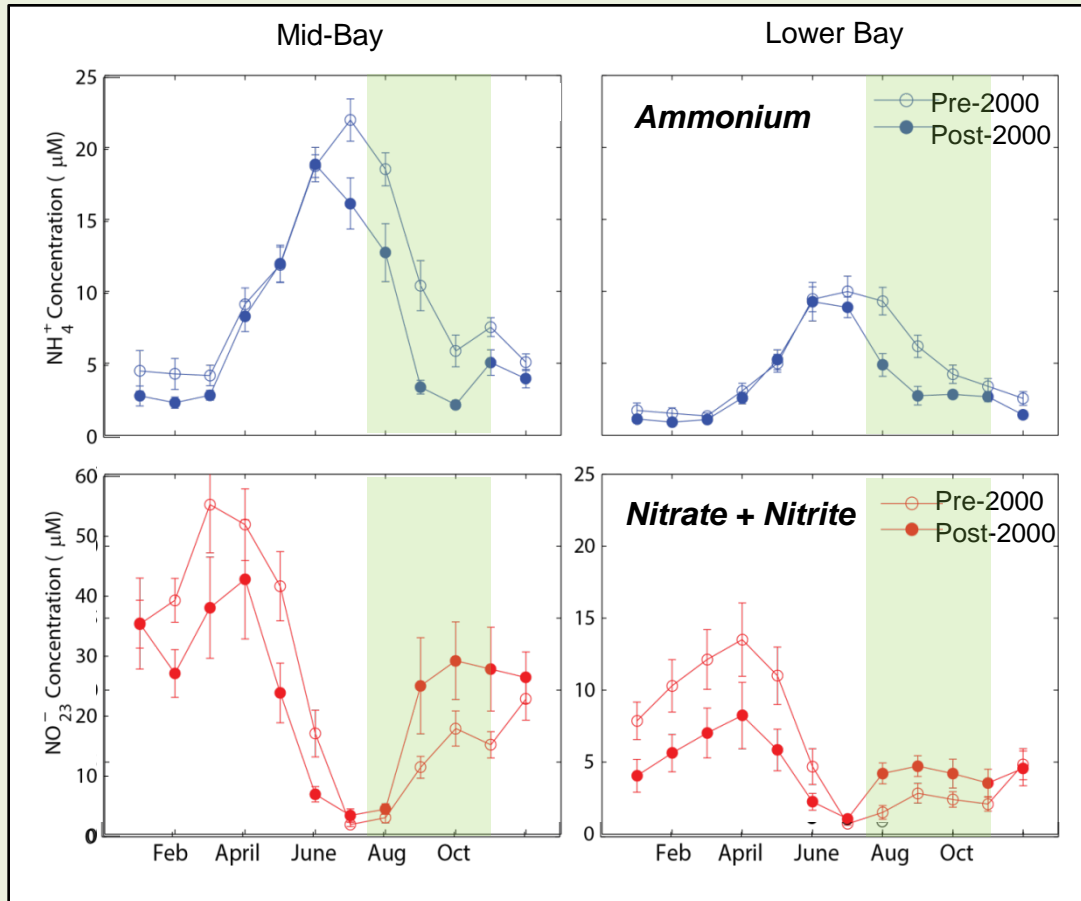
Winter Blooms in Upper Bay Increasing



Opposing Shifts in Seasonality of Chl-a In the Upper Bay vs Lower Bay

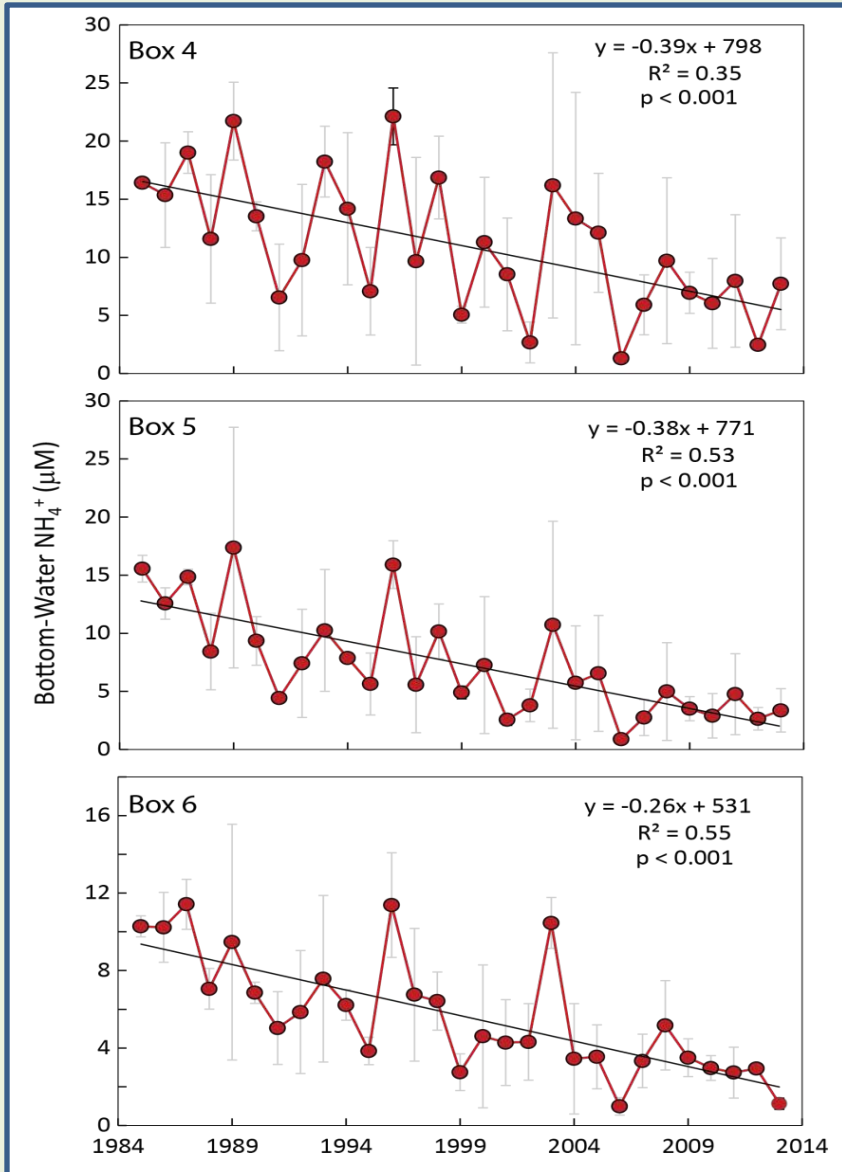


Associated Alterations of Seasonal Cycles of NH_4 & NO_3



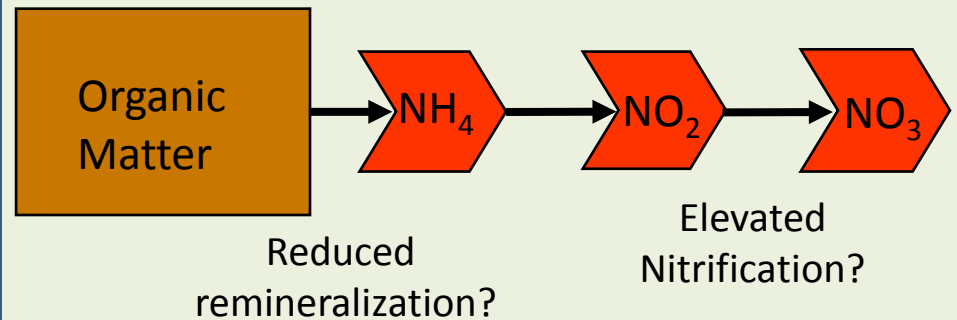
- NH_4 levels lower in recent 15 yr compared to previous 15 yr
- NH_4 differences are greater in late summer to early fall
- NO_3 values are lower in winter-spring and higher in summer-fall
- NO_3 differences are greater in upper Bay end of hypoxic region
- Long-term trends reveal that 50% of NH_4 decline could be explained by NO_3 increase

Long-Term Bay Trends for Lower-Layer NH_4 in Late Summer

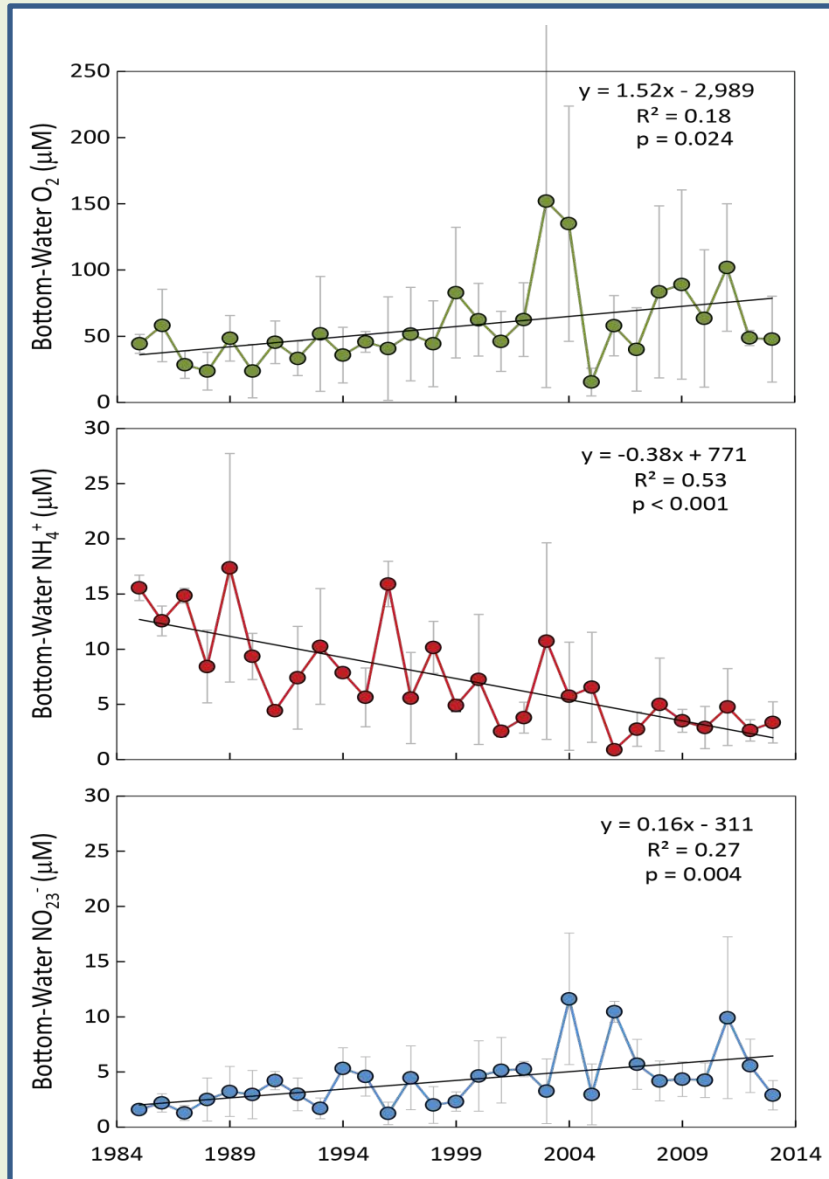


- Significant trends over 3 decades
- NH_4 late-summer mean values
- NH_4 is main nitrogen metabolite of organic decomposition
- Bottom-layer pools in hypoxic region of Bay

*What drives this NH_4 trend?
Why has nobody noticed it?*

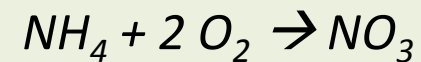


Long-Term Bay Trends for O_2 , NH_4 , & NO_3 in Late Summer

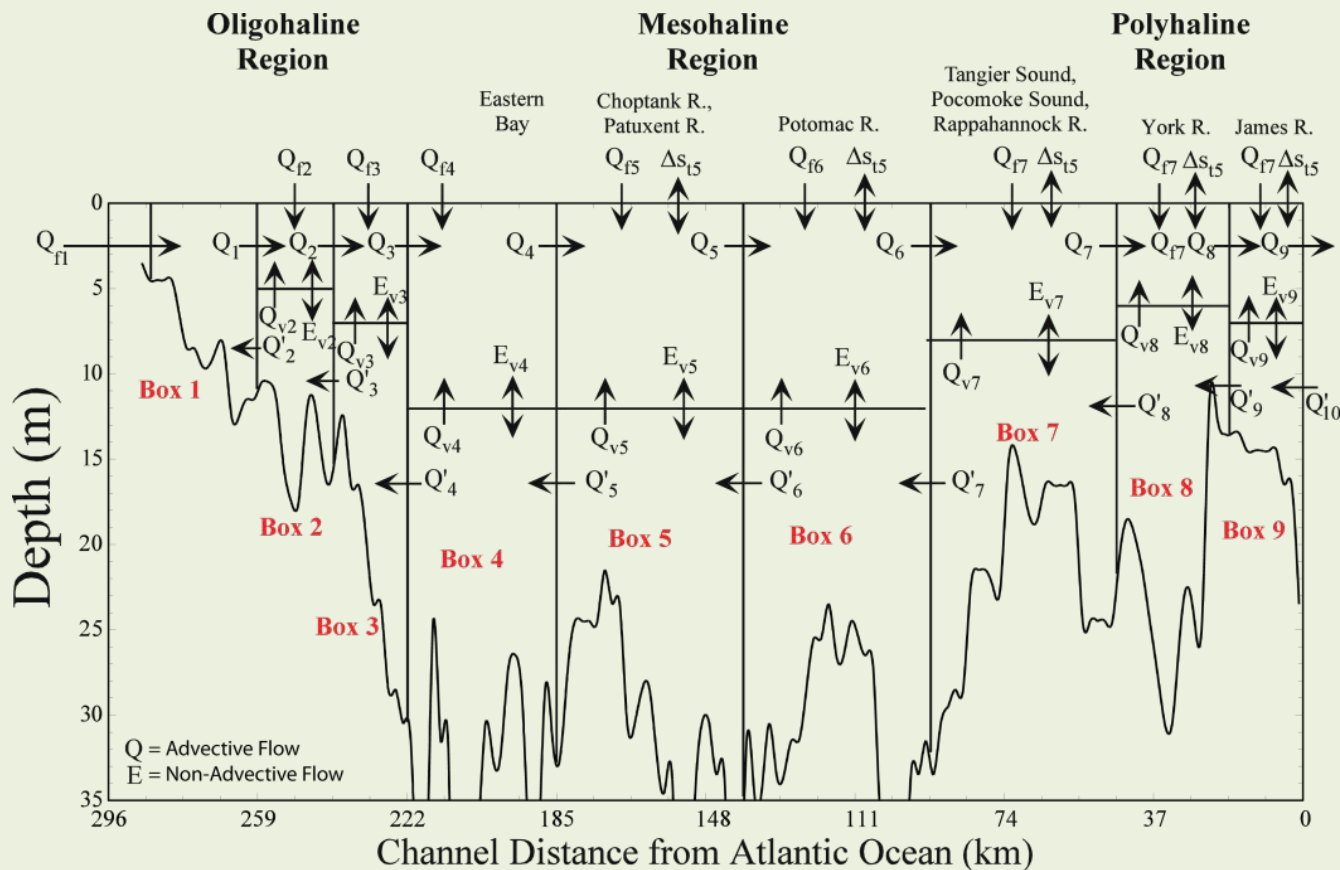


- Significant trends over 3 decades
- Late-summer mean values
- Increasing **dissolved oxygen**
- Decreasing **ammonium**
- Increasing **nitrate**
- Hypoxic region of Bay

Is nitrification involved in trends?

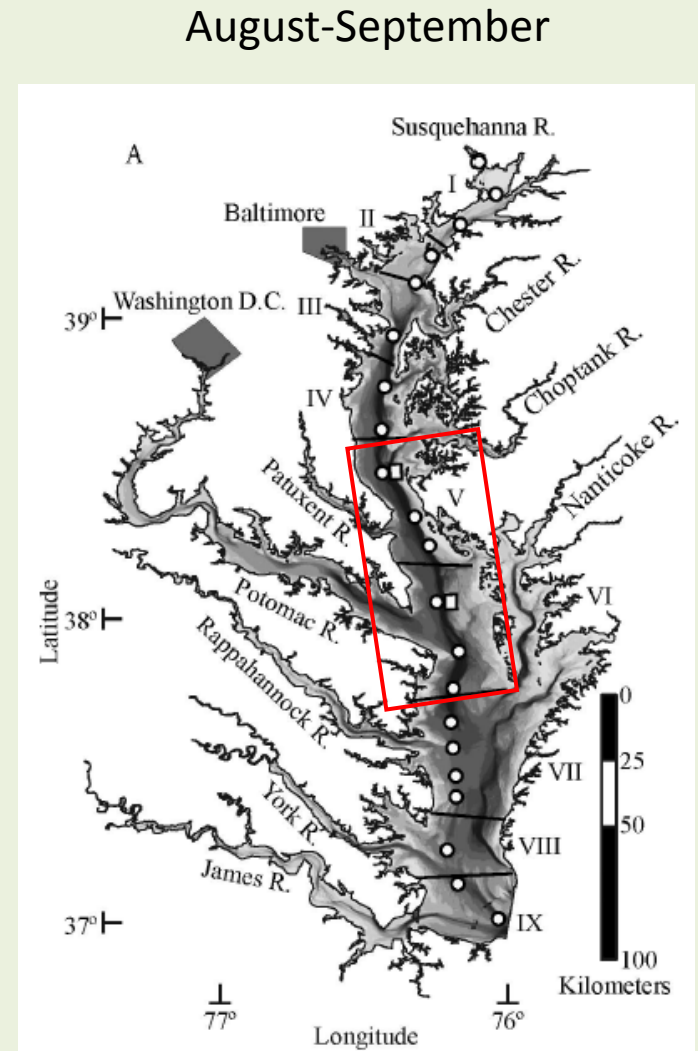
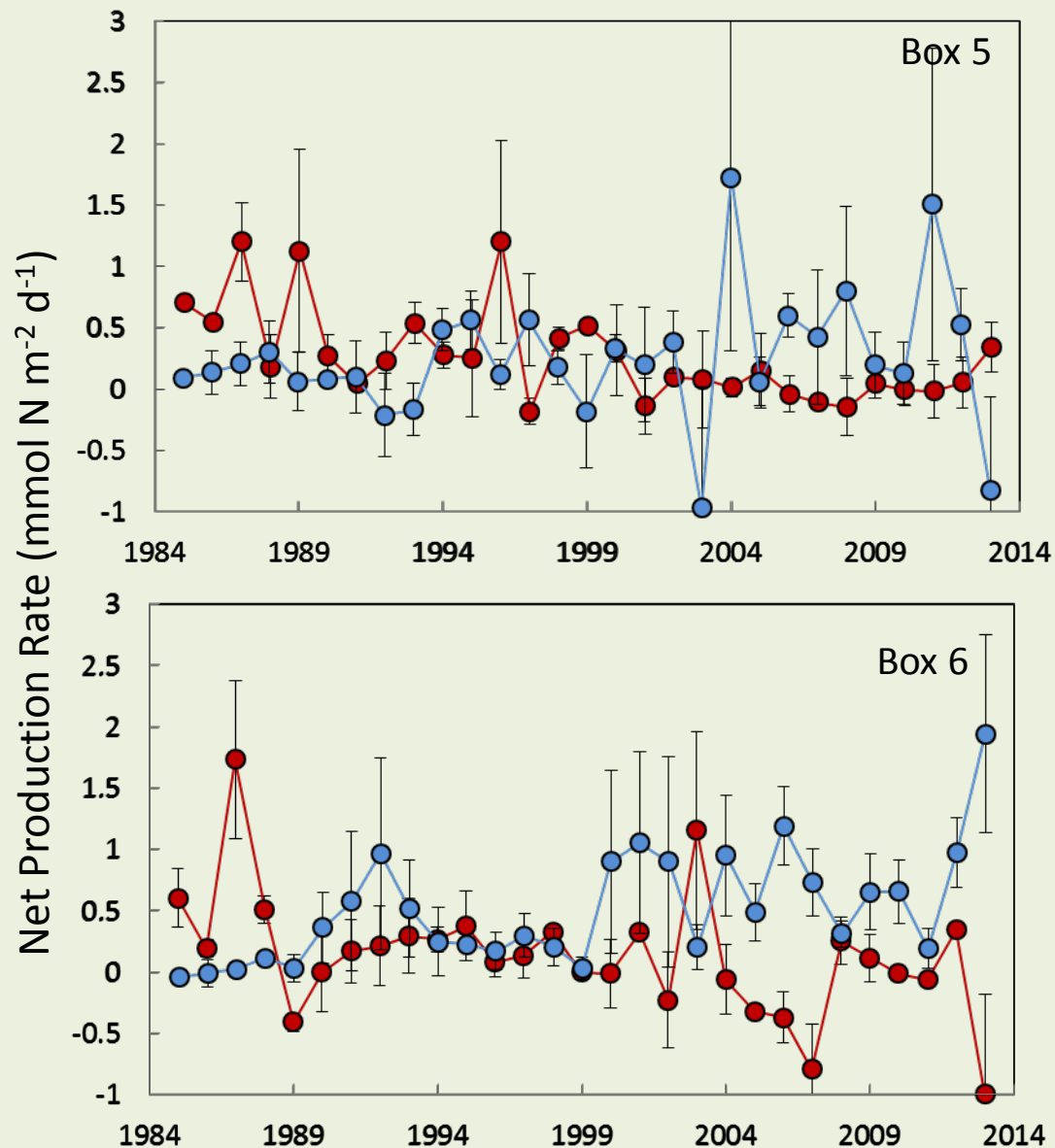


Box-Modeling: A Tool for Calculating and Analyzing Fluxes

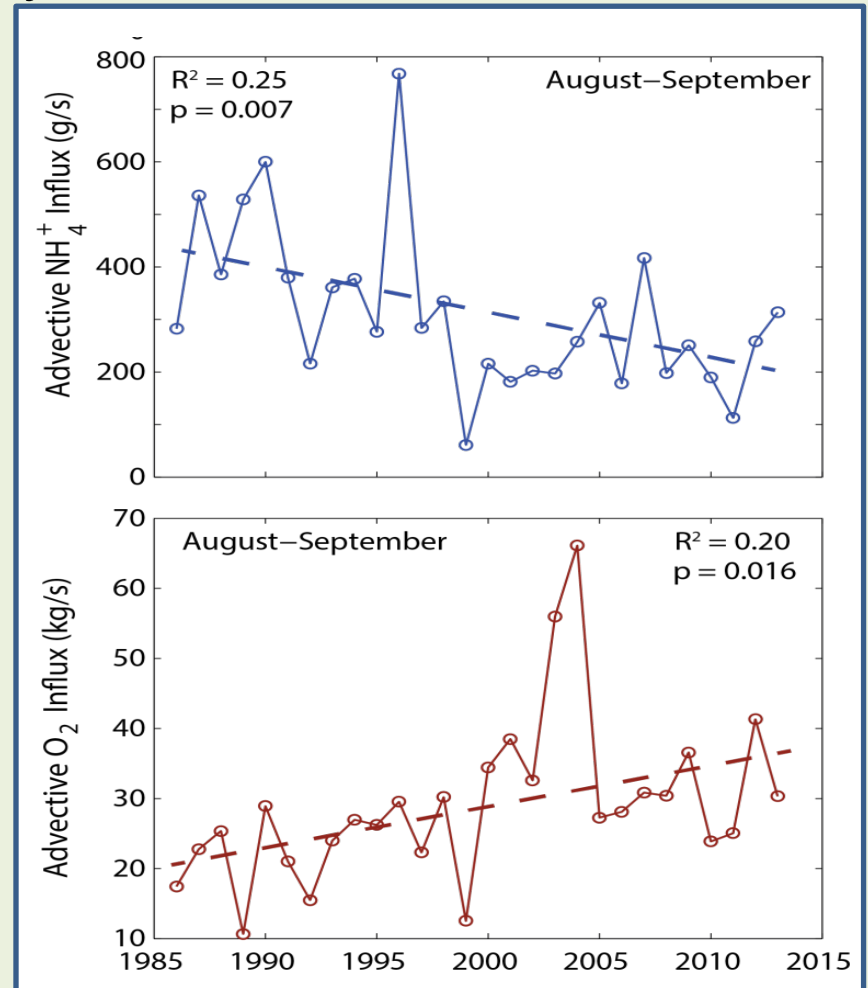
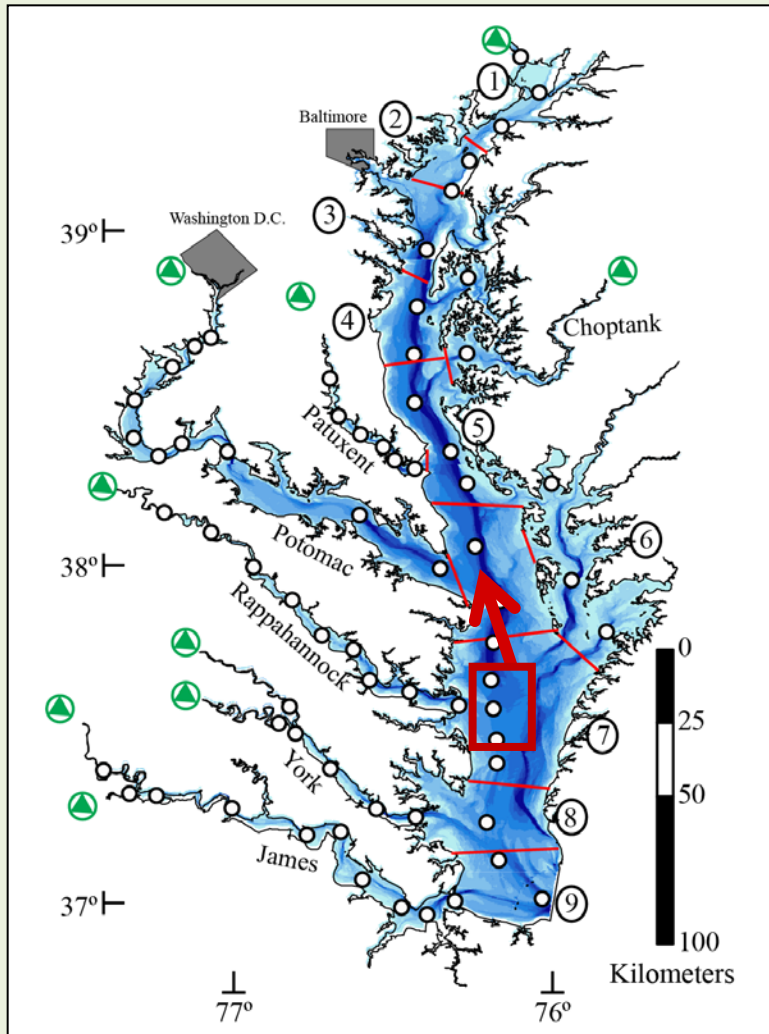


- Box-model uses salt- and water-balance equations to compute net fluxes
- Box-model computes rates from WQ concentrations and hydrologic flows
- Note that net transport is seaward in surface-layer & landward in bottom-layer

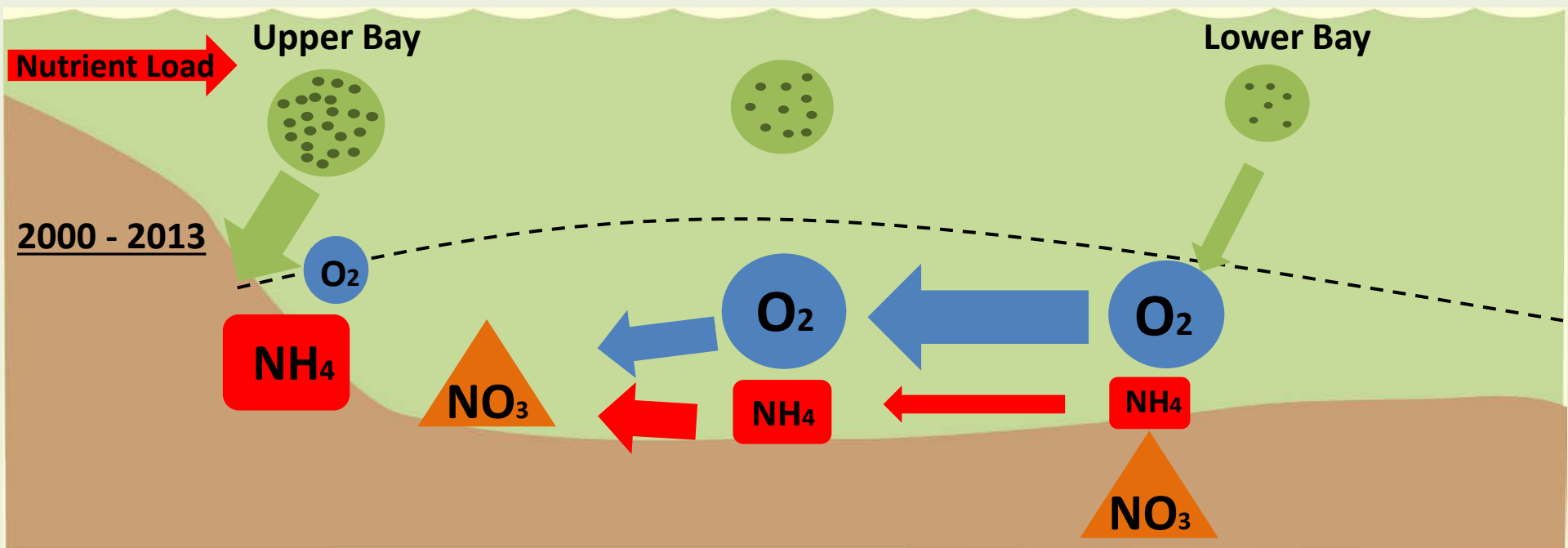
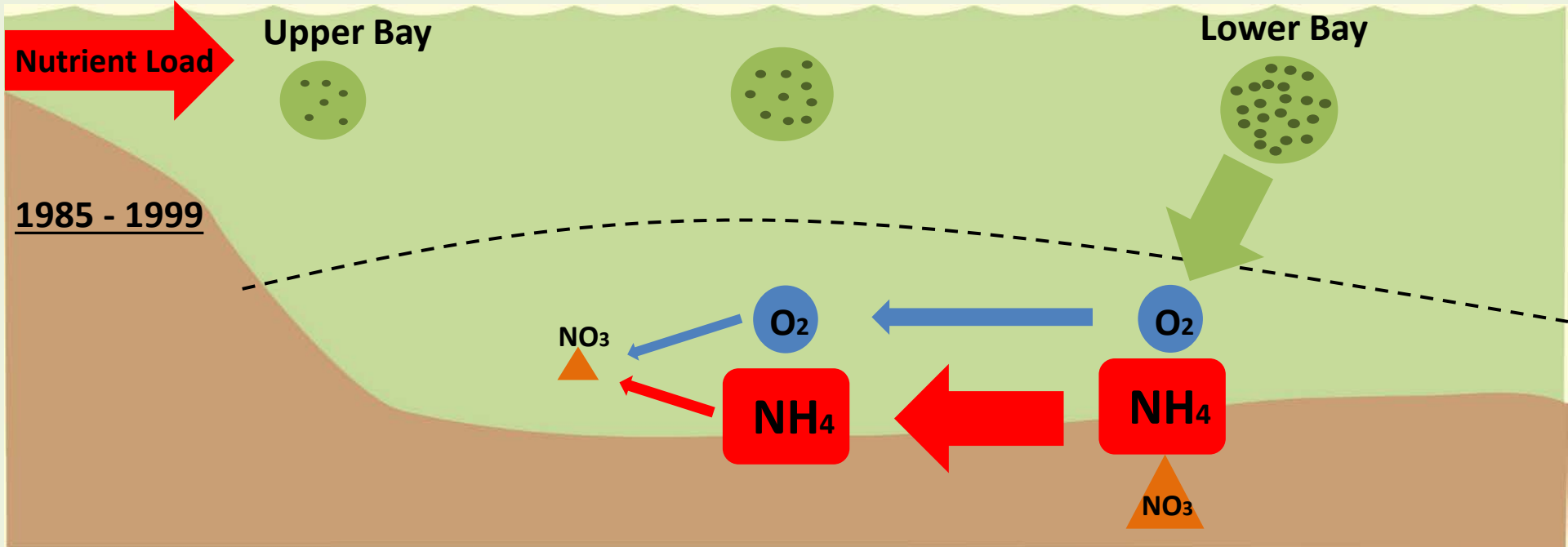
Concentration Patterns Coincide with *Declining* NH_4^+ Production and *Increasing* NO_{23}^- Production



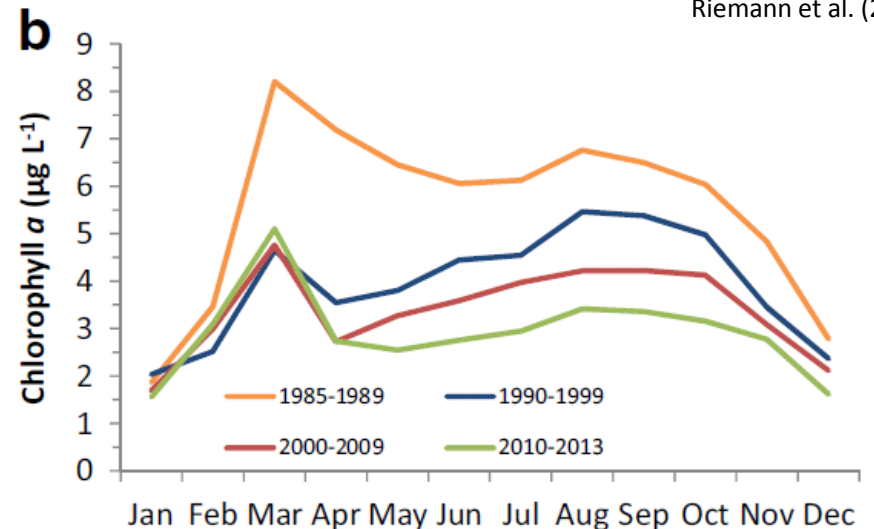
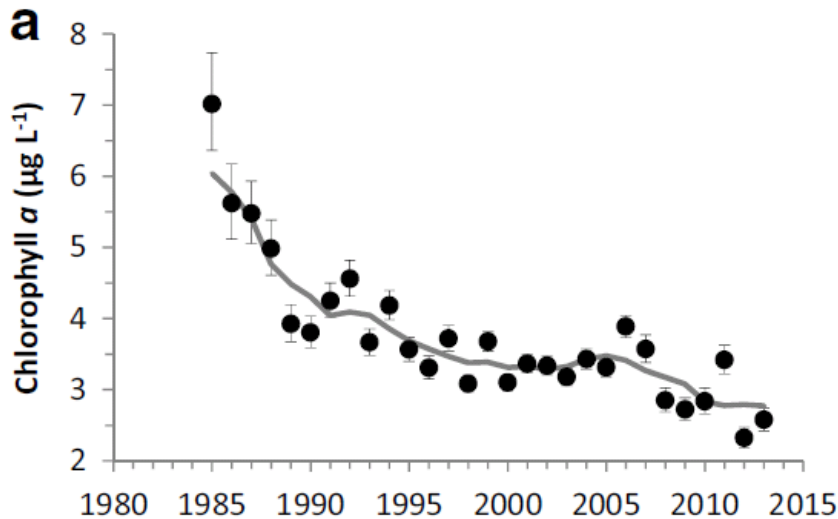
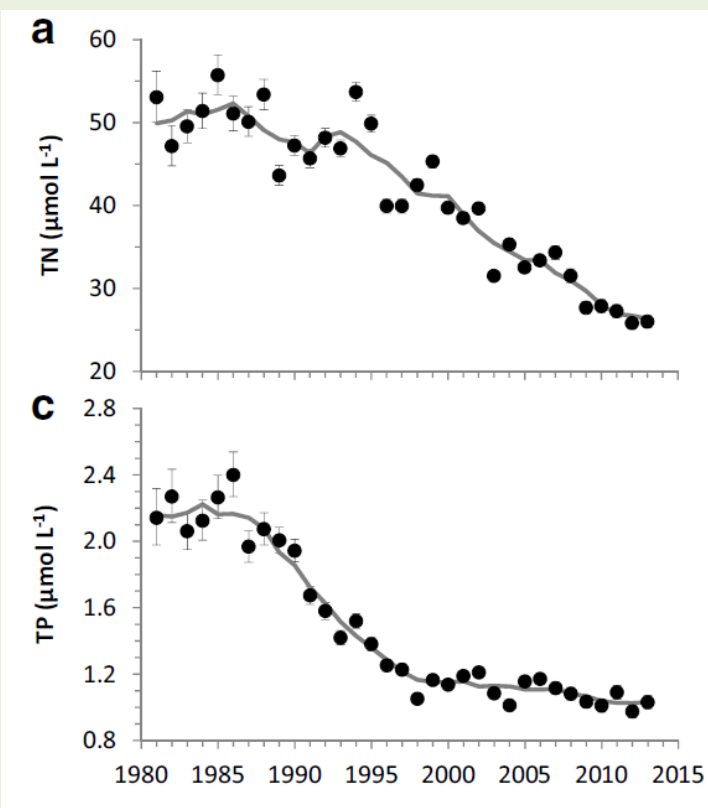
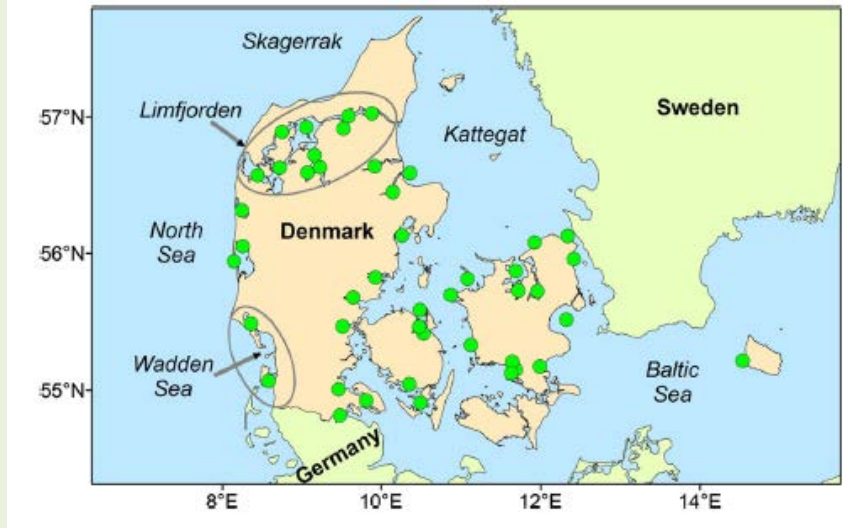
Long-Term Trends for O₂ Landward Transport from Lower to Upper Bay in Late Summer



- Up-bay bottom-layer transport of O₂ from lower to mid estuary shows increasing trends
- Reduced algal production and associated respiration?



Seasonal Component to Load-Responses in Other Estuaries



Riemann et al. (2015)

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Data: Chesapeake Bay Program



Maryland Department of Natural Resources



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