Thresholds in Recovery of Eutrophic Bay Sub-Systems: Five Case-Studies

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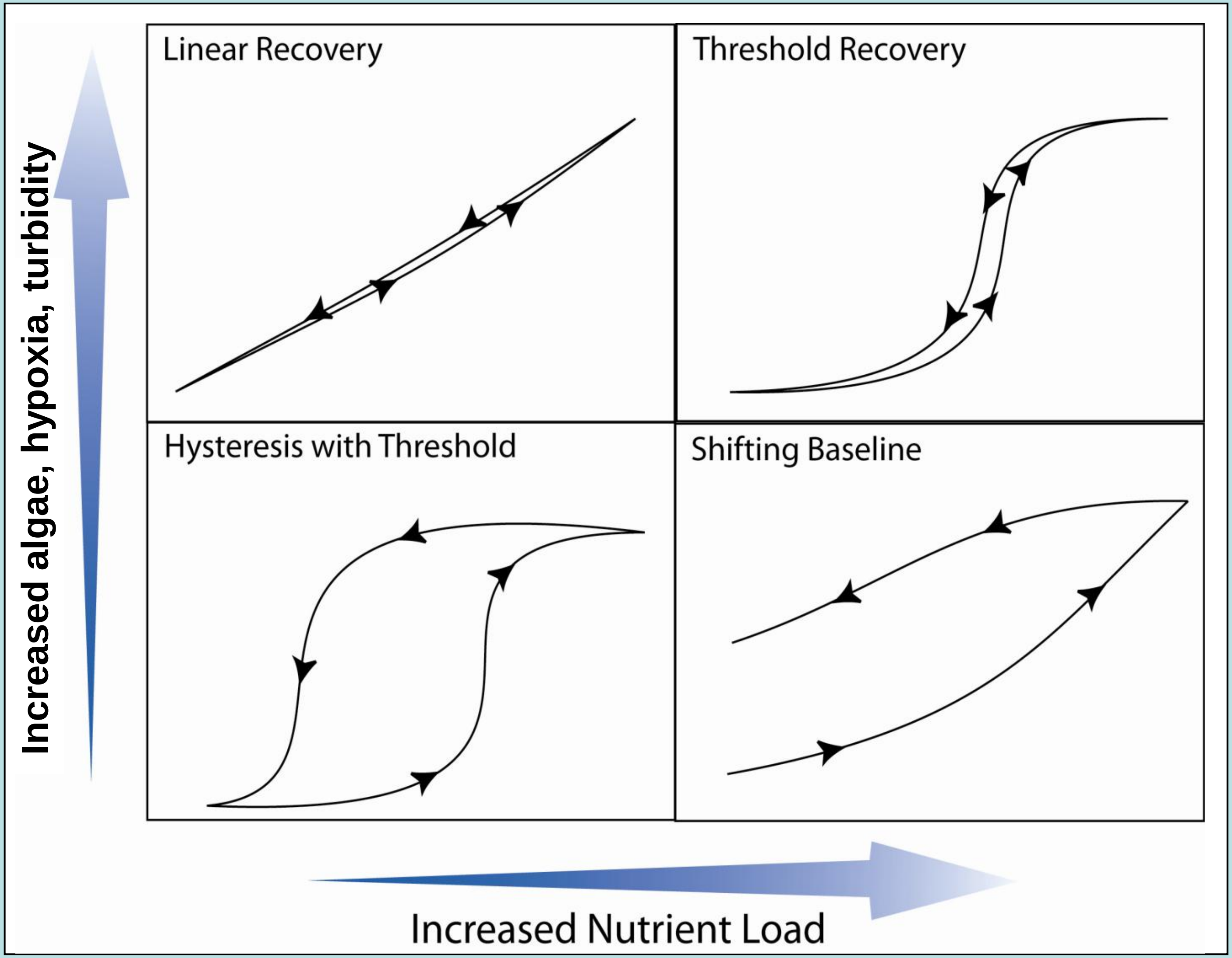
Chesapeake Bay STAC
Annapolis, MD (7 June 2011)

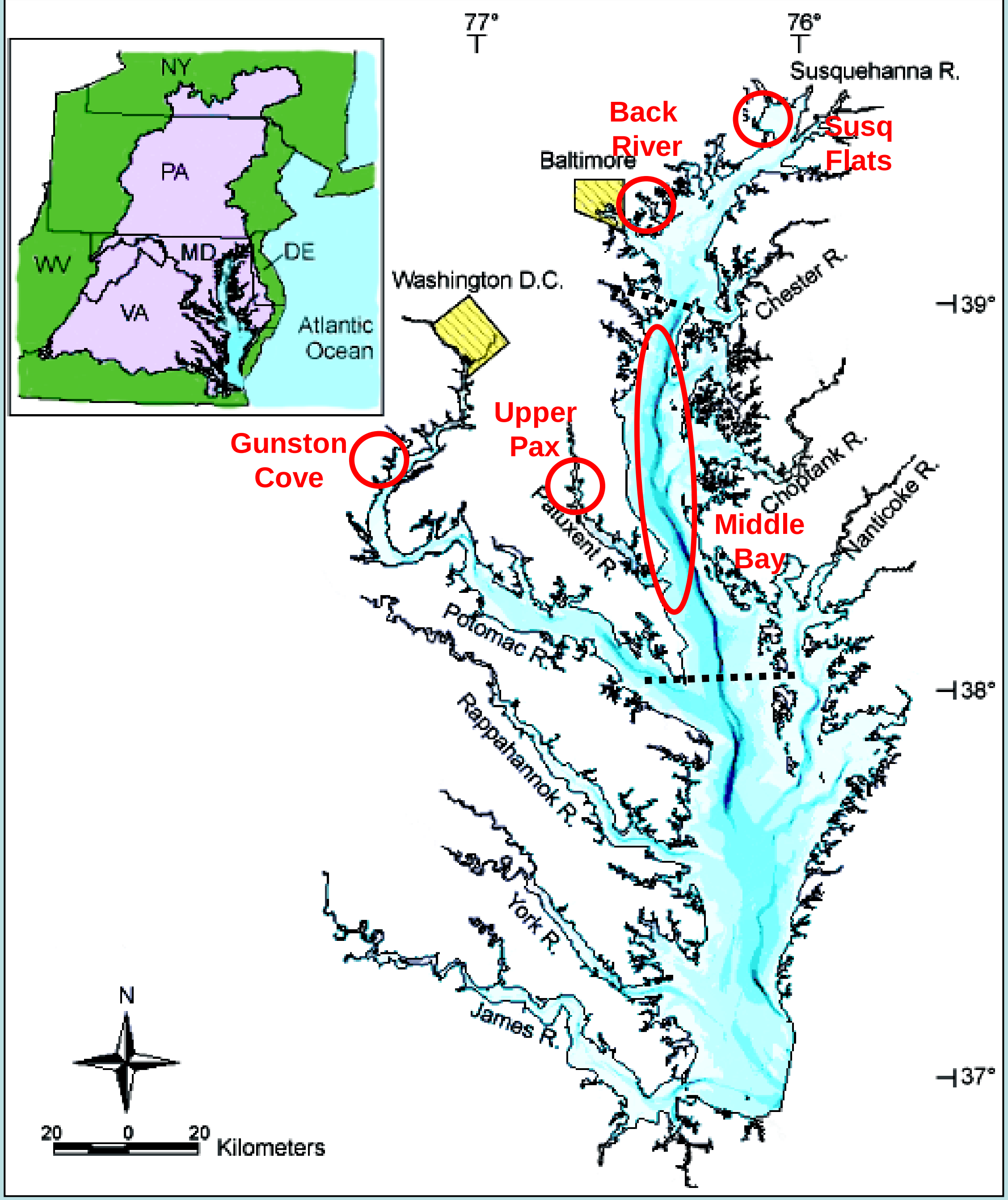
Research Support:
NOAA/MDSG, EPA

Theoretical Ecosystem Responses to Nutrient Degradation & Remediation



Chesapeake Bay:
Five Case Studies

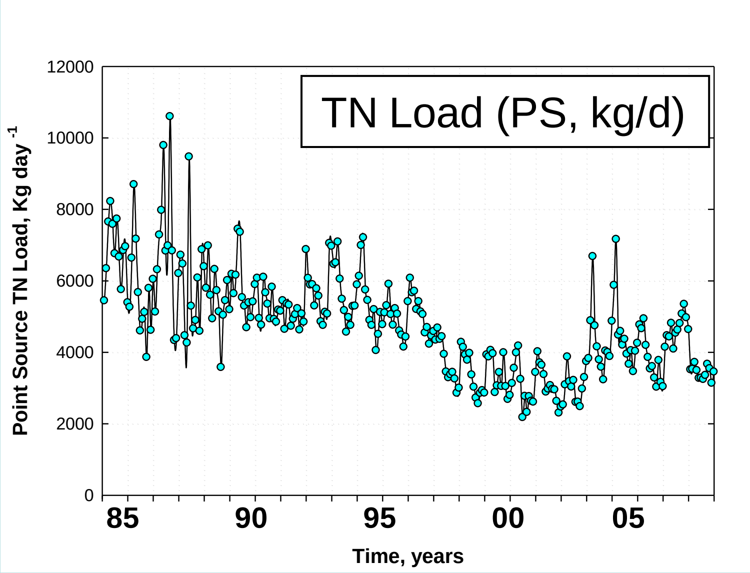
- ***Back River***—Muted response
- ***Upper Patuxent***—Threshold
- ***Gunston Cove*** —Hysteresis?
- ***Main Bay***— 'Regime shift'?
- **Susq Flats—Abrupt resurgence**

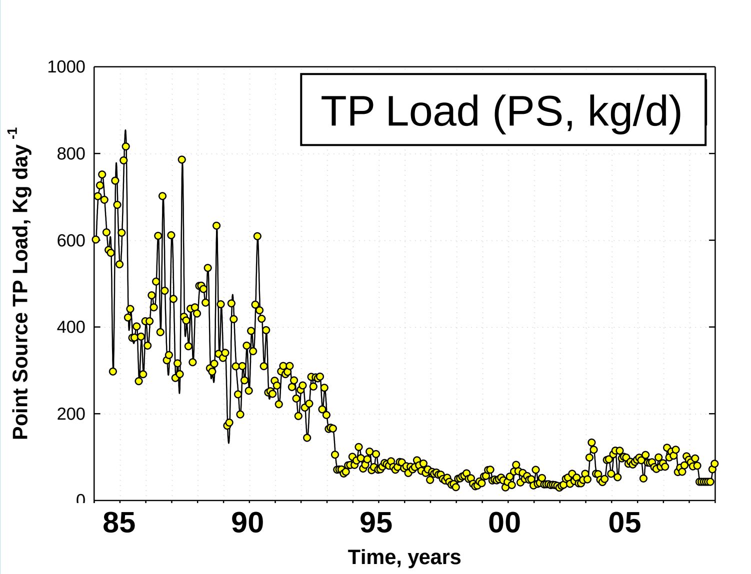


Back River Estuary

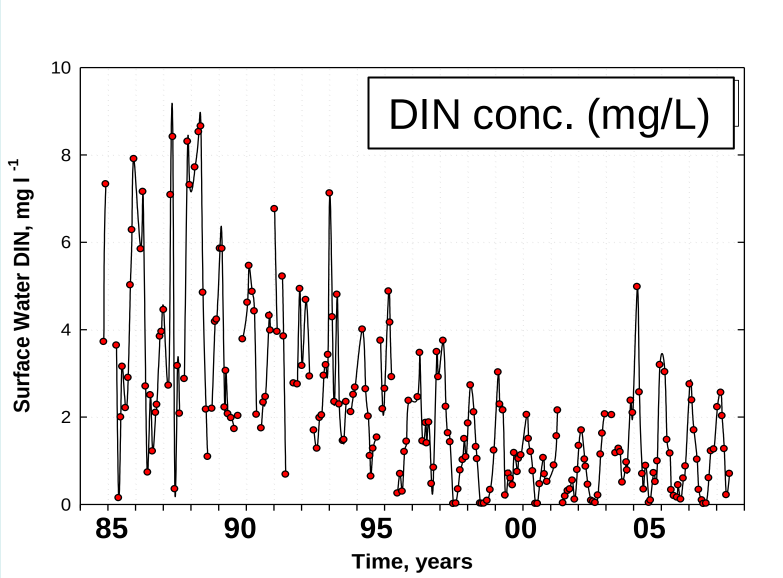
- Small tributary, Baltimore suburb
- Very eutrophic
- Point sources N & P dominate
- Ongoing WWTP upgrade
- Muted response (30-40%) in Chlorophyll-a
- N & P levels are still relatively high
- WWTP sometimes diverted to Patapsco
- Further nutrient control will yield big benefits

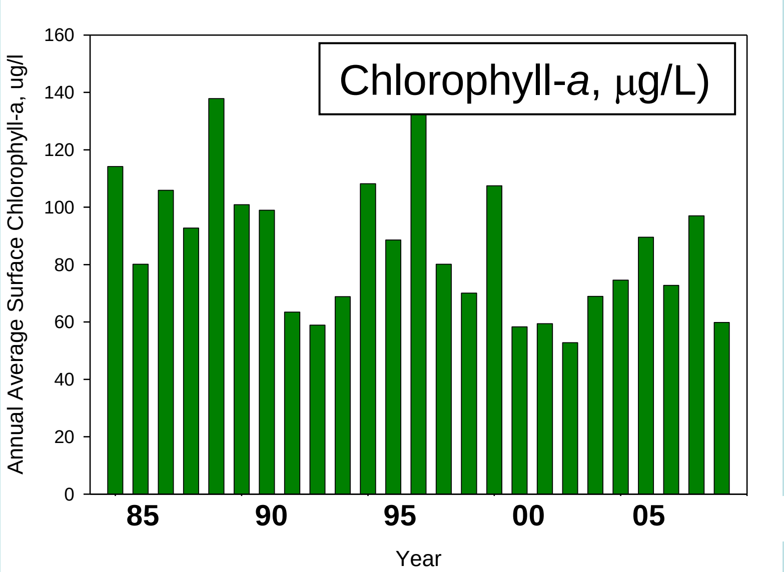
Back River Declines in TN & TP Loading



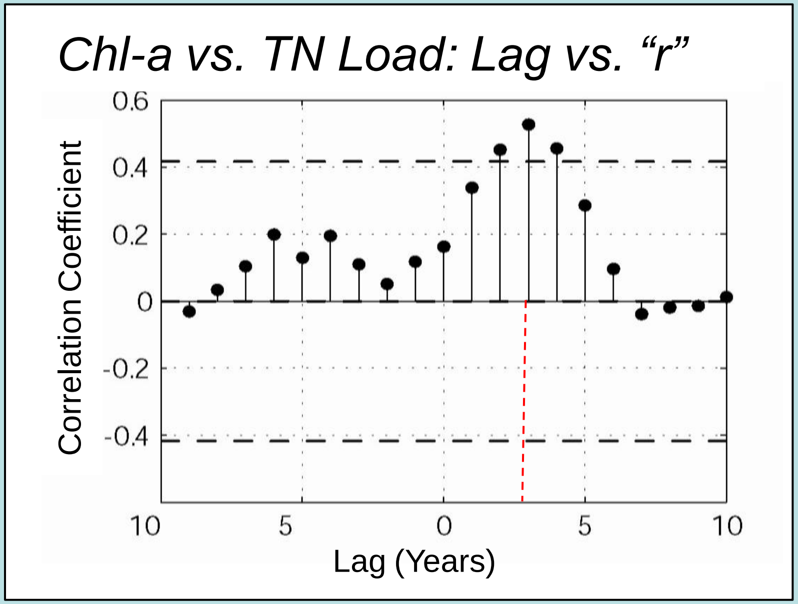


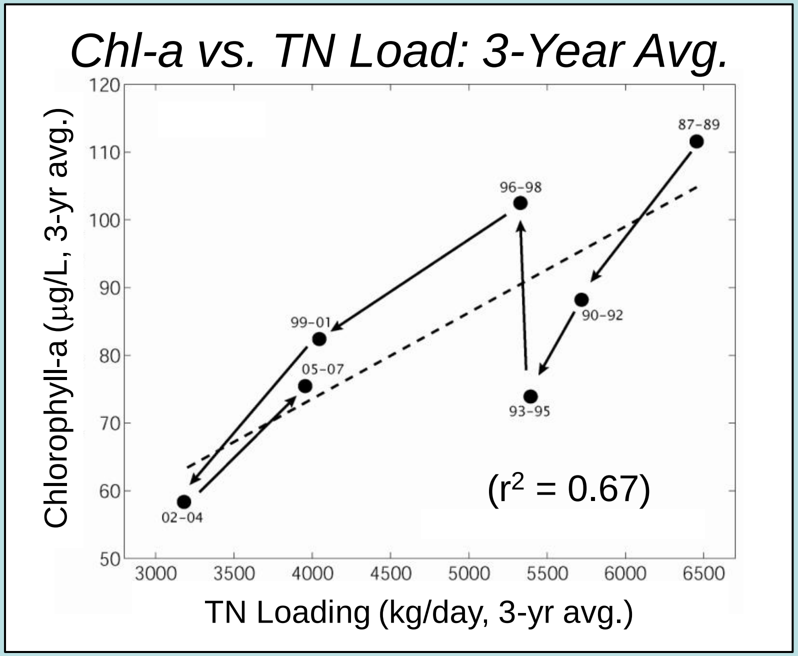
Back River Improvements in Water Quality





Chlorophyll vs. TN Load: 3-Year Lag Response

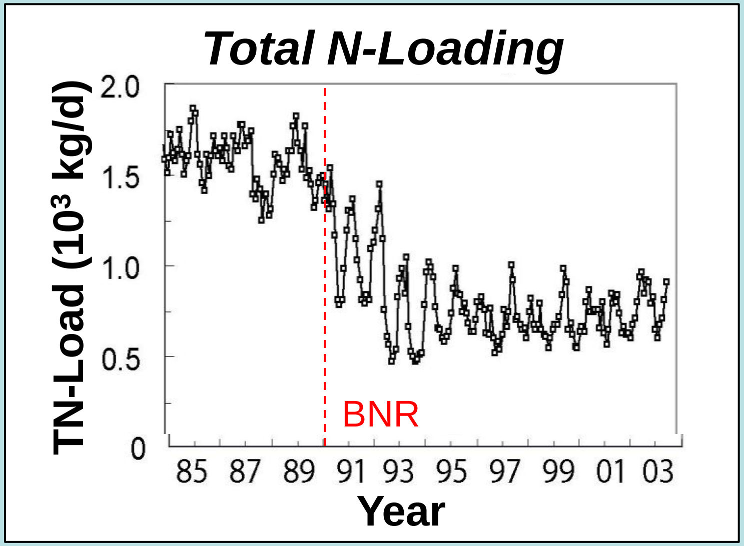


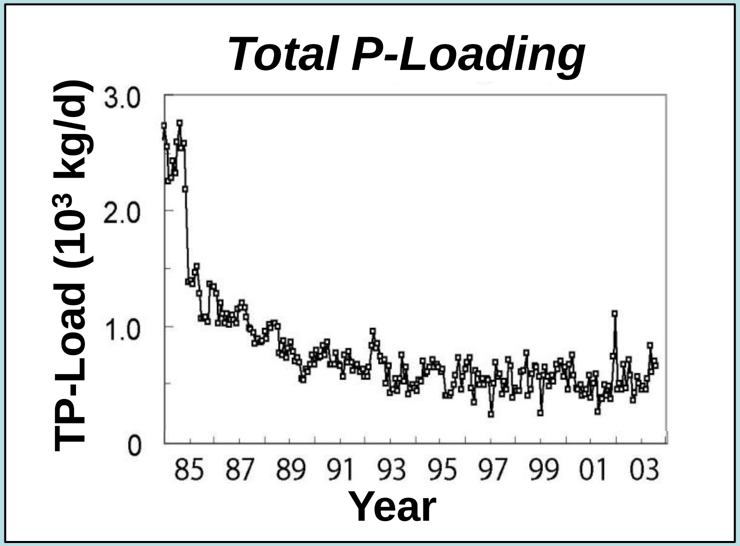


Upper Patuxent Estuary

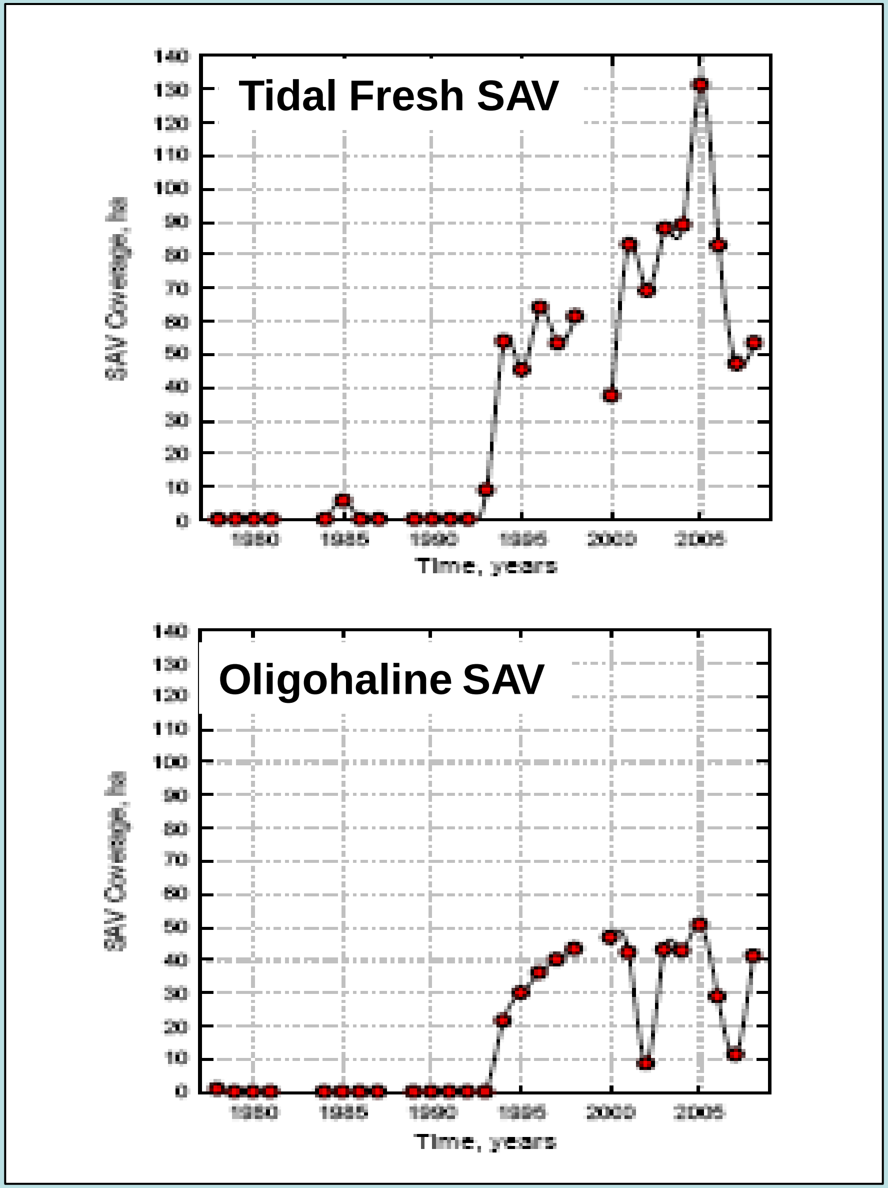
- Larger tributary (suburbs-rural watershed)
- Moderately eutrophic
- Point sources N & P dominate
- Recent WWTP upgrade
- Upper estuary decline (30-40%) in N & P
- Rapid Threshold SAV response (after 1992)

Phosphorus & Nitrogen Point-Sources to Patuxent

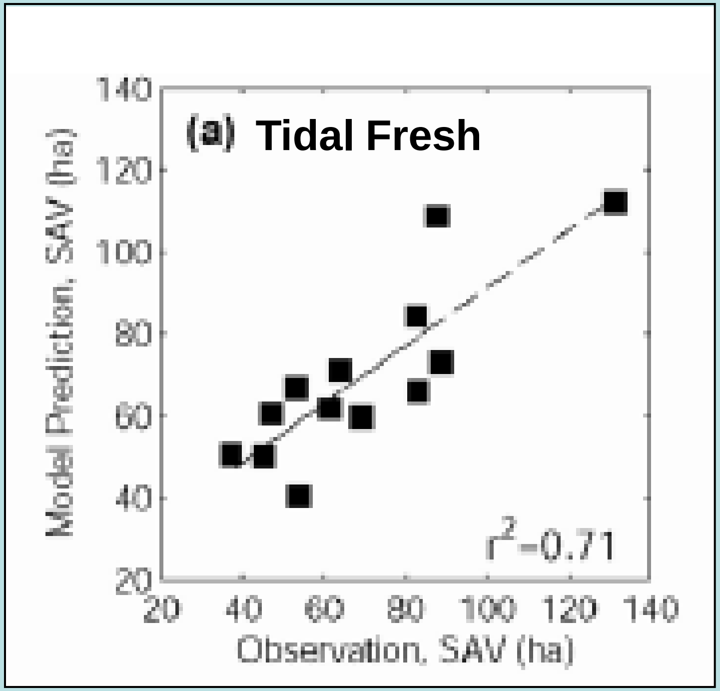


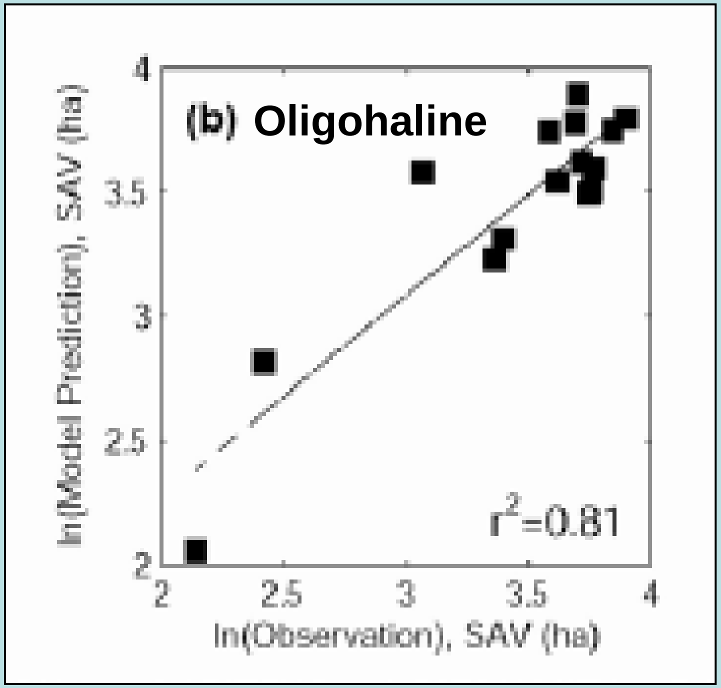


“Threshold Response” in SAV Recovery



Regression Models for Patuxent SAV





Y = *f* (N & P Load, Temp)

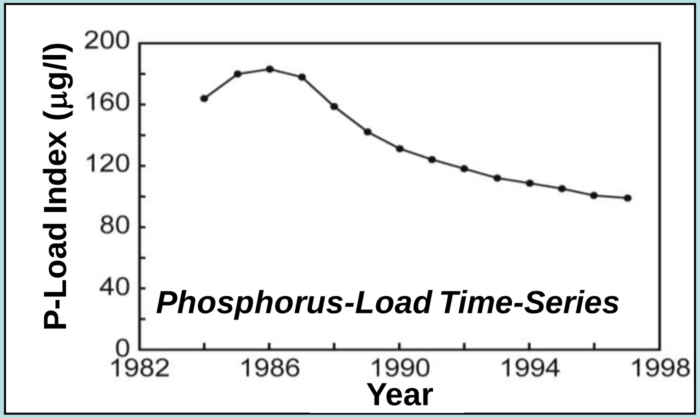
Y = *f* (Salinity, Temp)

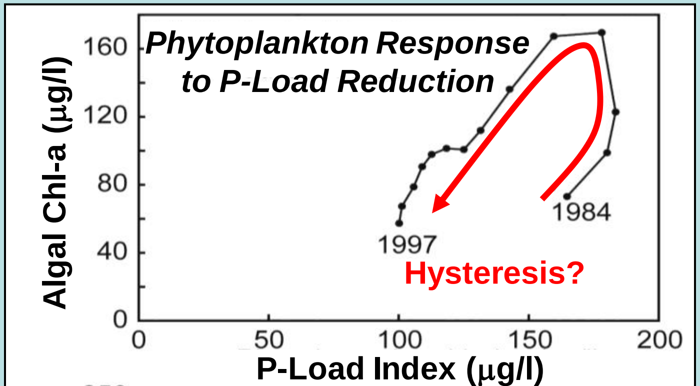
(Regressions Only Use Data After 1992!!)

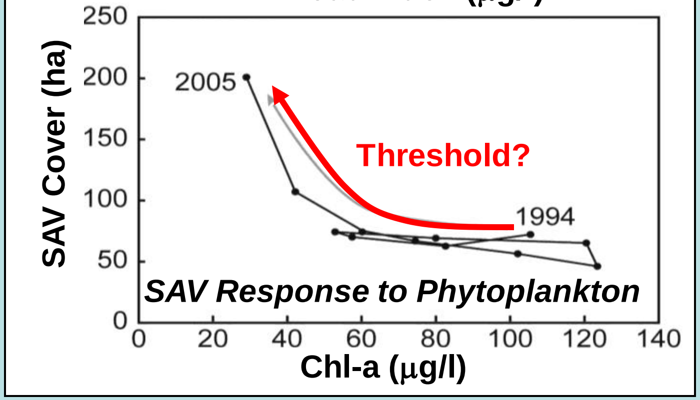
Gunston Cove Estuary

- Small brackish Potomac tributary (DC suburbs)
- Was very eutrophic
- Point sources N & P dominate
- STP upgrade in 1980s
- Possible inputs from Potomac (relatively small)
- P-limited algal growth
- Short Time-lag for Chlorophyll-a response
- Longer delay with Threshold SAV response

Gunston Cove P-Load, Phytoplankton, SAV

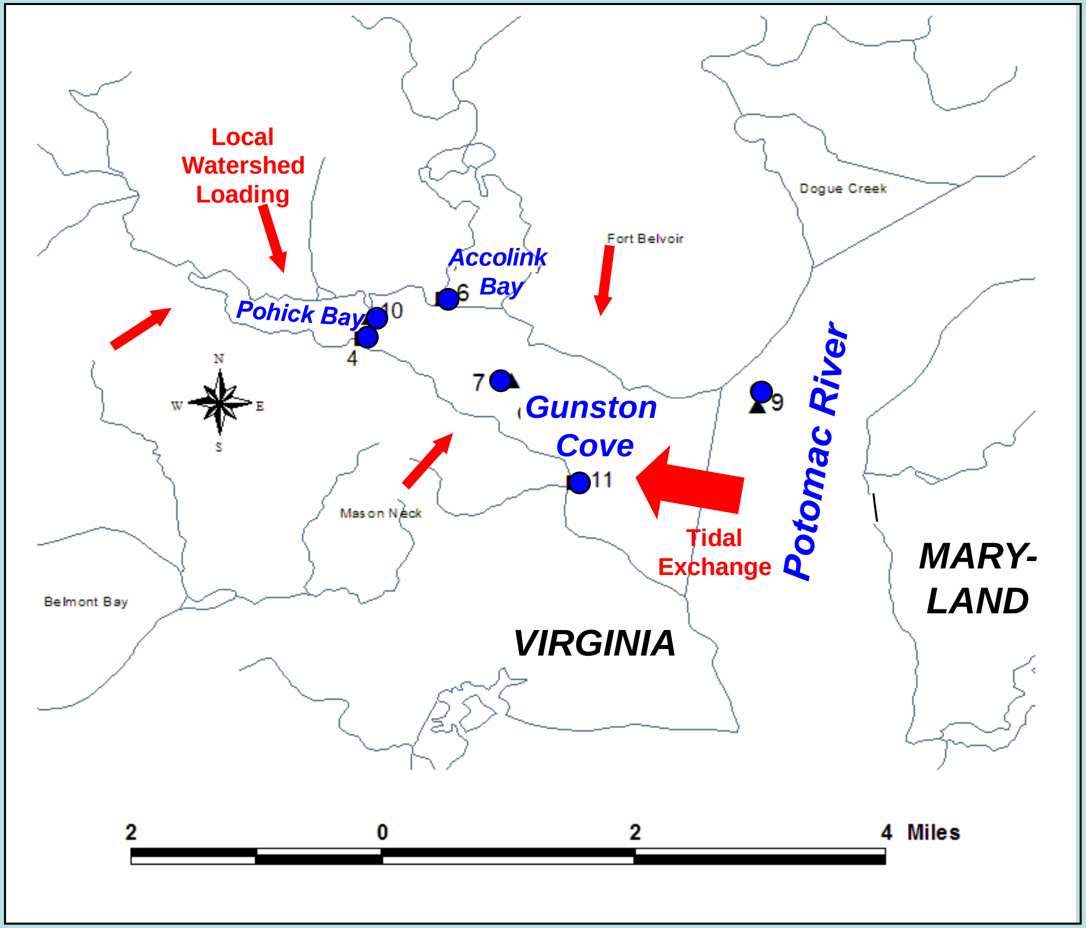






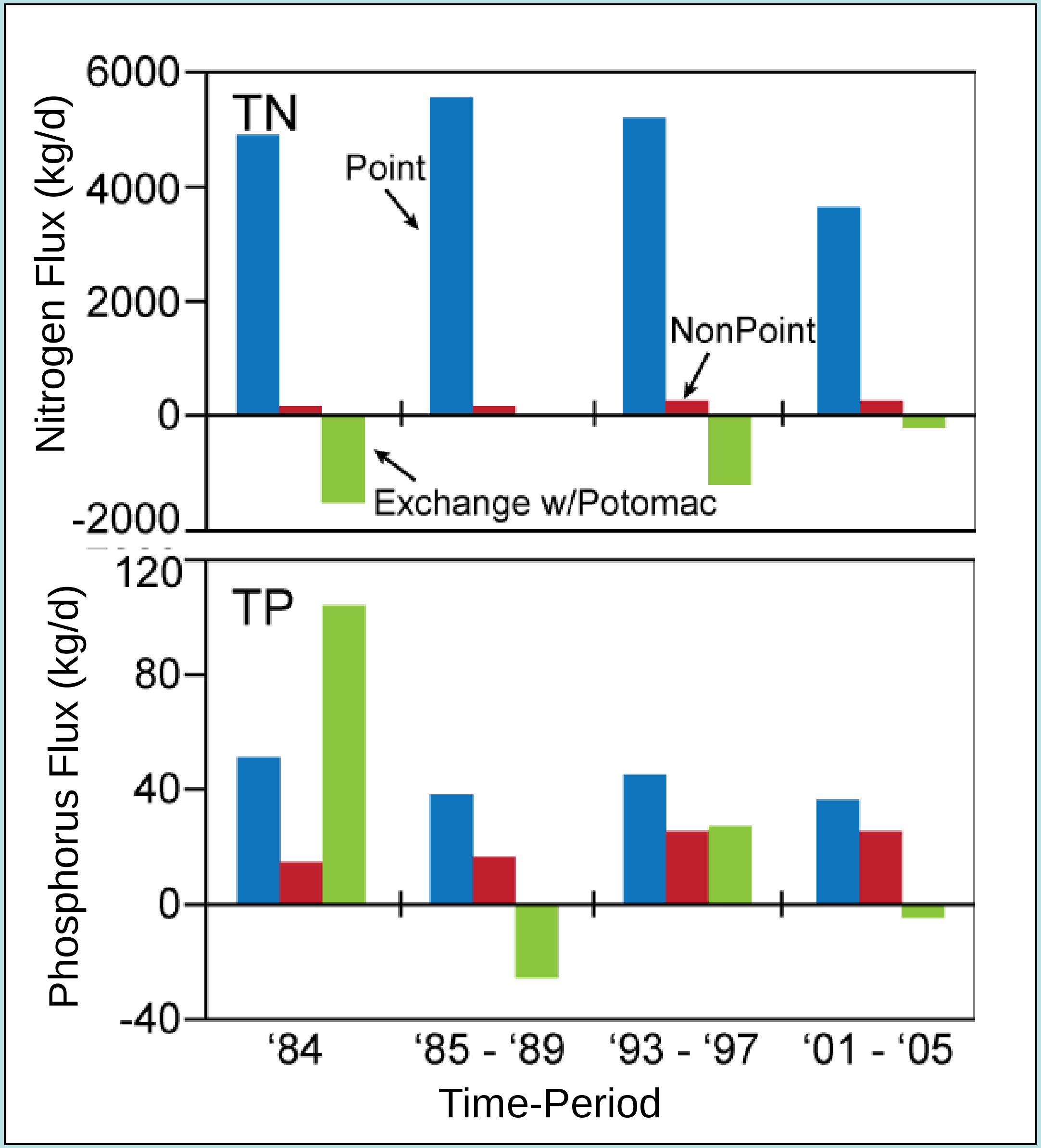
- Time-series of P-loading index includes periods of brief increase and gradual decline
- Phytoplankton chl-a shows response to P-load reduction after decade delay, probably due to slow purging of sediment DIP pools (hysteretic response pattern?)
- Reductions in phytoplankton chl-a brought improved water clarity until a light threshold is reached allowing growth and survival of submersed plants

Gunston Cove Restoration Study



- Phosphorus is the primary limiting nutrient in this tidal fresh or oligohaline region of Potomac River estuary
- P-loading to Gunston Cove comes both from surrounding local watershed and from tidal exchange with adjacent Potomac.
- Recent declines in P-loading cause recovery of plankton, water clarity and SAV

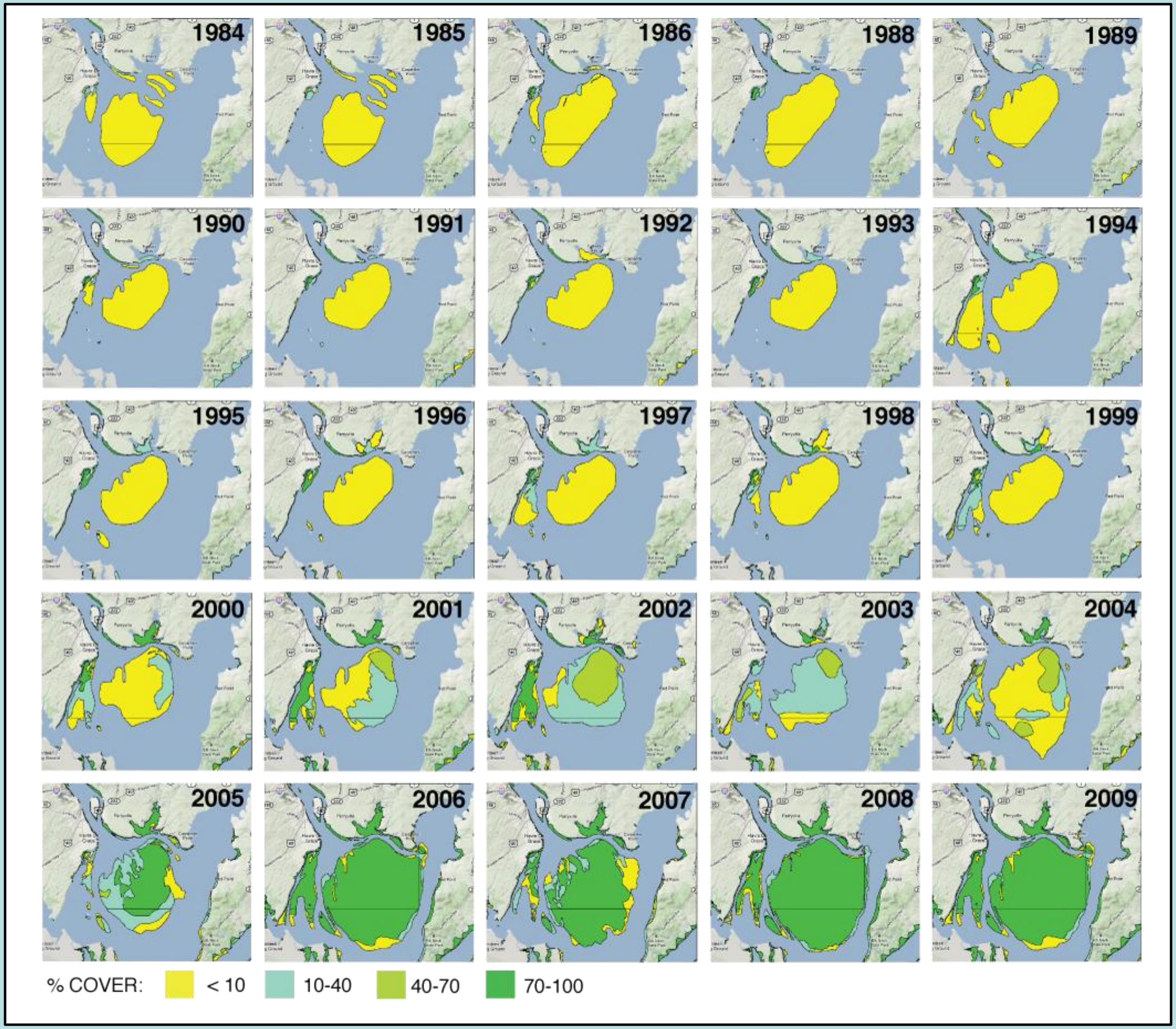
Gunston Cove N & P Loading Budgets



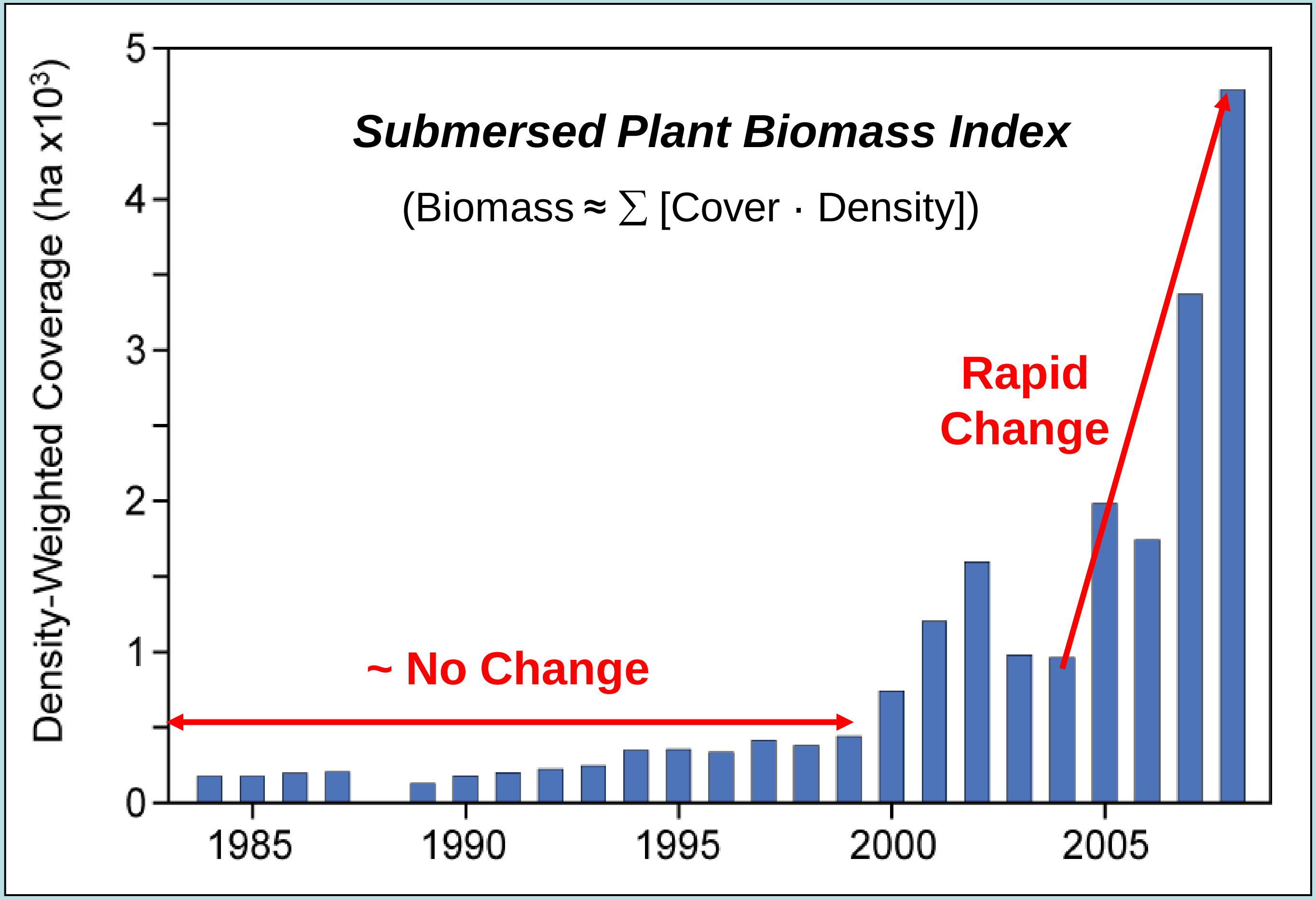
Susquehanna Flats

- Large shallow region of upper main Bay
- Direct inputs from Susquehanna River
- Diffuse sources N & P dominate
- Modest decline in TN loading since 1990
- Recent small improvement in water quality
- Abrupt resurgence of large SAV bed
- Currently unexplained, but Thresholds involved
- Rare opportunity to study unexpected SAV recovery
- Possible insights into SAV restoration strategies

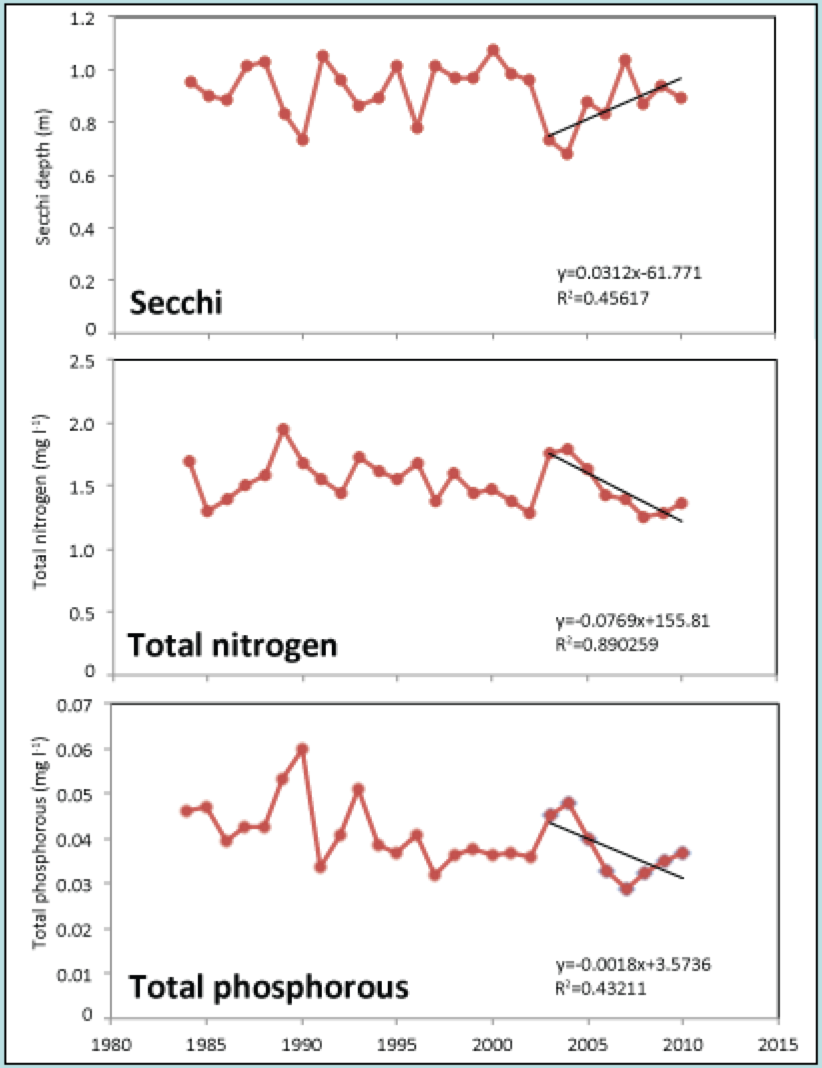
Submersed Plant Trends in Susquehanna Flats



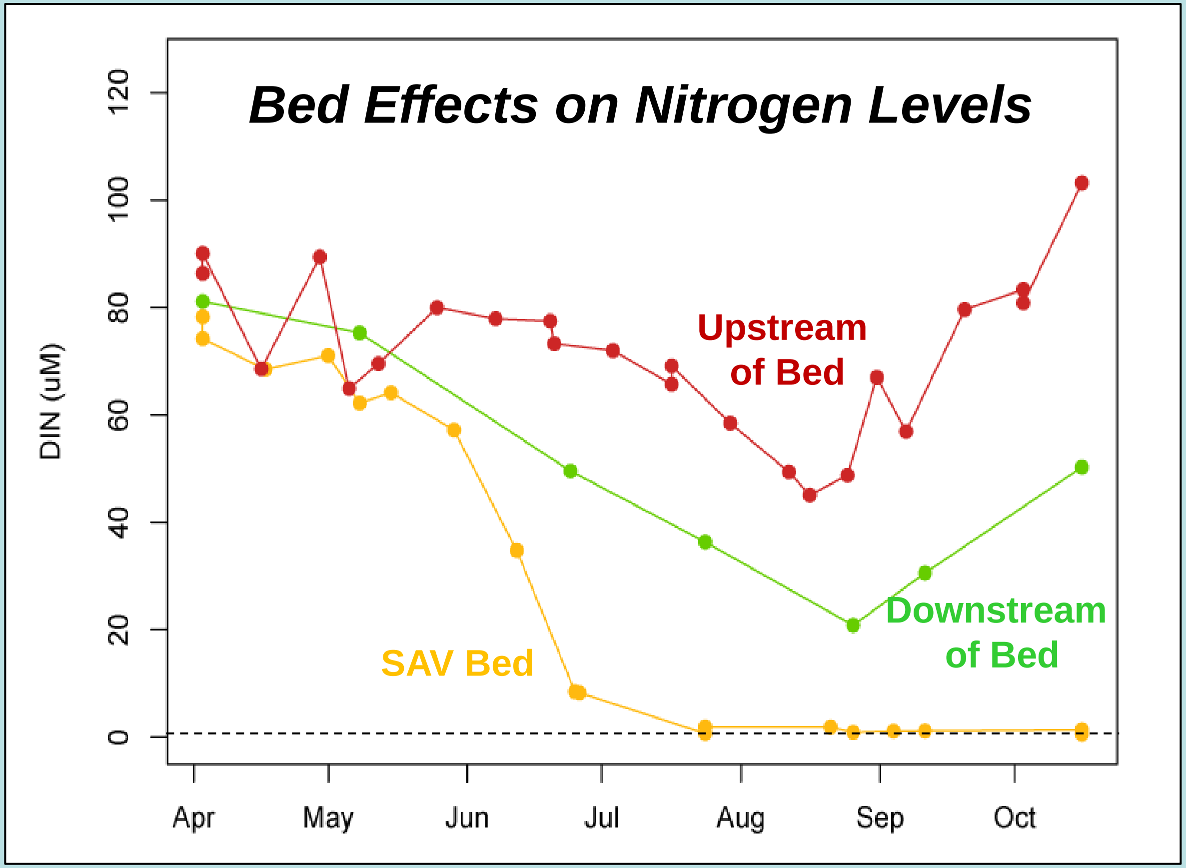
Abrupt Resurgence of SAV in Susquehanna Flats



SAV Resurgence & Water Quality Improvements



Feedback Effects of SAV Beds on Water Quality

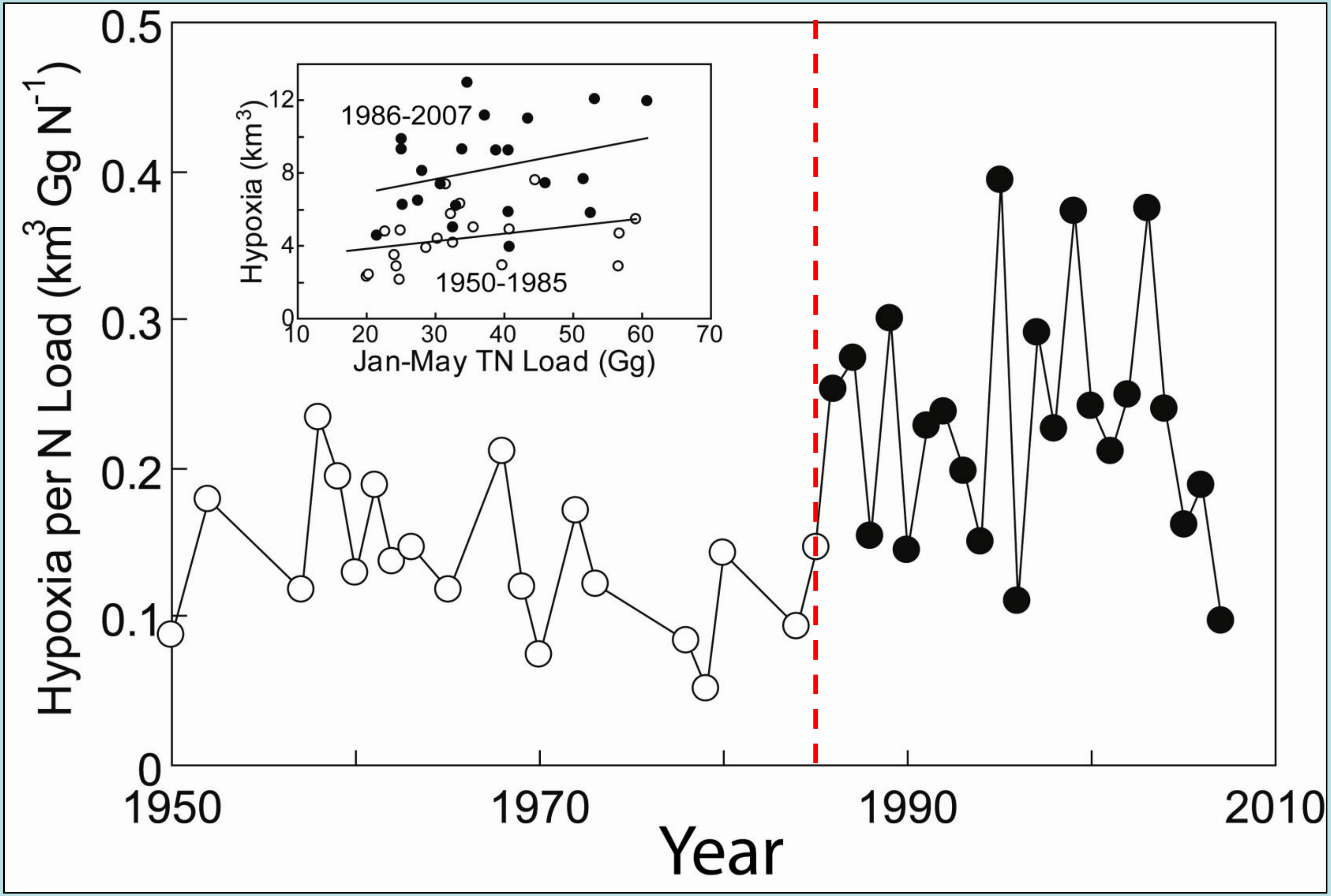


(www.eyesonthebay.net)

Mesohaline Mainstem Bay

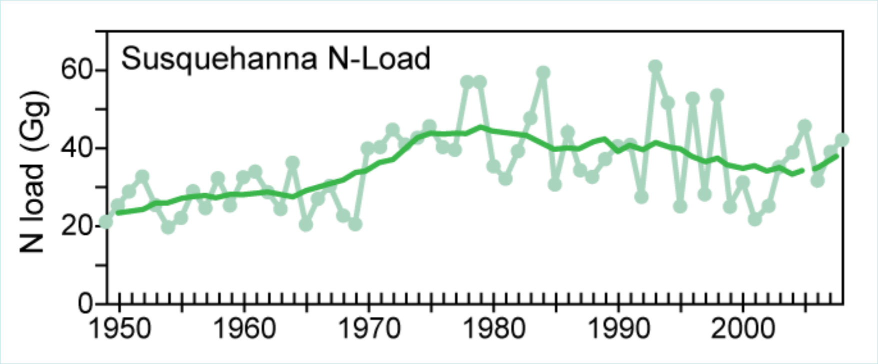
- Deep Channel of middle region of main Bay
- Direct inputs from Susquehanna River
- Diffuse sources N & P dominate
- Abrupt increase in hypoxia yield per N load to Bay (~1982)
- “Regime Shift” implies more nutrient reduction needed
- Shift applies to Early Summer hypoxia
- Shift linked to Climate Change (stratification, ventilation)
- Mid Summer hypoxia directly linked to N-Loading
- Seasonally different responses to Climate vs. Nutrients

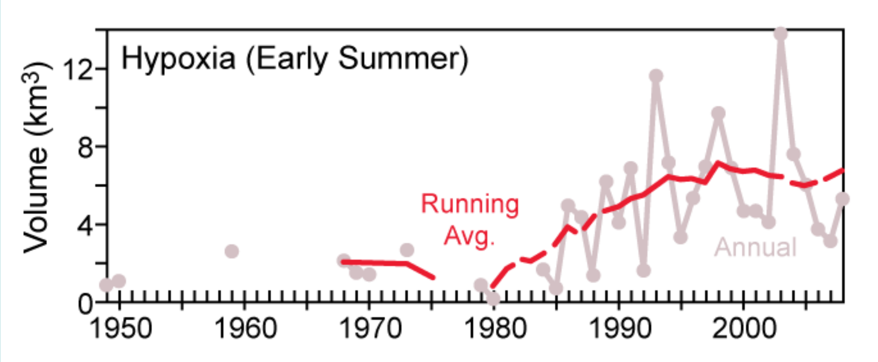
Trend in Bay July Hypoxic Volume

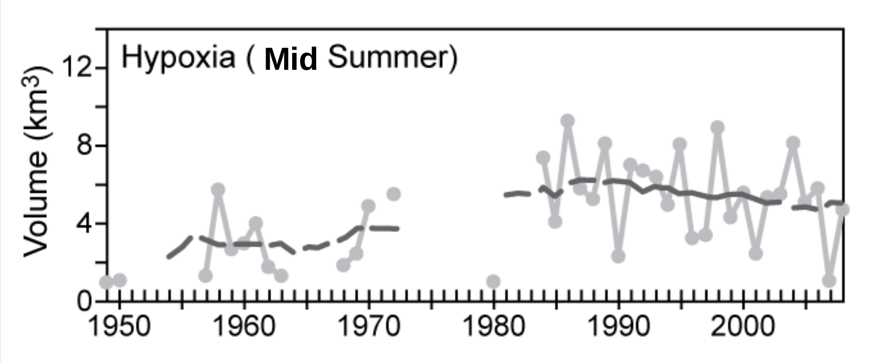


(Kemp et al. 2009)

Hypoxia Trends Related to N-Loading



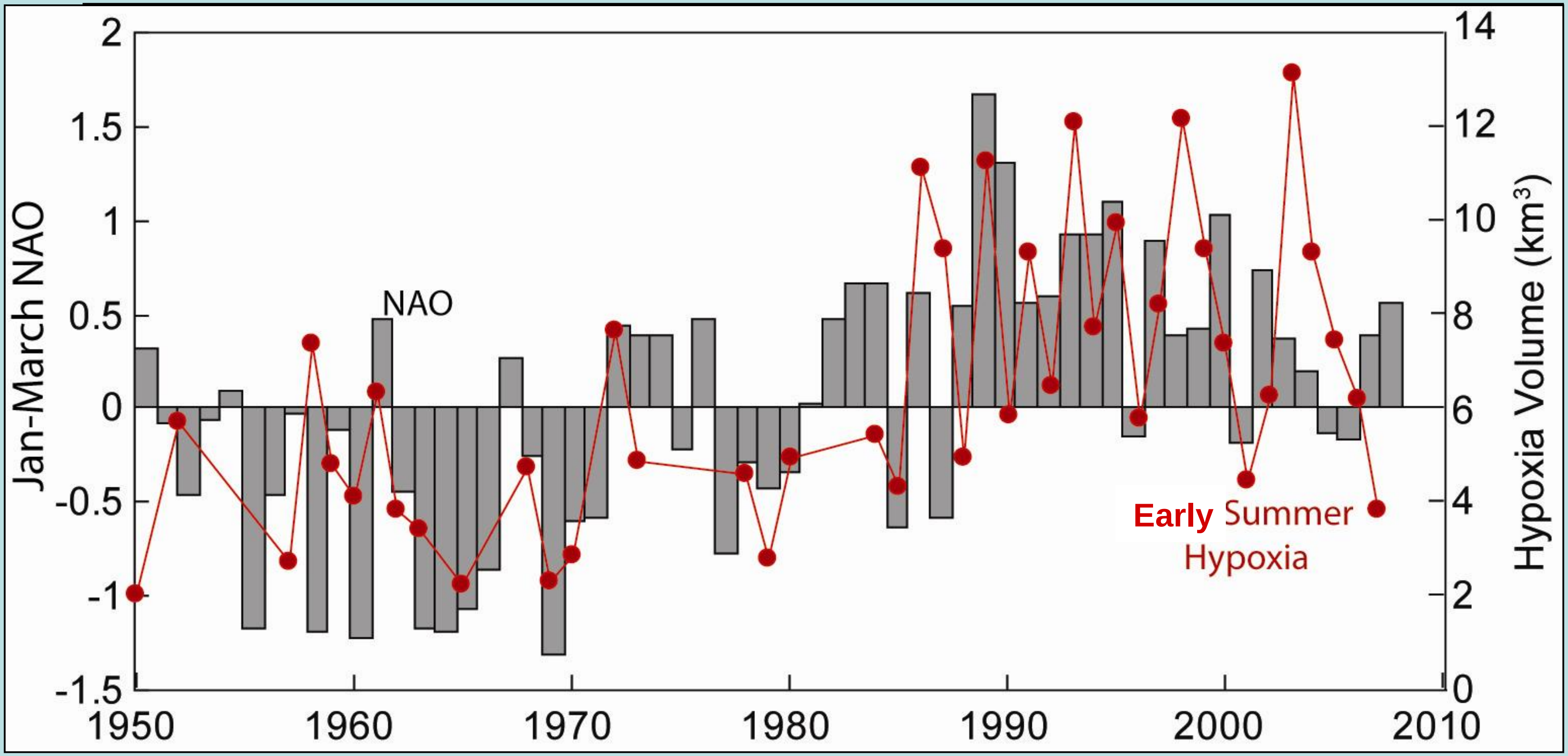




- **N-Loading increased until mid-1980s, then declined gradually into 2000s**
- **Inter-annual variations blur long-term trends; clarify with running means**
- **Early summer hypoxia shows rapid increase since 1980 (earlier graph)**
- **Mid-summer hypoxia has actually declined parallel to the decline in N-load**
- **Hypoxia & N-Load highly correlated (r^2 = 0.77)**

(Murphy et al. 2011)

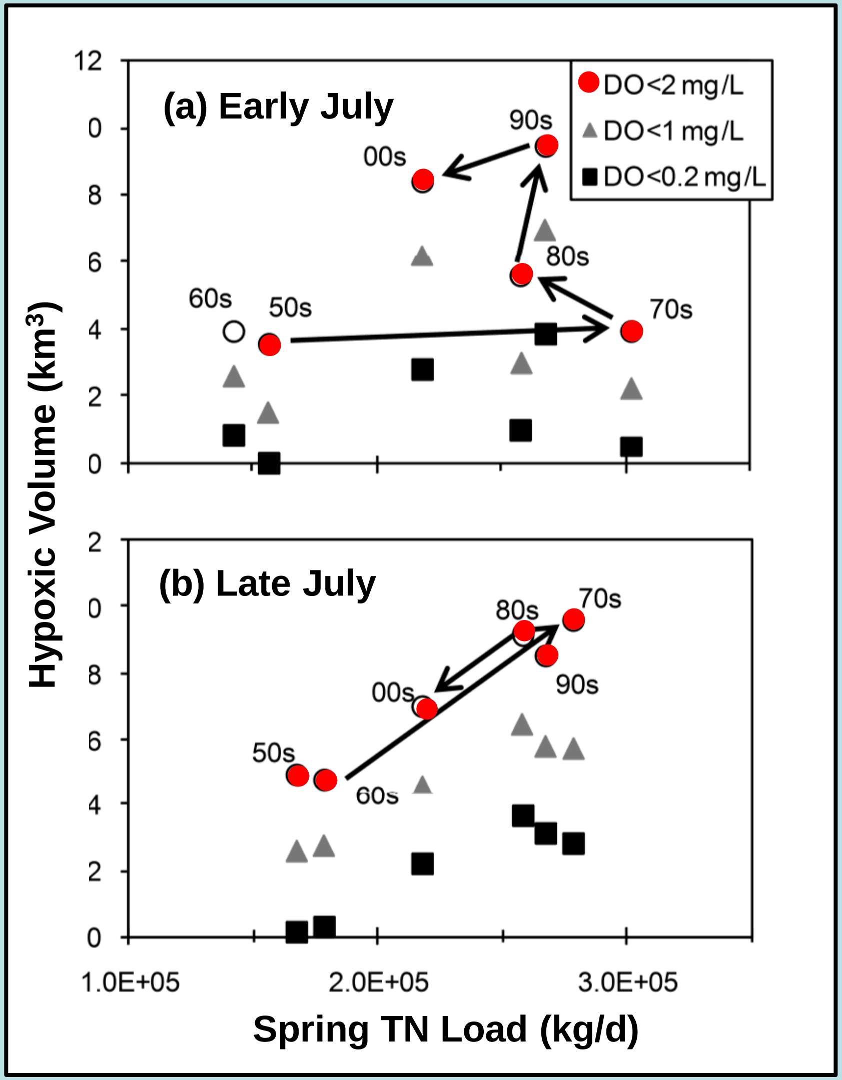
Climate Effects on Mid-Summer Hypoxia: North Atlantic Oscillation Index



- **Winter NAO Index reflects regional climate and ocean circulation**
- **NAO measured as atmospheric pressure difference Iceland-Azores**
- **NAO correlates well ($r^2 = 0.51$, $p < 0.01$) with early summer Bay hypoxia**

(Testa 2009)

Decadal shifts in Hypoxia vs. N-Loading

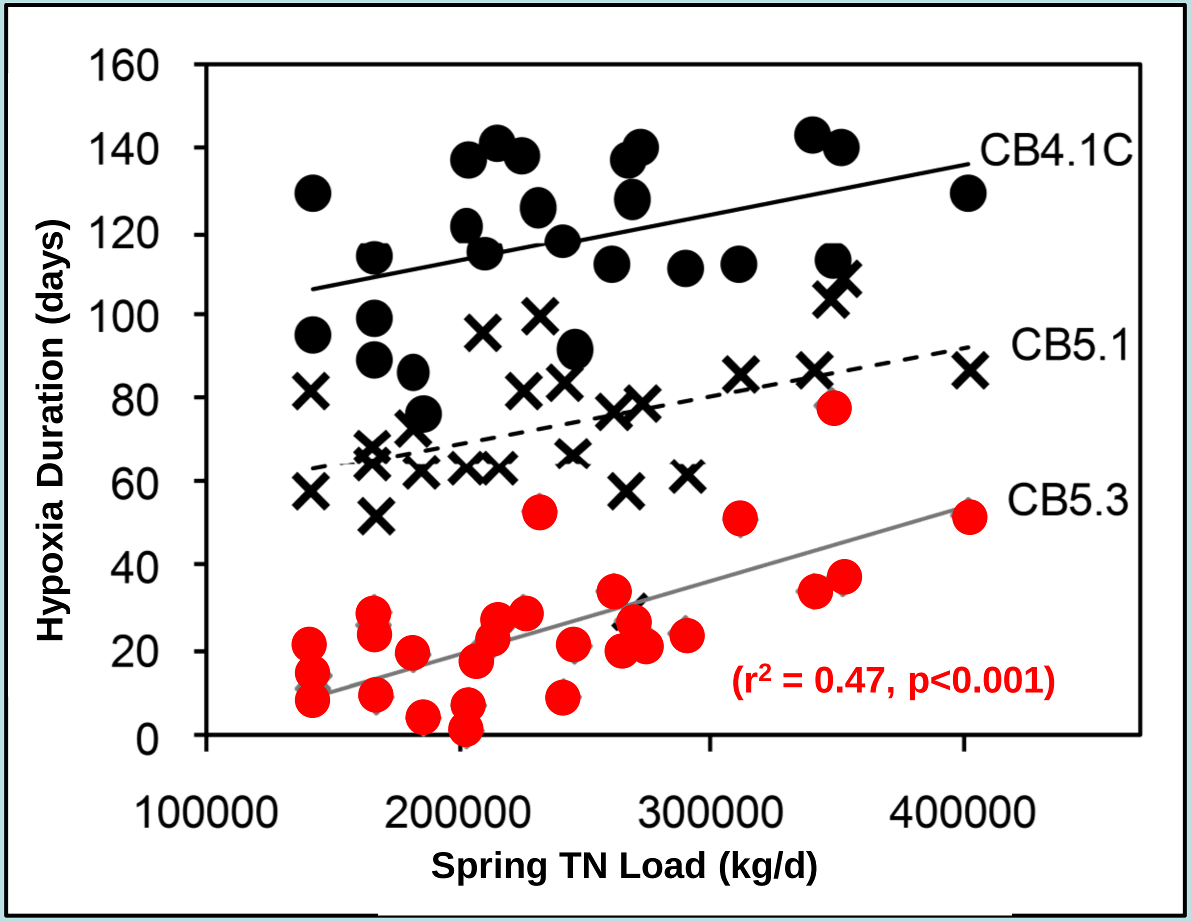


(Murphy et al. 2011)

Concluding Comments

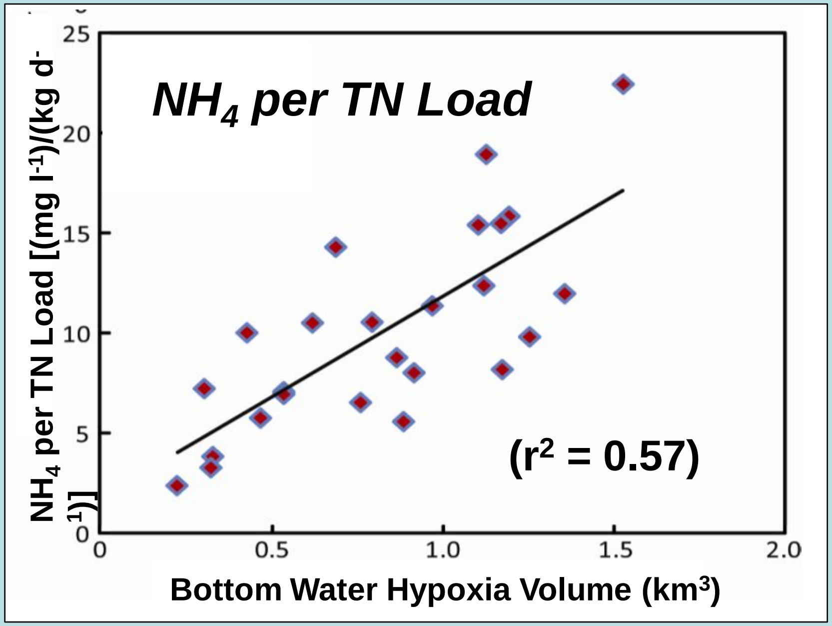
- Small, low-salinity estuarine tributaries of Chesapeake Bay (with urban-suburban watersheds) are prime candidates for restoration.
- Algal growth in low-salinity regions is often limited by P, where sediment storage & biogeochemical *feedbacks* may cause decadal delays.
- Recovery of low-salinity SAV beds is likely to exhibit *threshold* responses to improved water quality (apparent propagule banks).
- Positive *feedback* effects of SAV beds on water quality appear to accelerate recovery once initial environmental *thresholds* are crossed.
- For mainstem Bay, modest improvements in water quality may spark rapid recovery of SAV and hypoxia, reinforced by positive feedback mechanisms.
- Why have Susquehanna River nutrient loads declined? Who knows?
- Improve understanding of how *climate cycles and changes* modulate ecological responses to nutrient management.
- Continue ‘mining’ historical data (monitoring time-series & paleo-ecological proxies) for evidence of nutrient response trajectories & environmental controls.

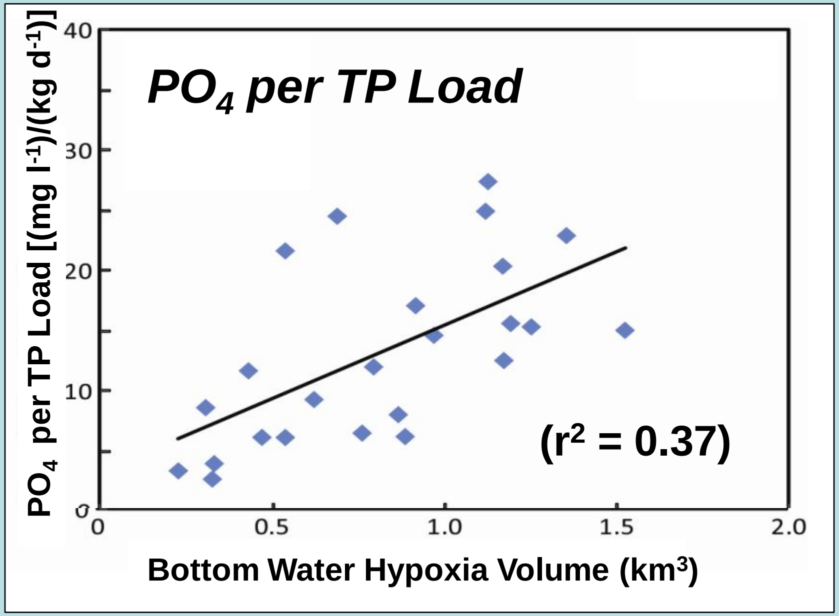
Duration of Hypoxia vs. N-Loading



(Murphy et al. 2011)

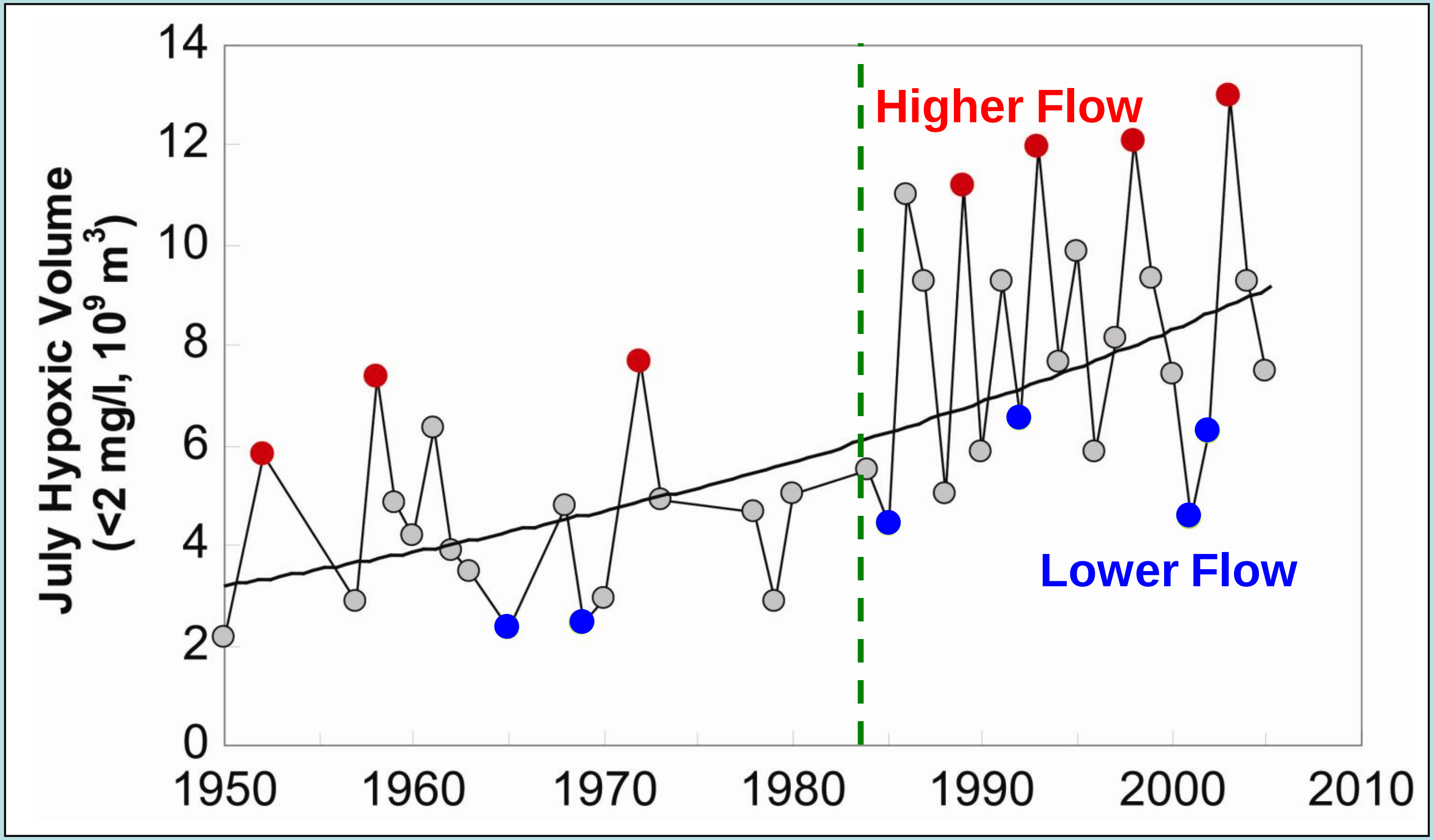
Nutrient Pools per Load vs. Hypoxia Volume





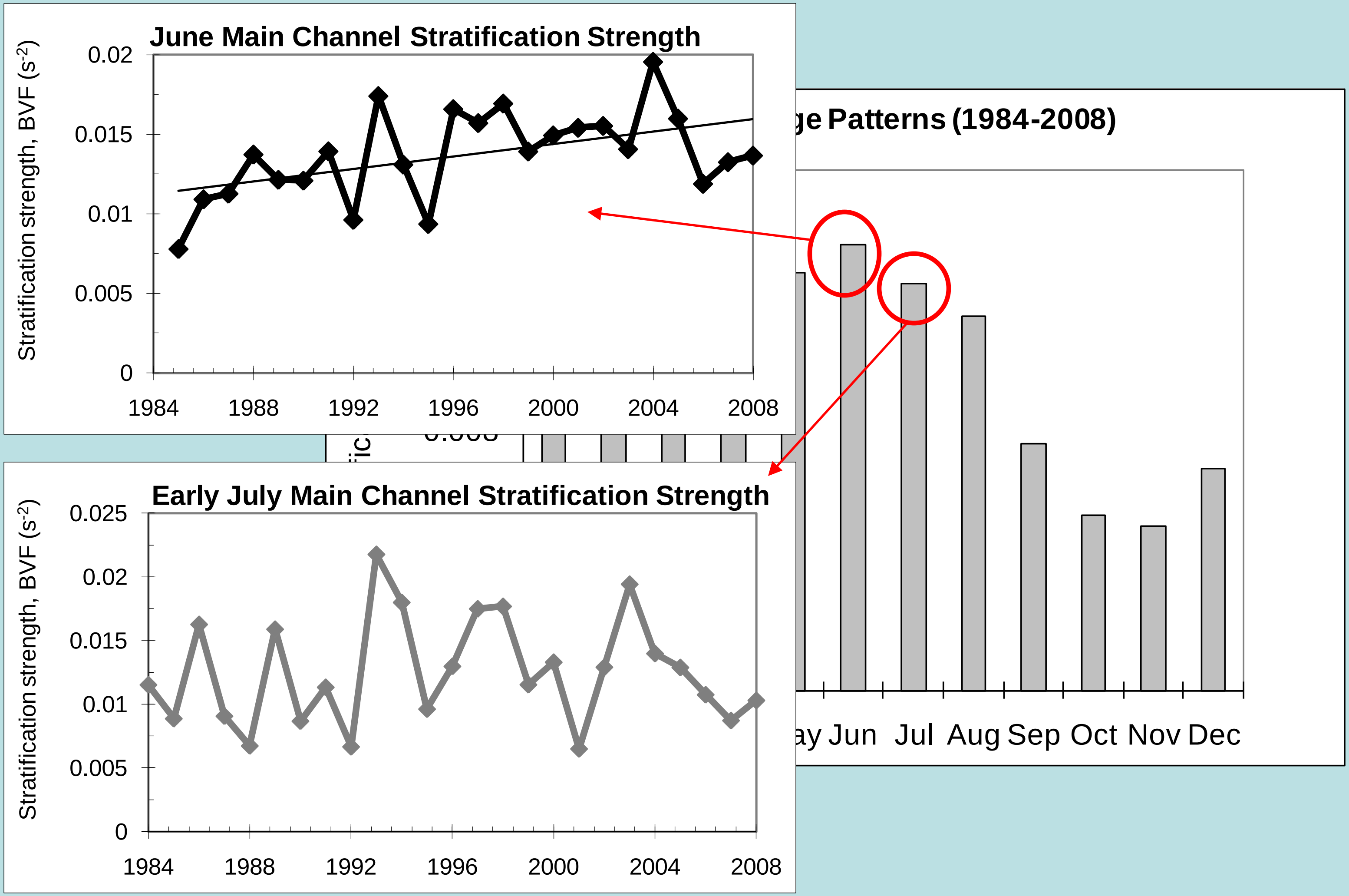
(J.Testa 2011, unpublished)

Trend in Bay July Hypoxic Volume



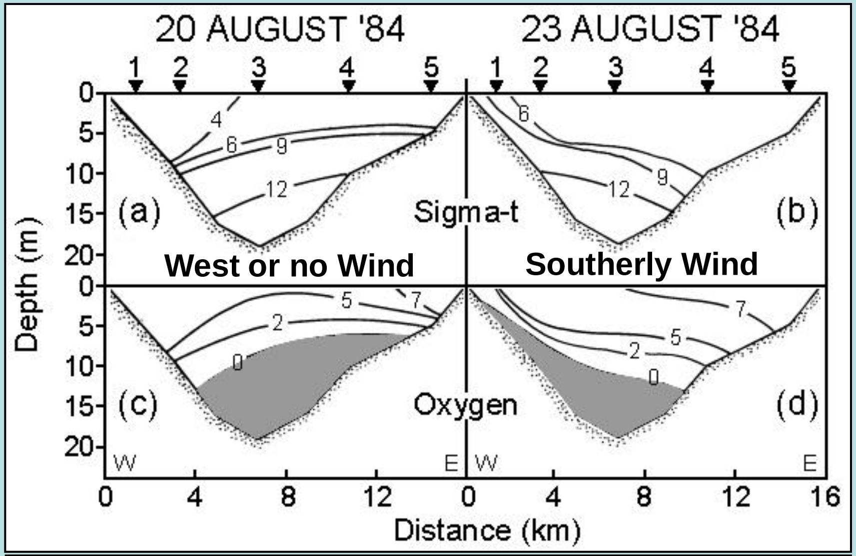
(after Hagy et al. 2004)

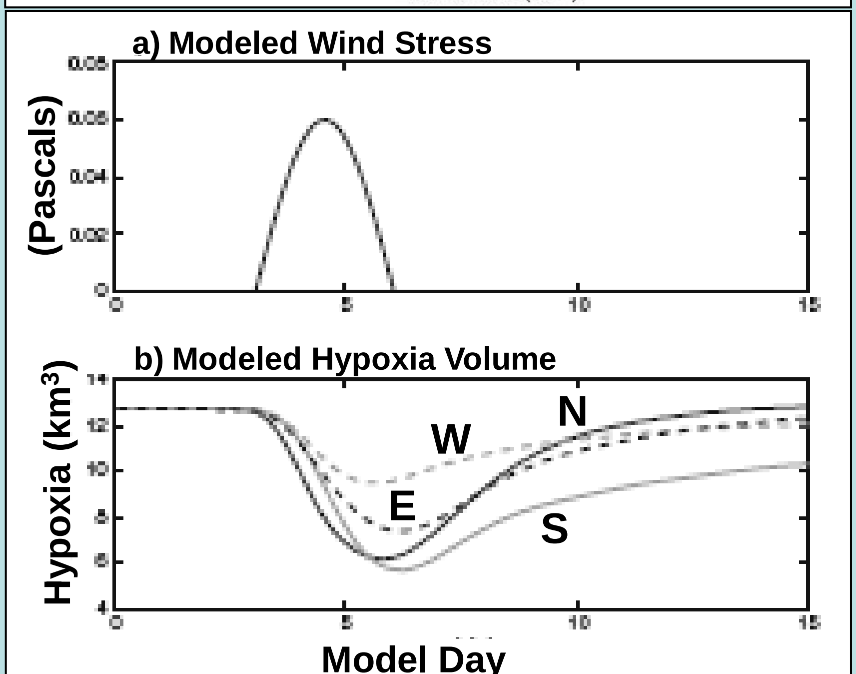
Results: Stratification Trends



(Murphy et al. 2011)

Climate: Summer Wind Direction Affects Hypoxia





- Cross-section looking up-Bay
- With no wind Coriolis causes fresher water to pile on west side
- Wind from South pushes surface water up-Bay causing up-tilt to West
- Hypoxic bottom water approaches air-water surface & is oxygenated

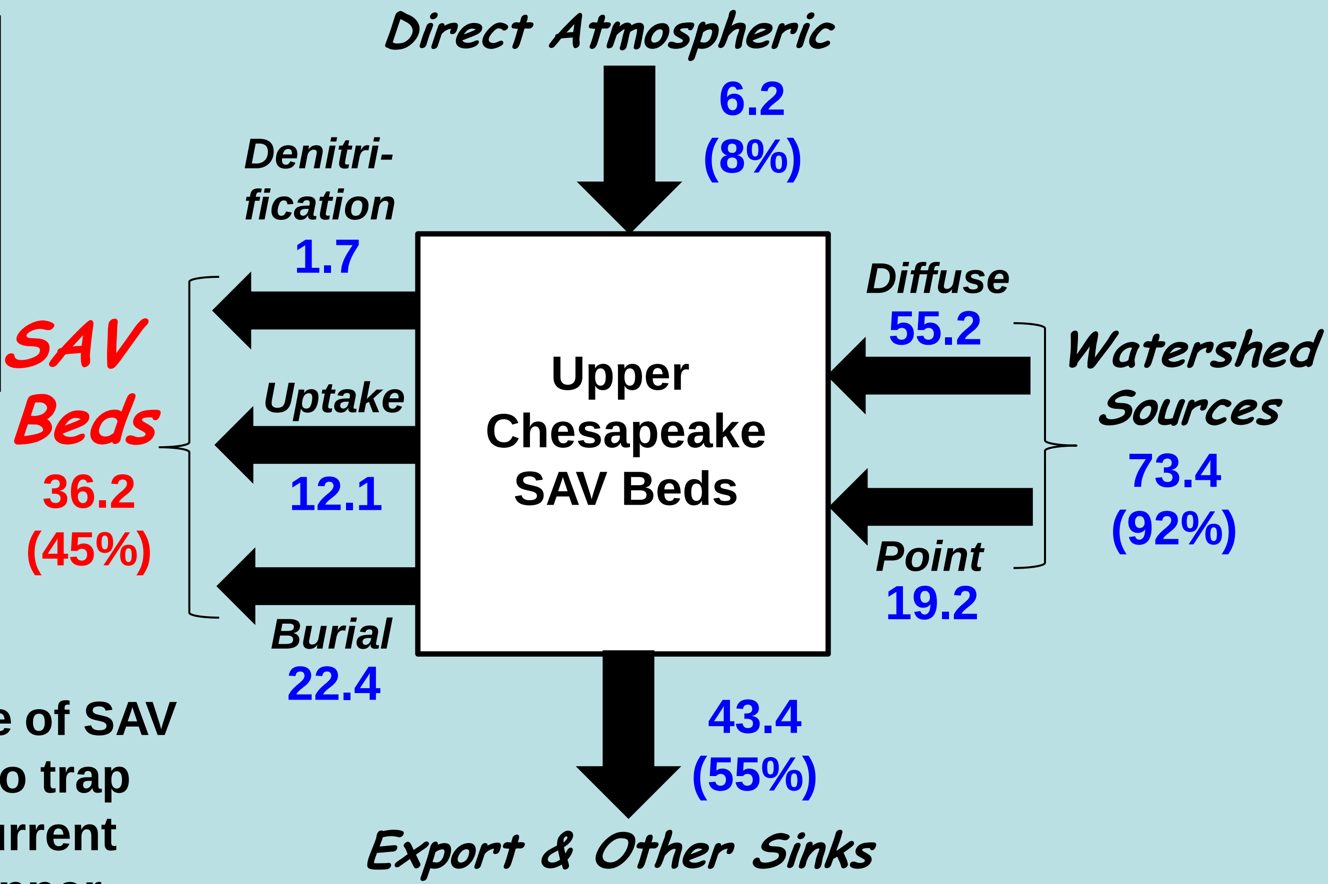
(Malone et al. 1986 MEPS)

- Using ROMS circulation model with simple respiration algorithm
- Apply 3-day wind pulse from different directions
- Hypoxia volume declines for all winds, but most from South and least from West

(Scully 2010 E&C)

Present Susquehanna Flats SAV Form Broad Dense Meadow

SAV Beds Remove Nitrogen from Bay Water

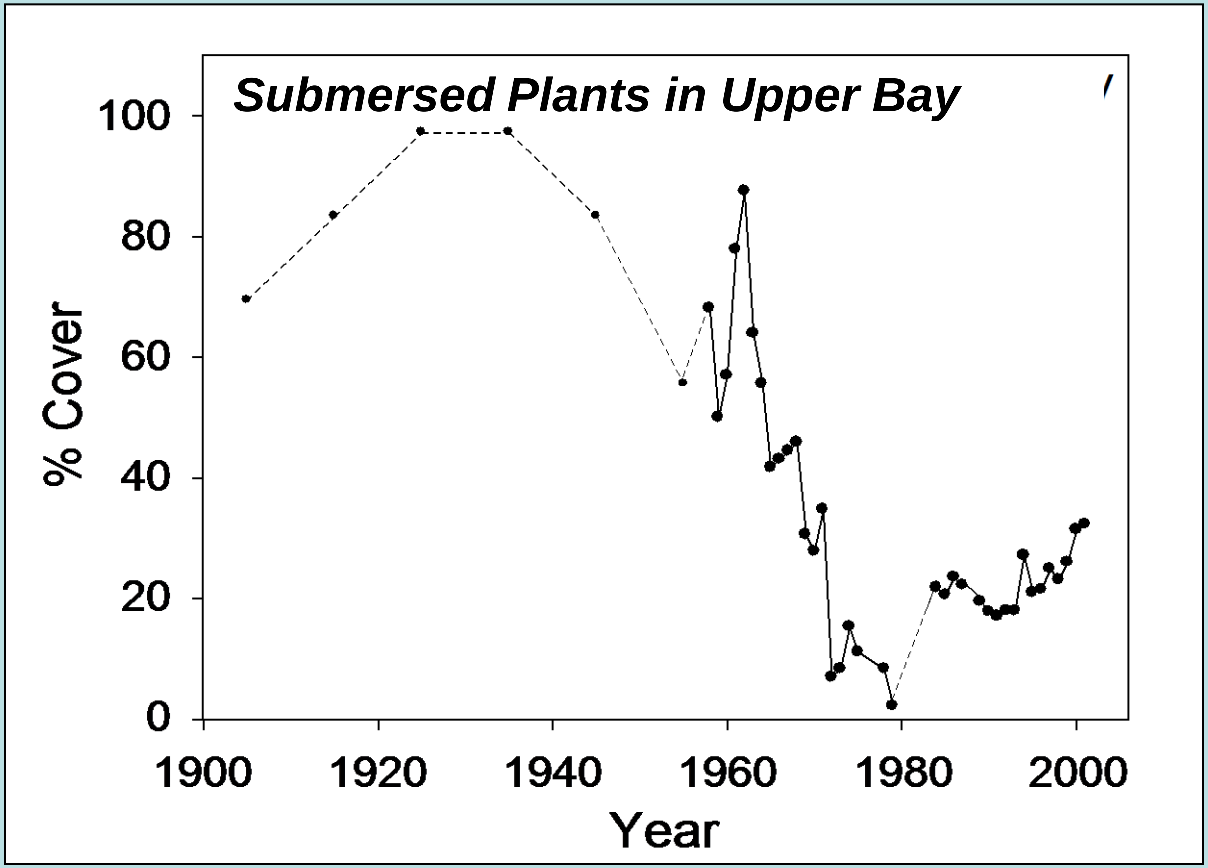


Historical abundance of SAV beds was sufficient to trap and store ~45% of current inputs of total N to Upper Chesapeake Bay, thus reducing eutrophication.

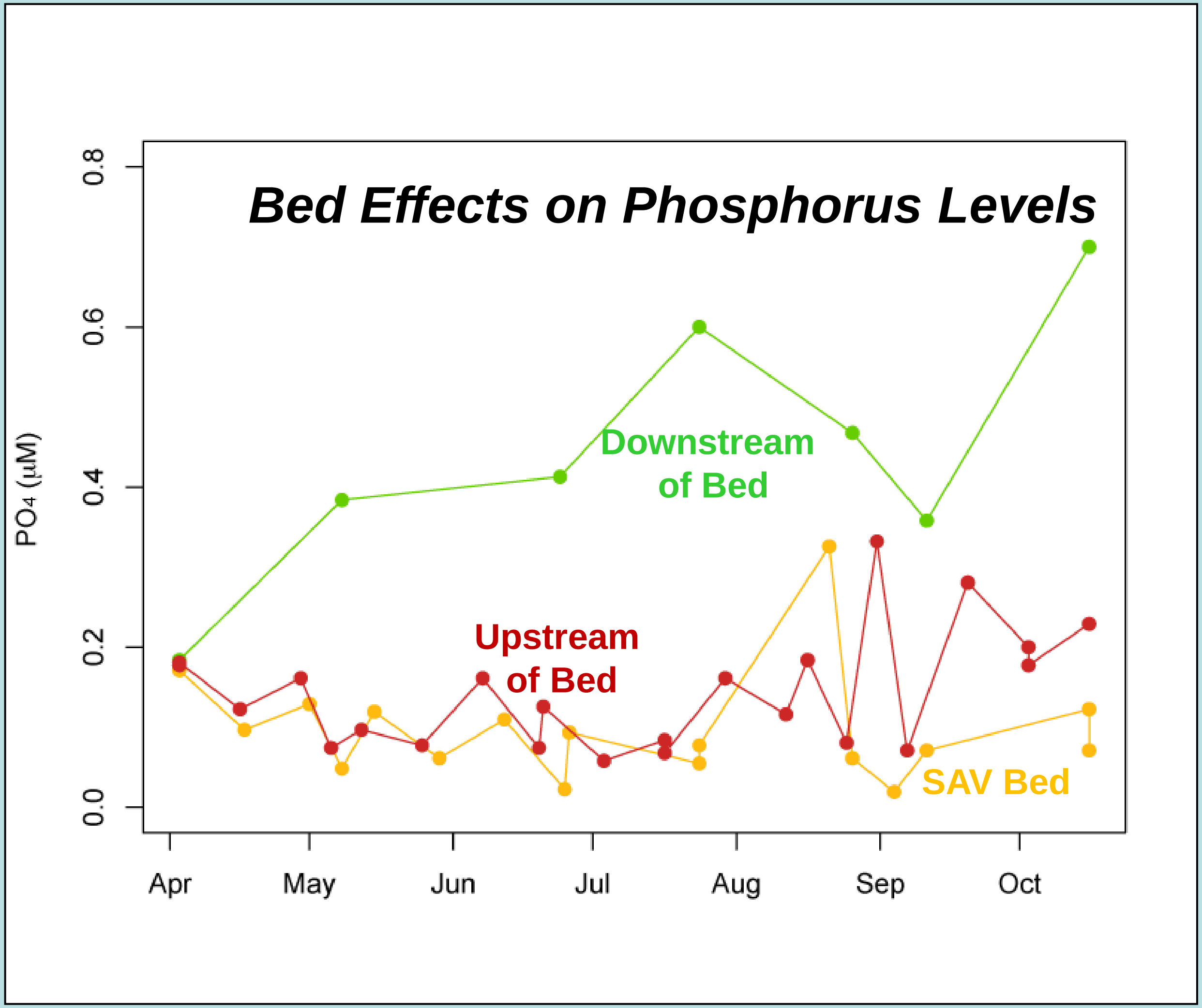
(Flows: 10^6 kg N yr^{-1})

(Kemp et al. 2005)

Submersed Plant Trends in Susquehanna Flats

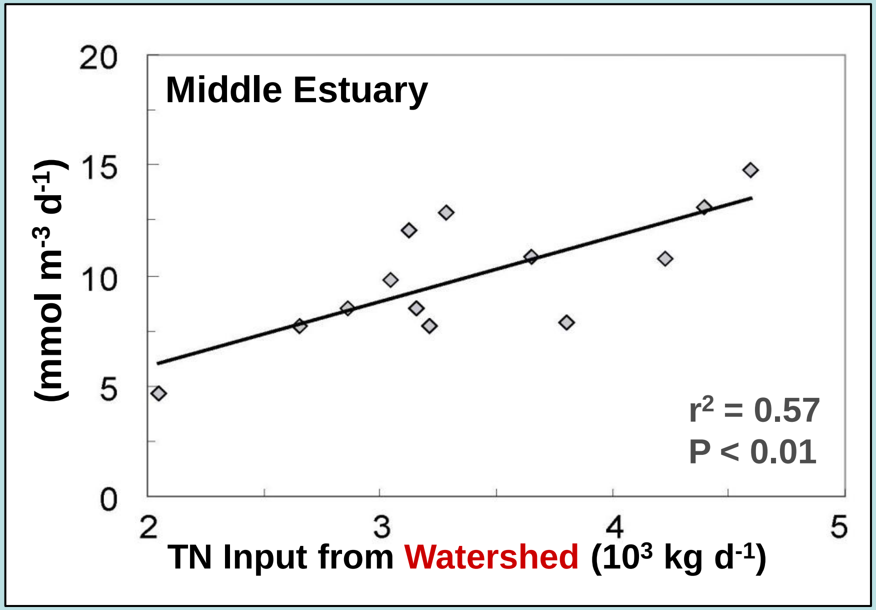


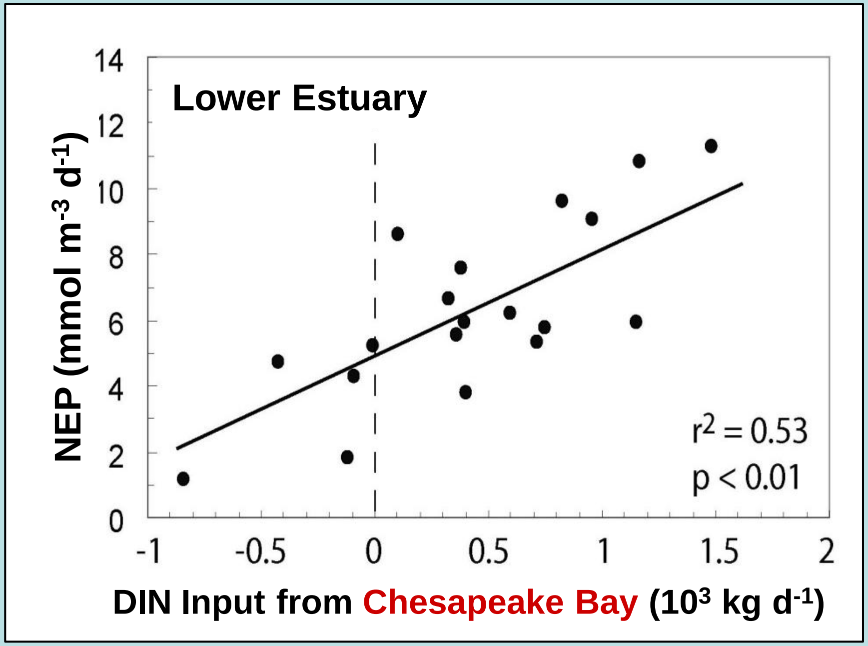
- **Sharp SAV decline in upper Bay in early 1960s**
- **Modest recovery since mid-1980s, but still only 30% of former levels**

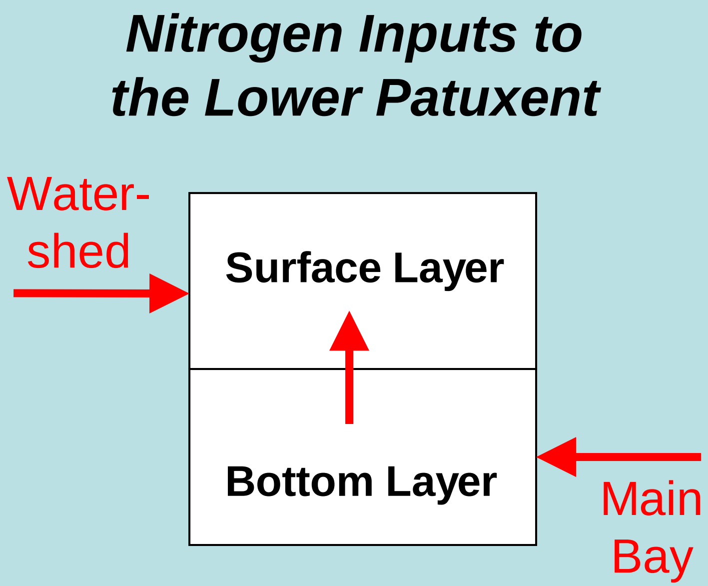


(www.eyesonthebay.net)

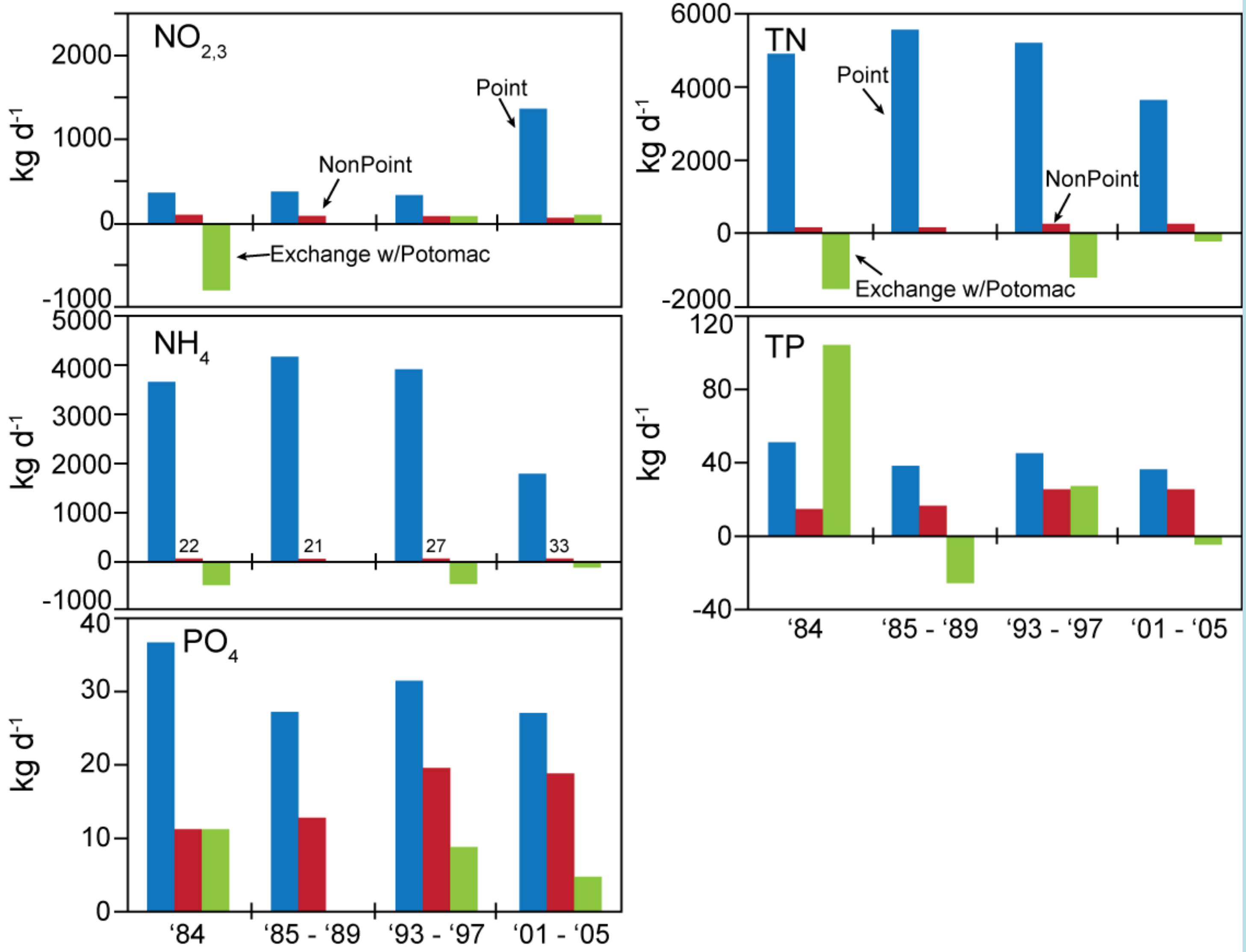
Regional NEP Trends Driven by Different N Sources





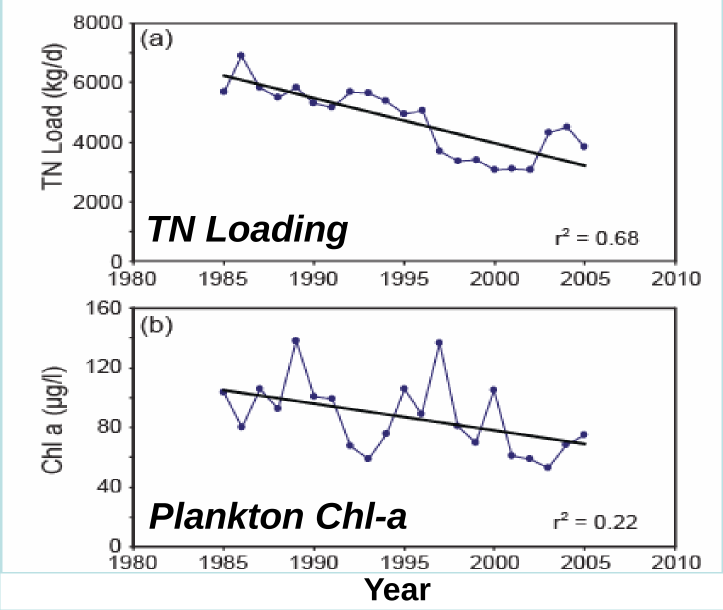


Mean Flux

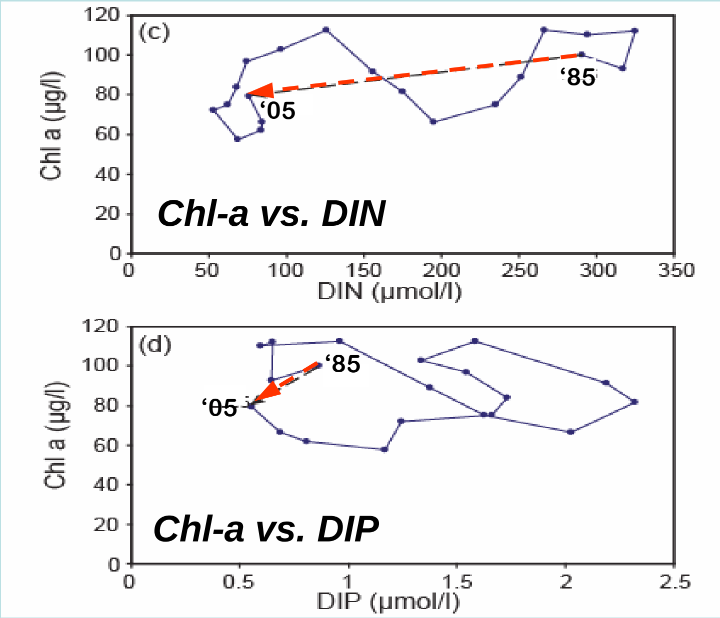


NO2,3
Point
NonPoint
Exchange w/Potomac
kg d-1
2000
1000
0
-1000
NH4
5000
4000
3000
2000
1000
0
-1000
22
21
27
33
PO4
40
30
20
10
0
'84
'85 - '89
'93 - '97
'01 - '05
TN
6000
4000
2000
0
-2000
TP
120
80
40
0
-40

Responses to N&P-Reduction: Back R. Tidal Fresh

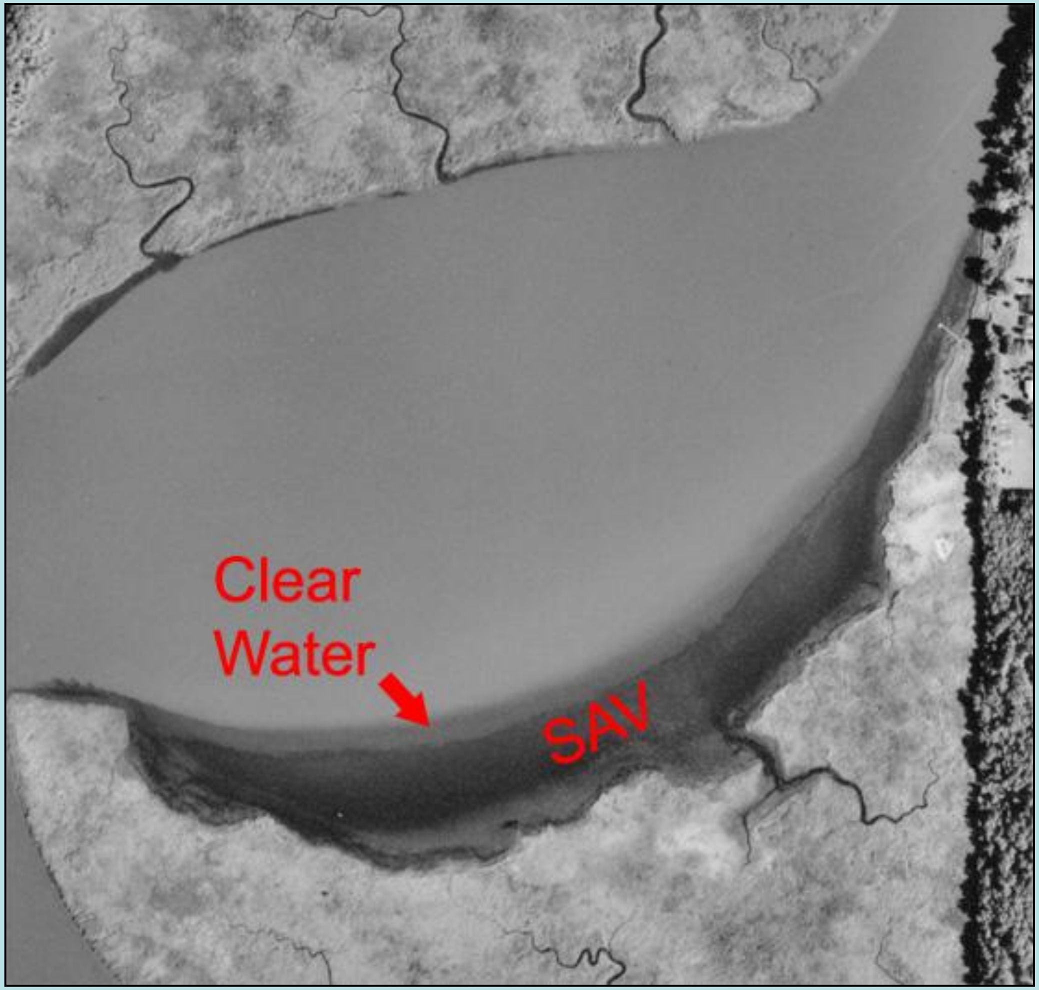


- *Back R. Estuary* located north of Baltimore in oligohaline region of Bay
- TN loading decreased by ~50% from 1985 to 2005
- Phytoplankton Chl-*a* decreased by 30% during that time, with strong inter-annual variability



- Chl-*a* was weakly related to DIN (annual means) with shallow slope
- Chl-*a* was not related to DIP, and no trend over two decades
- Note that mean 2005 levels of DIN (~75 µM) & DIP (0.6 µM) are well above limiting levels

Small Increase in Water Clarity Stimulates SAV Growth in Shallow Habitats

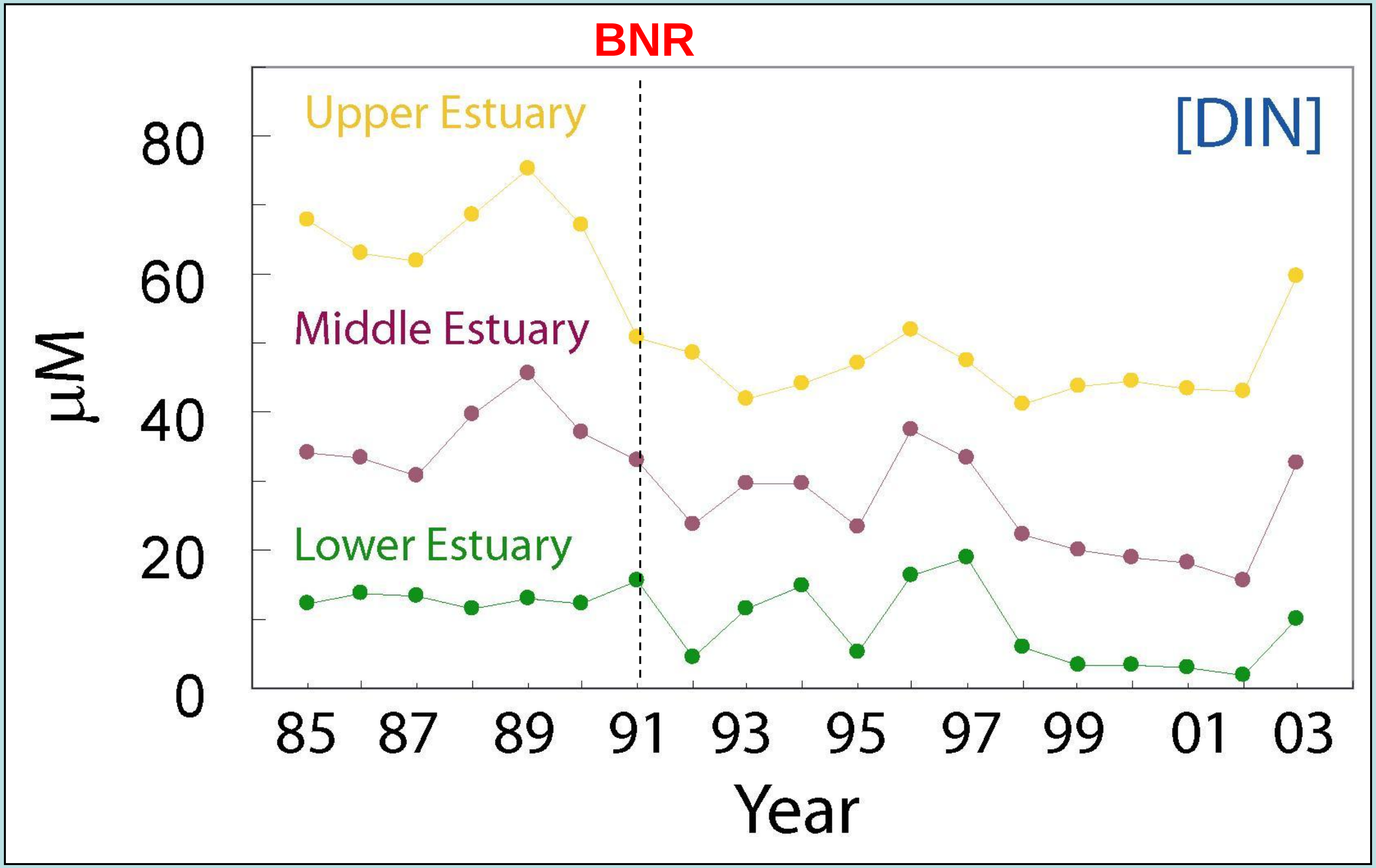


- Water still turbid in open water, but enough light penetrates to ~0.7m

- Once growth is initiated, SAV expand to deeper water due to ‘feedback effect’ clearing water

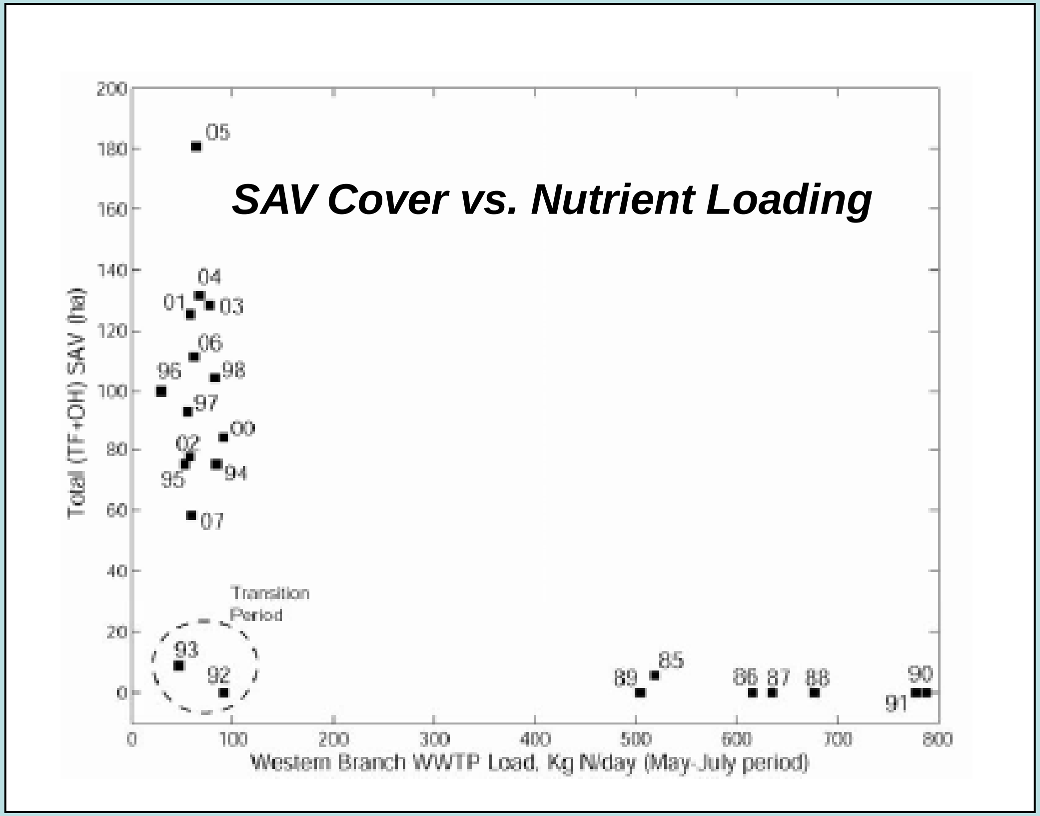
- Note this effect in aerial photograph

Declining Trends in DIN Concentration



- Strong DIN decline in upper estuary, especially in early 1990s
- Weak DIN decline in middle estuary, especially in lower estuary
- Similar declines in DIP

Threshold Nutrient Level for SAV Recovery



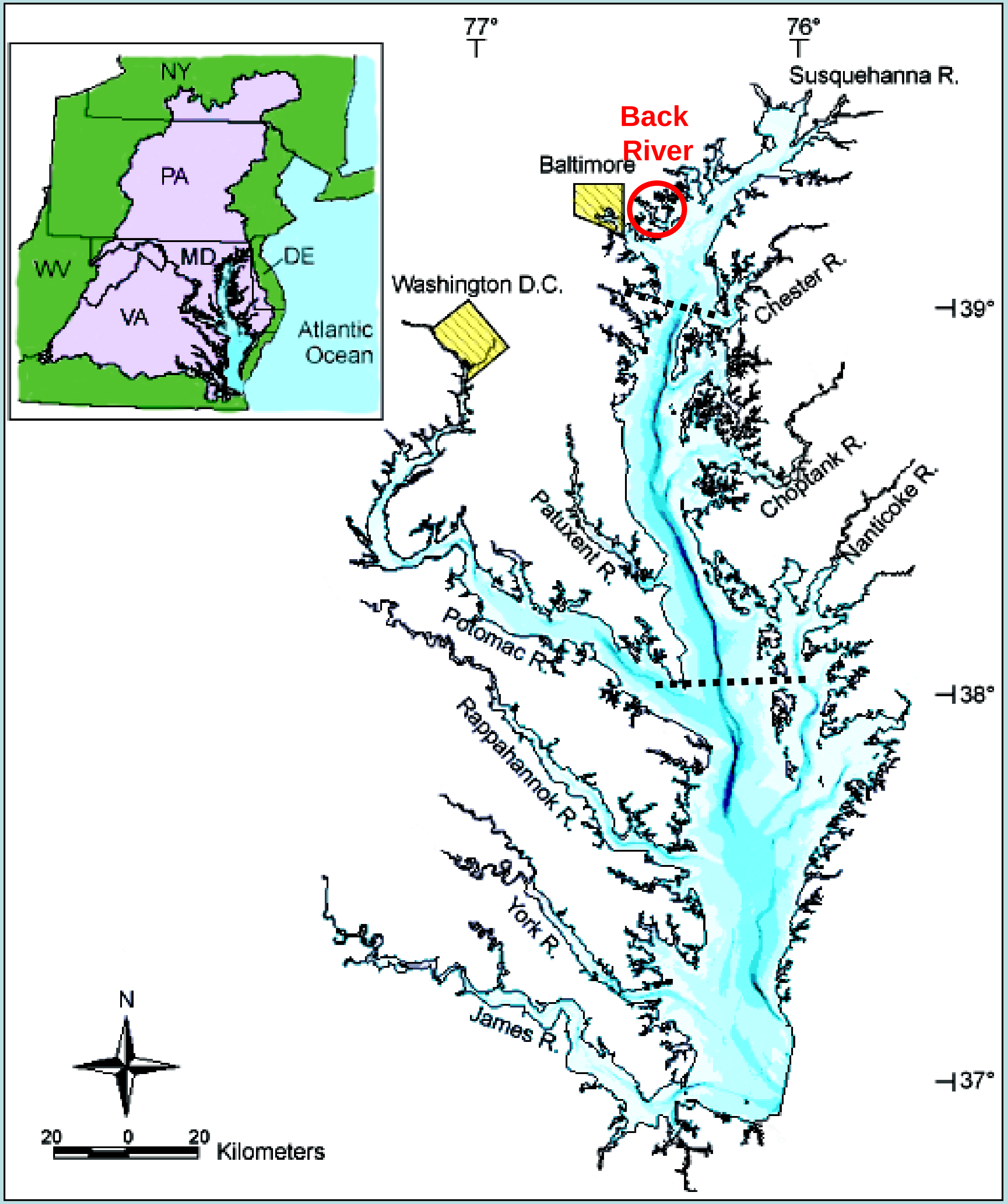
Motivation—Why is this an Important Problem?

- **Coastal eutrophication is a globally pervasive problem!**
- **Coastal systems are tightly linked to their watersheds.**
- **Major societal initiatives are underway to reduce watershed nutrient loading.**
- **We need to know what to expect in terms of timing and magnitude of response to expensive nutrient remediation.**

Chesapeake Bay:

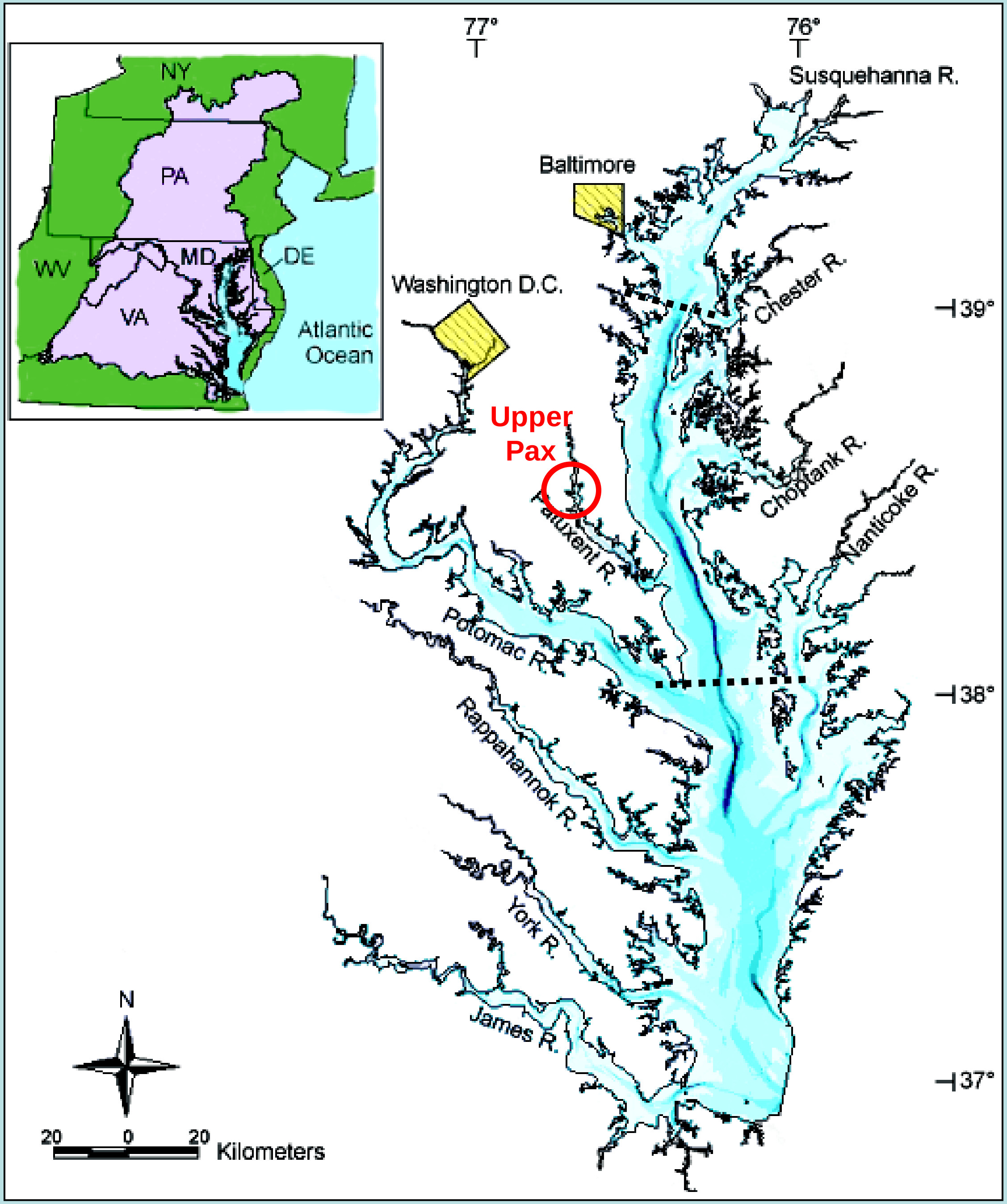
Back River Estuary

- Urban watershed near Baltimore city
- Low salinity tributary of Chesapeake Bay
- Point source inputs dominate from treatment facilities
- Recent Reductions in N and P loading



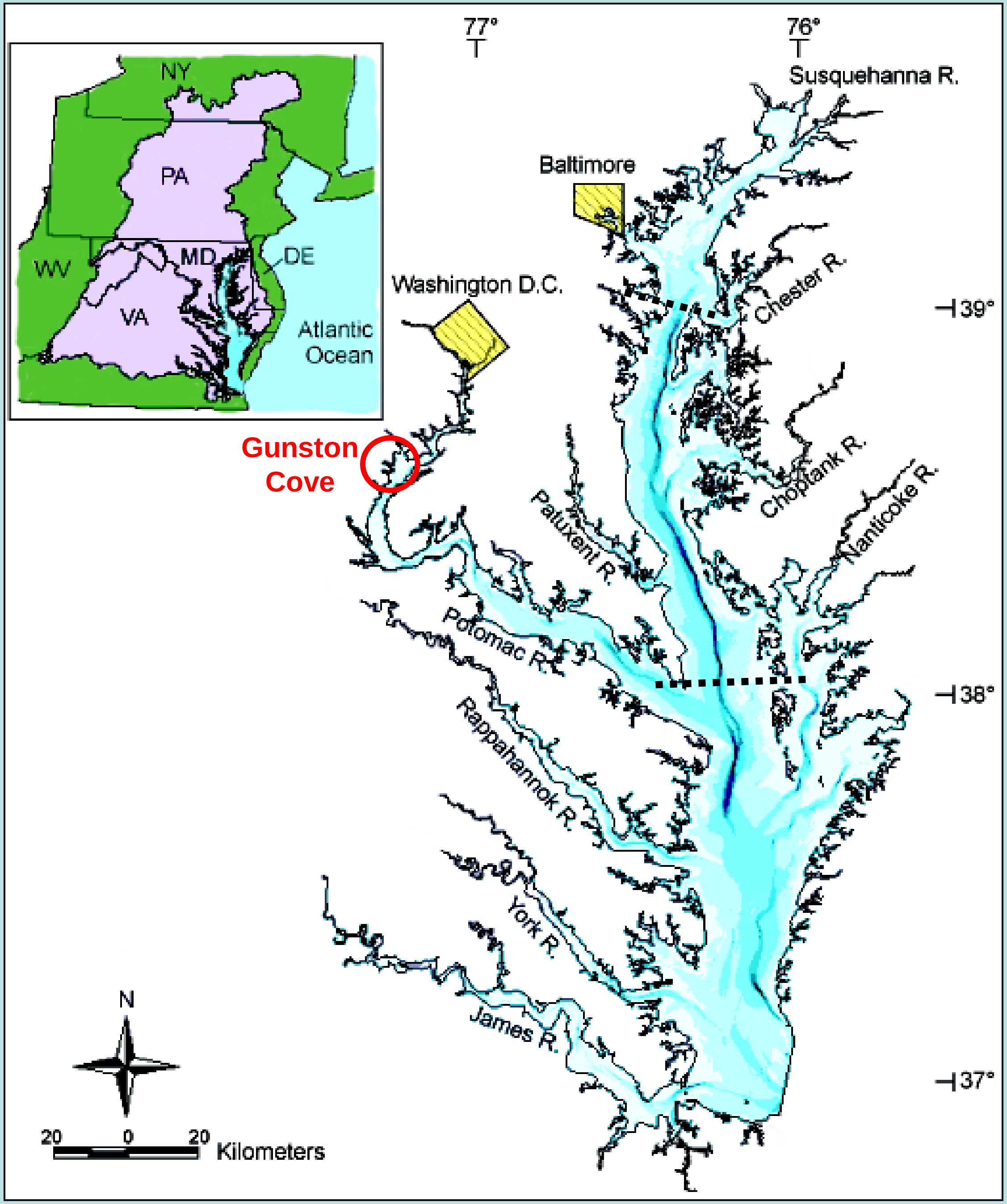
Upper Patuxent R: 'Rapid Response'

- Tributary of Ches. Bay
- Mostly suburban land-use in watershed
- Major reduction in point source N and P inputs
- Large & rapid response in low salinity region of estuary
- Reduced turbidity and recovery of shallow SAV
- More saline regions show complex response



Gunston Cove: 'Hysteretic Response'

- **Small shallow tributary of Chesapeake Bay & Potomac River estuary (tidal fresh)**
- **Reduced P loading from Wash, DC point sources and local diffuse sources**
- **Response to in P-load reductions were delayed with hysteresis**
- **Purging of P pools in estuarine sediments has caused delayed response**

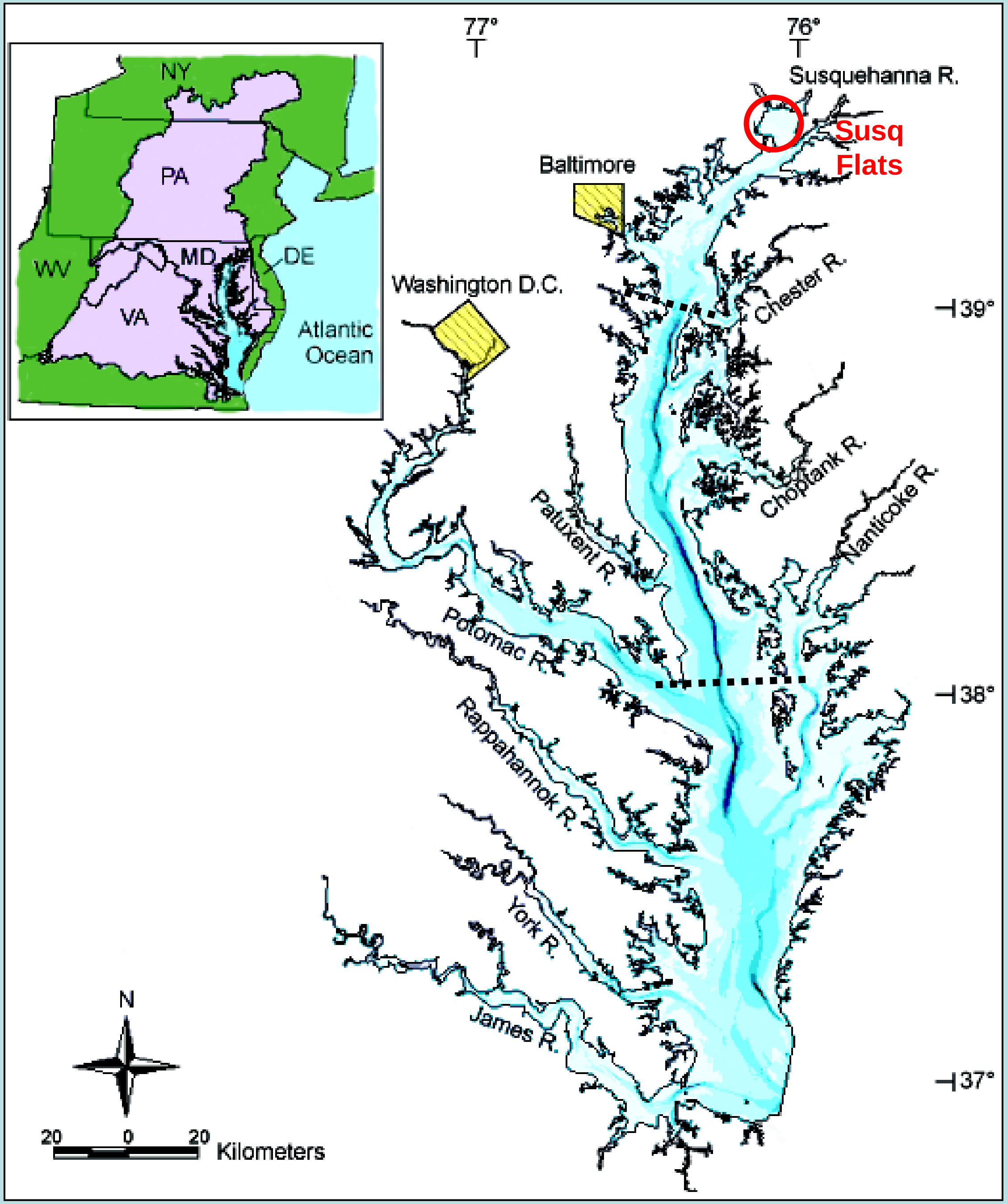


Chesapeake Bay

Susquehanna Flats:

'Spontaneous Recovery'

- **Very large shallow area at the head of Ches. Bay**
- **Dominated by shallow water (< 2m depth)**
- **Broad near-shore areas (mean depth 0.5-1.0 m)**
- **Sparse SAV beds in 1980s showed explosive growth after 2000**



Chesapeake Bay

Mid-Bay Mainstem: 'Regime Shift'

- Deep channel is seasonally *stratified*
- North-South orientation with large fetch to prevailing winds
- Relatively long water residence time (~ 6 mo)