

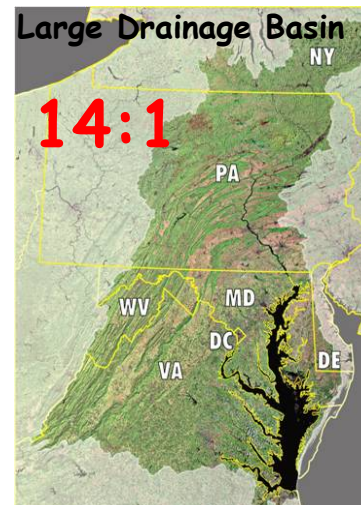


CHESAPEAKE BAY RESTORATION: History, Lessons Learned, Successes and Major Challenges

*STAC Presentation
Annapolis, MD*

June 2017

- 17 Million people
- Mixed land uses
- Shallow but seasonally stratified
- Estuary "flushes" slowly (4-6 mo)
- Many rivers connect land to Bay



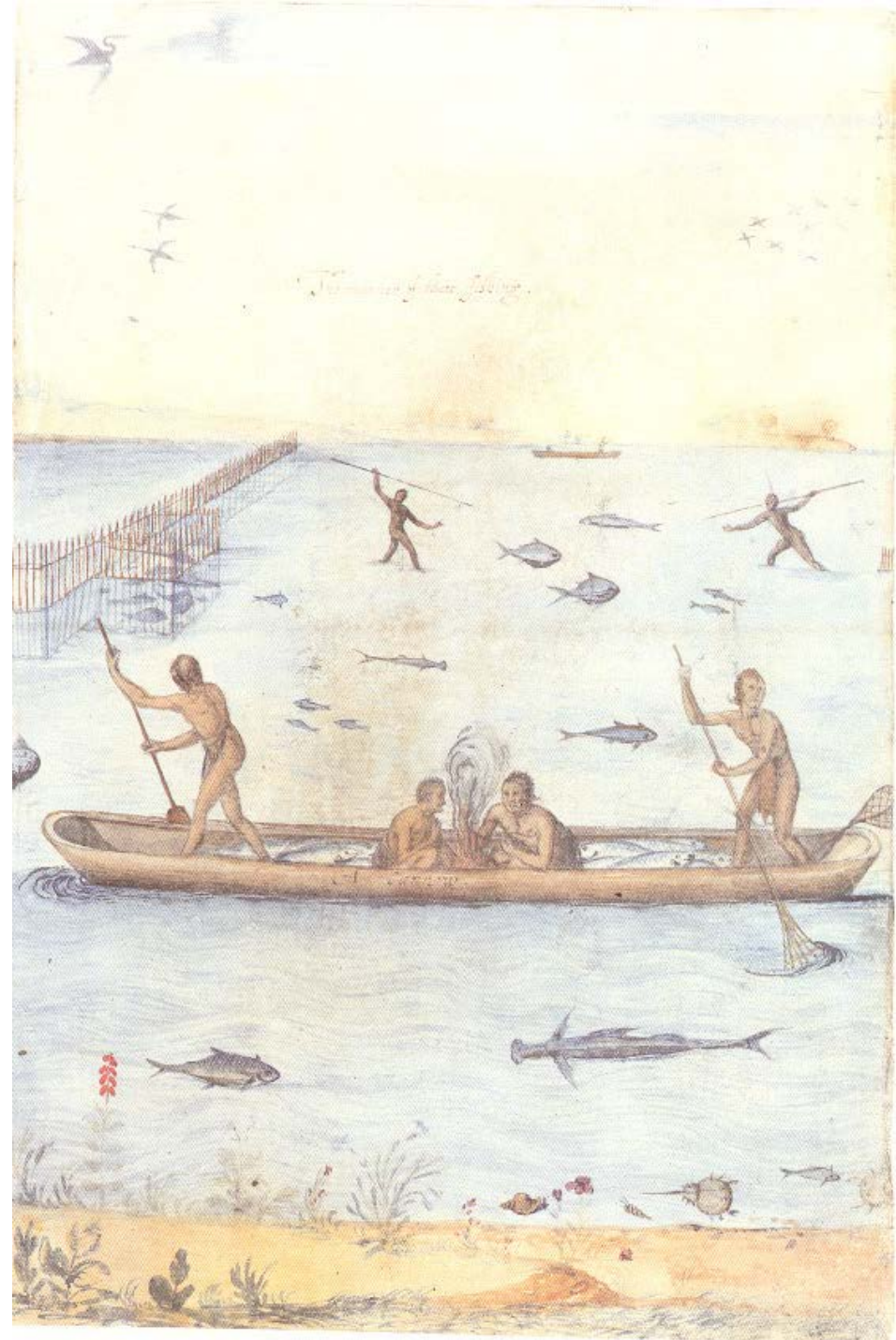
**Walt Boynton and
Many Colleagues**

Chesapeake Biological Lab,
Center for Environmental
Science, Univ MD

A Famous Chesapeake Bay Painting

- Clearly, fish were important
- Emphasis on shallow waters...and there are lots of these everywhere
- **CLEAR WATER** and **SAV**...a clear water benthic dominated painting and likely a benthic dominated ecosystem

From T. De Bry in Harriot 1588



A John Smith Diet

- Traded with natives for corn, venison, fish, oysters, nuts, beans, pumpkins...traded swords for turkeys (a 1 for 1 deal...probably not a good deal for the English)
- Tobacco... "it purges the superfluous phlegm and other gross humours and openeth all the pores and passages of the body" from Harriot who died of a nasal tumor in 1621...the 400 year tobacco wars are still with us.
- Jamestowners preferred a seaman's diet of pork, beefe, fish, wheat and barley (even with the ever present worms)...not too adaptive even when hungry
- Sturgeon (dried and pounded)
- The Starving Time (winter 1609-1610)...cats, dogs, horses and people...this was a very tough life indeed!

Patuxent River Estuary

Circa 1832



"So transparent are its waters that far out from shore you may see, in the openings of the seaweed forest, on its bottom the flashing sides of the finny tribe as they glide over the pearly sands." *The Old Plantation by Hungerford (1859)*

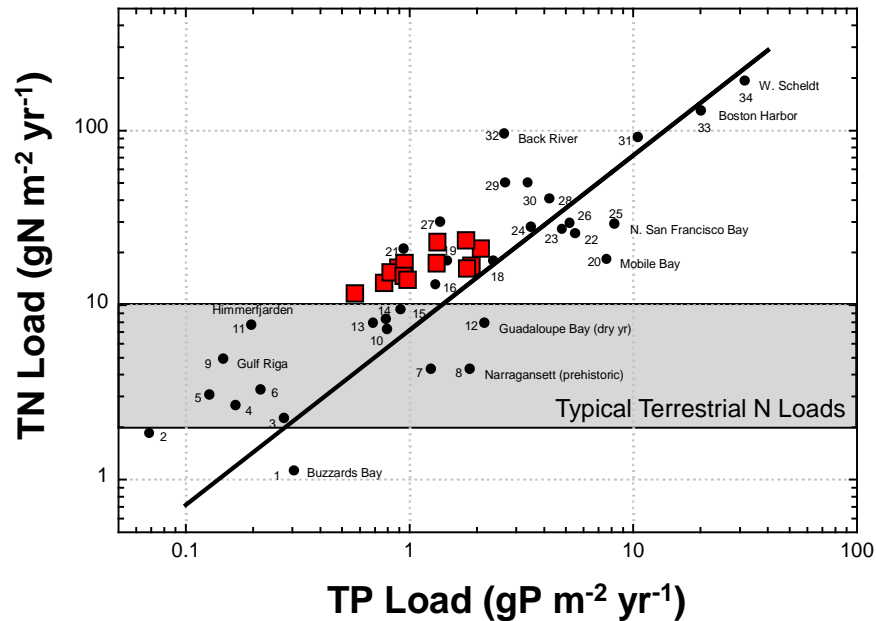
Water Quality and Habitat Conditions can be much improved...not to the 1832 condition and that may not be the optimal status

Major Events in Chesapeake Bay History: Science, Management and Politics

- 1950-60s: Pollution not possible in estuaries because of tidal flushing. The Bay is just fine and productive. Almost no "Estuarine Science" literature available
- 1960s: There is nothing ...and we mean nothing...wrong with Chesapeake Bay. Reports of pollution are false and unpatriotic. You can be fired for this sort of loose talk
- 1960-70s: The more nutrients we can pour into the Bay the better...farmers know that fertilization is good so lets get on with fertilizing the Bay. About 90% of SAV are gone and the causes are unclear
- 1970-80s: So, OK estuaries can be polluted...big deal. The only thing needed for restoration is control of PHOSPHORUS and that's easy. Restoration efforts need to focus on POINT SOURCES
- 1980-90s: Both NITROGEN and PHOSPHORUS from MANY SOURCES are killing Bay habitats ...the bay is nutrient obese and needs a nutrient diet...big time
- 2000-17: Restoration is hard and expensive. Fears that all aspects of the Bay have long memories proven false...Bay is responsive. However, pathways to restored conditions are not simple....expect some surprises

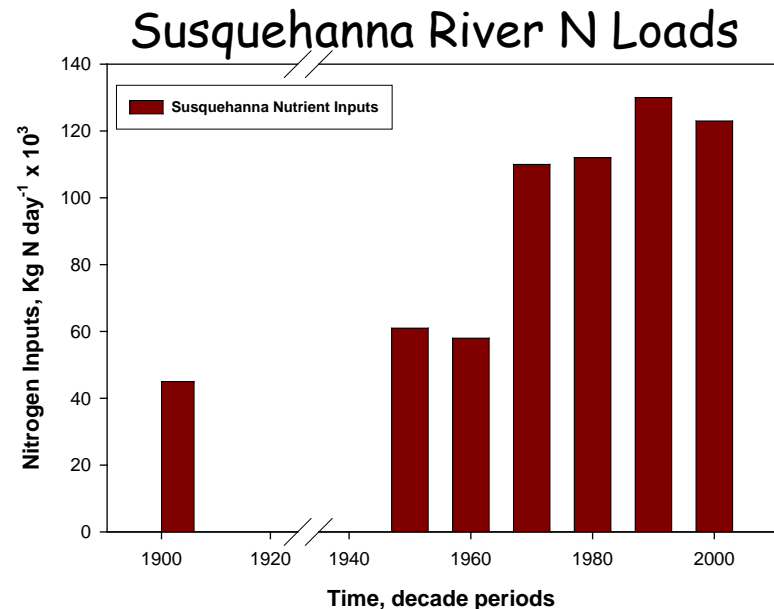
Nutrient Input Data More Available NOW

Nutrient Loads to Estuarine Systems

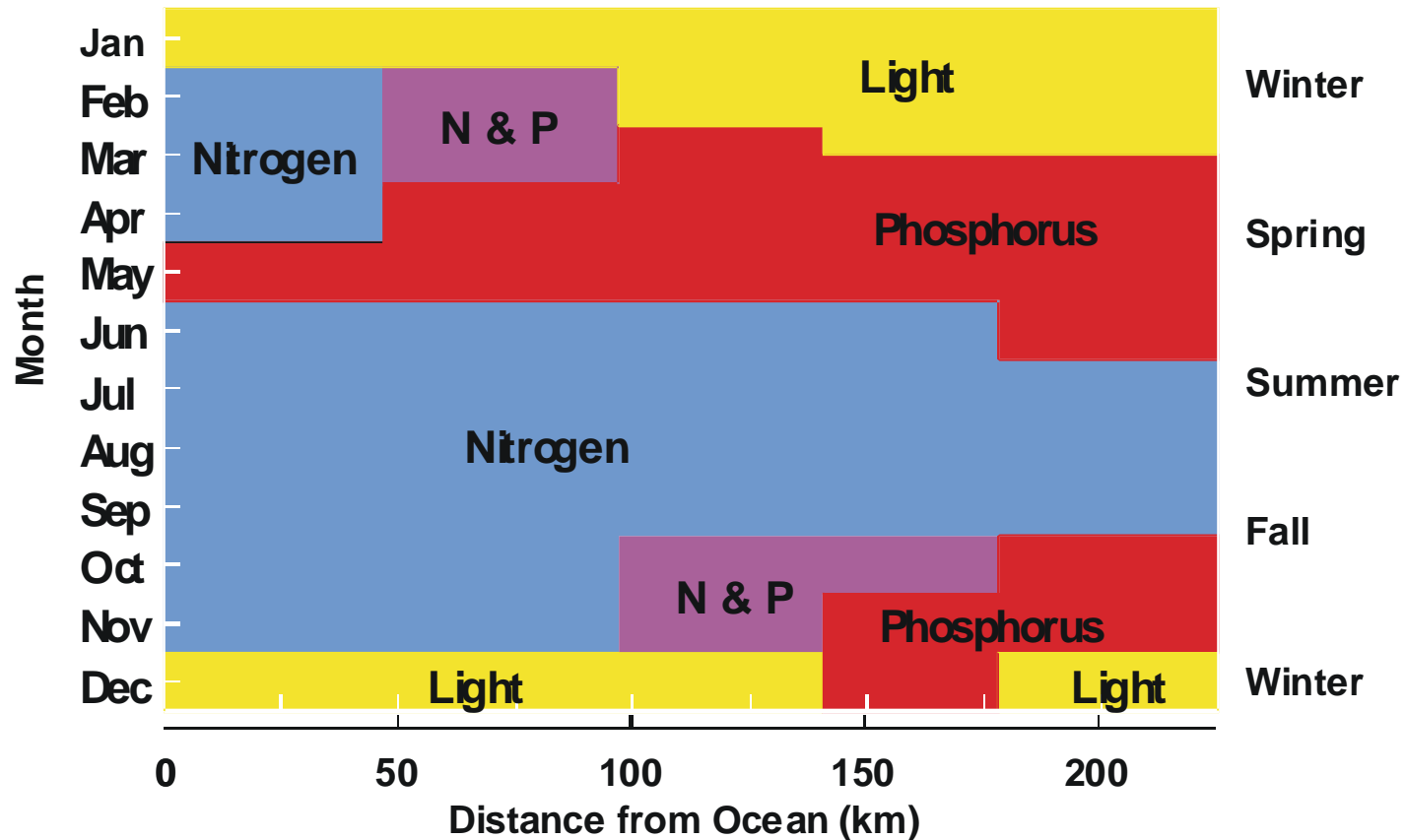


- Range in N and P loads ~ 2.5 orders of magnitude
- Inter-annual variability $\sim 2X$
- Many USA estuaries show a $\sim 2-3X$ increase during the 1960s-1980s

Not all estuaries respond in the same way to nutrient loads (e.g., Chesapeake Bay versus San Francisco Bay)



N versus P limitation in Chesapeake Bay and other estuaries largely resolved: dual nutrient reduction strategy is often needed



From Fisher et al. (1992)

Solomons Island SAV - 1933



Solomons Island SAV - 1963



THE SEAGRASS DECLINE HYPOTHESES

"Wild Guesses, Fond Hopes and Sacred Cows"

CONCEPT	MECHANISM	SUPPORTERS
• Boat Wakes	Wave action from boats increases turbidity shading plants; plants are uprooted	Some environmentalists Shoreline residents
• Toxics from Point sources	Toxics (CI) from power plants and sewage treatment plants kill SAV	MD Dept Nat Res Some fisherman
• Overgrazing/ Disruption by Animals	Animals such as ducks, geese, skates and rays overgraze or physically destroy SAV	Some biologists MAD Magazine
• Natural Cycle	The decline is simply a phase in the natural cycle of SAV abundance; no human influences are involved	Some management agencies Agriculture
• Water Column Turbidity	Some evidence of increased water column turbidity over past 20 years; light reduced enough to kill SAV	Scientists Agencies
• Catastrophic Events	Major hurricane in 1972 lowered salinity, buried plants, disrupted ecology sufficiently to cause SAV loss	Scientists Agencies
Diffuse Source Inputs <ul style="list-style-type: none"> • Herbicides • Nutrients, N&P 	Agricultural herbicides toxic to plants; nutrients cause light reductions sufficient to kill plants	Scientists Agencies Fishermen

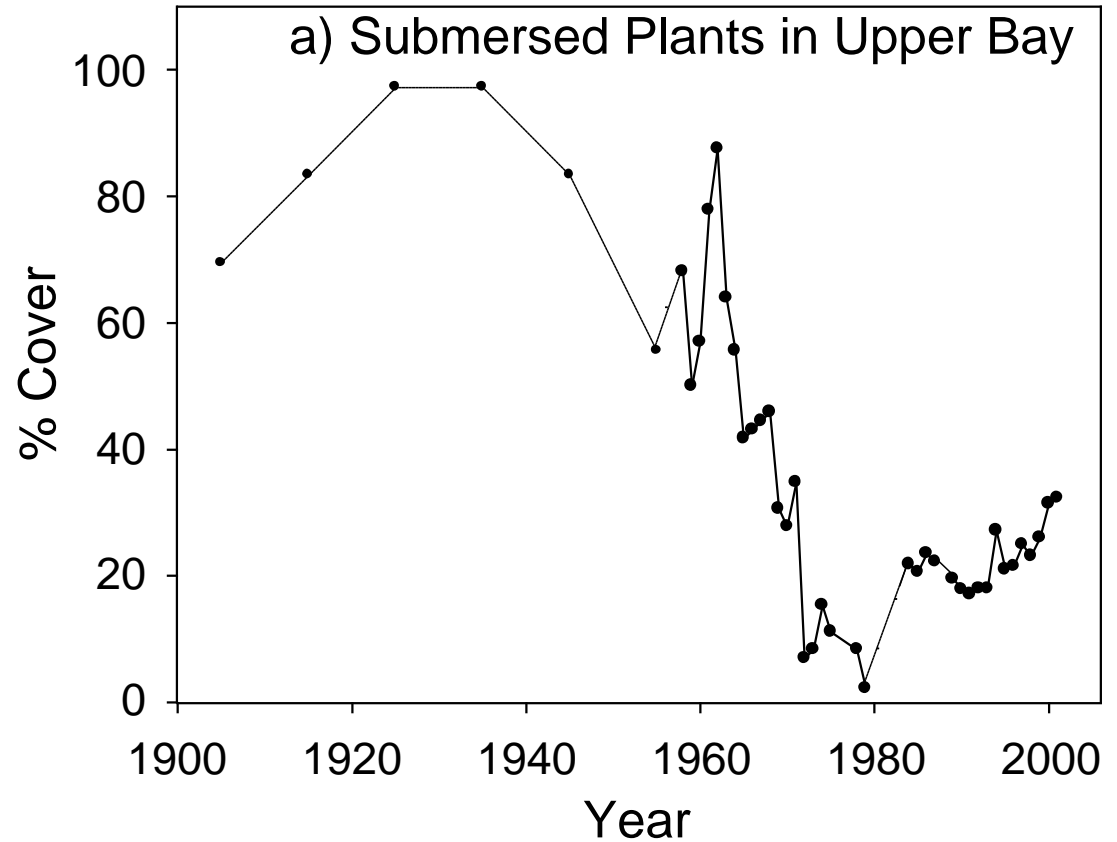


Multiple Hypotheses Often Associated with Environmental Issues

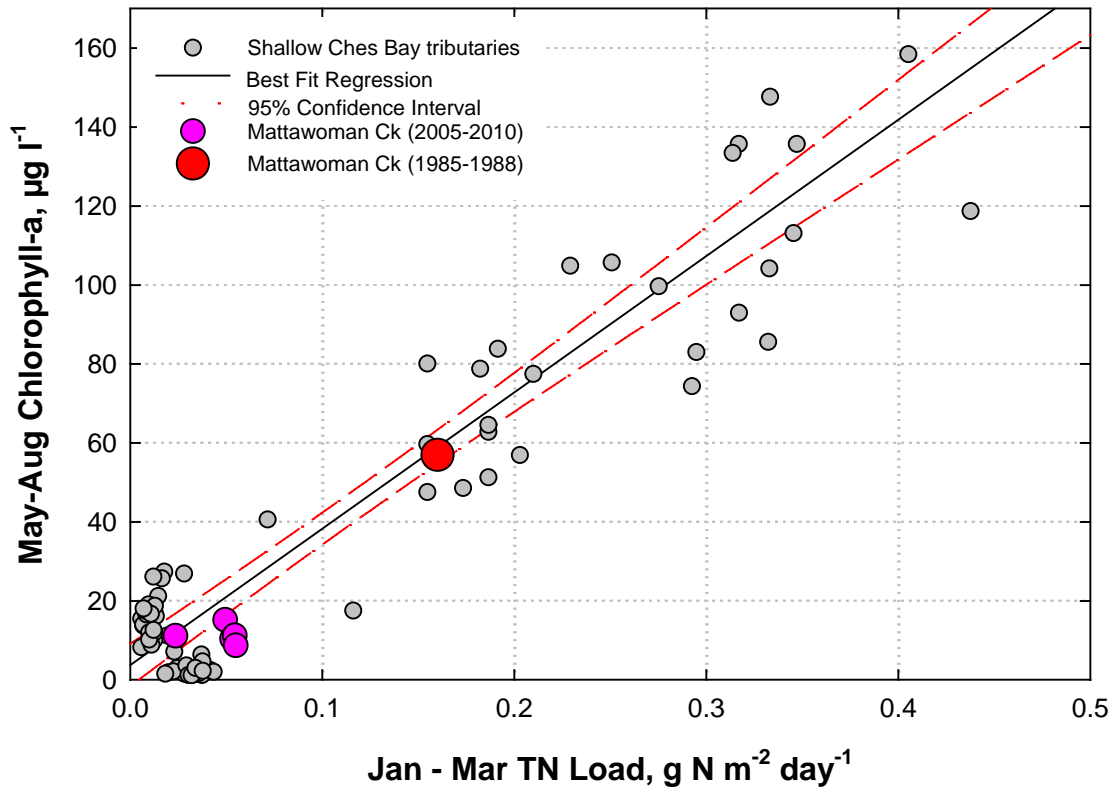
- Typically the case for water quality, habitat and fishery problems
- Lots of "finger pointing" goes on and the basic issue is...It's not me who done it!
- Job of science is to sort out these various ideas

Seagrass Decline in Chesapeake Bay and Other Coastal Systems

- Sharp *decline* in upper Bay and some tributary Rivers in early 1960's
- *Modest recovery* since mid-1980's
- *Nutrients and sediment* increase turbidity and enhance algal growth on SAV leaves... main cause of decline
- A huge *habitat change*

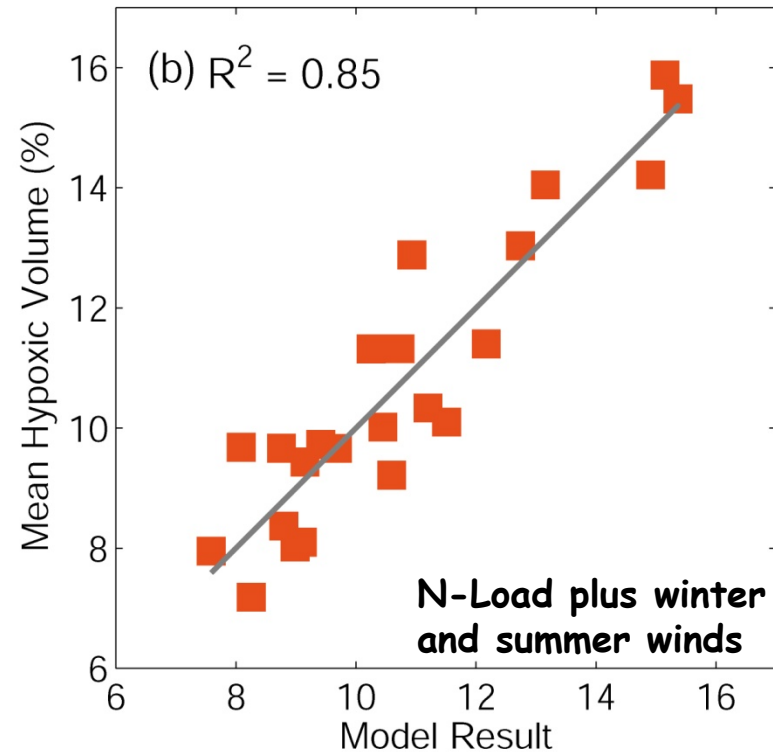
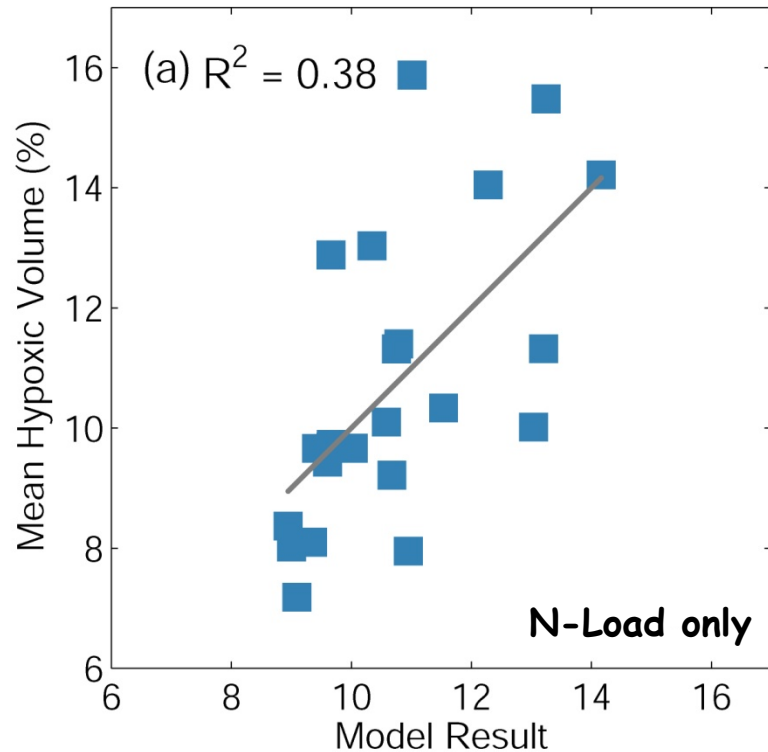


Shallow Estuarine Systems Respond to Nutrient Loads: Algal Biomass Accumulation



- Currently many examples supporting this relationship
- Generally stronger relationships for N than P loading
- Responses tend to be rapid...several years rather than decades (see red and purple dots for restoration site response)

Multiple Factors Involved in Determining Annual-Scale Hypoxia and Other Bay Processes

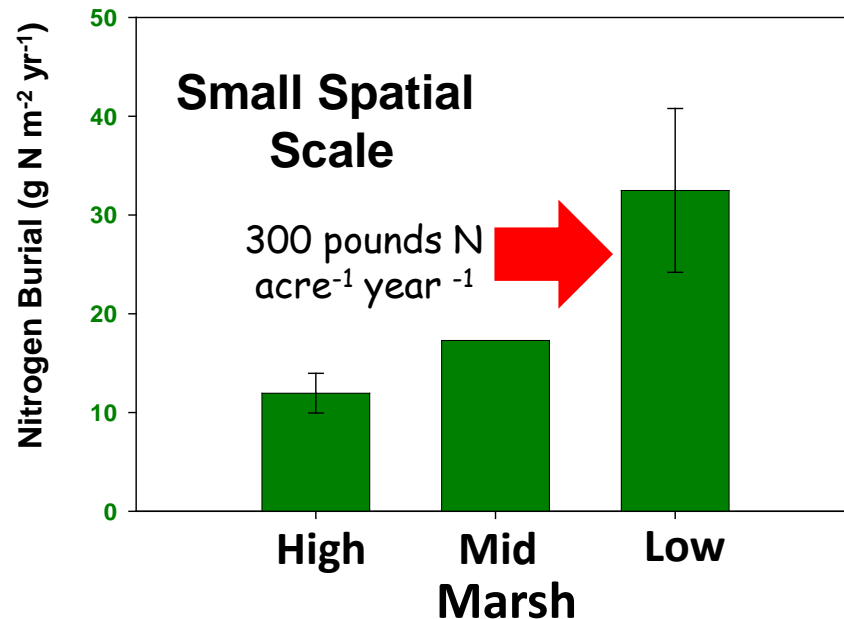
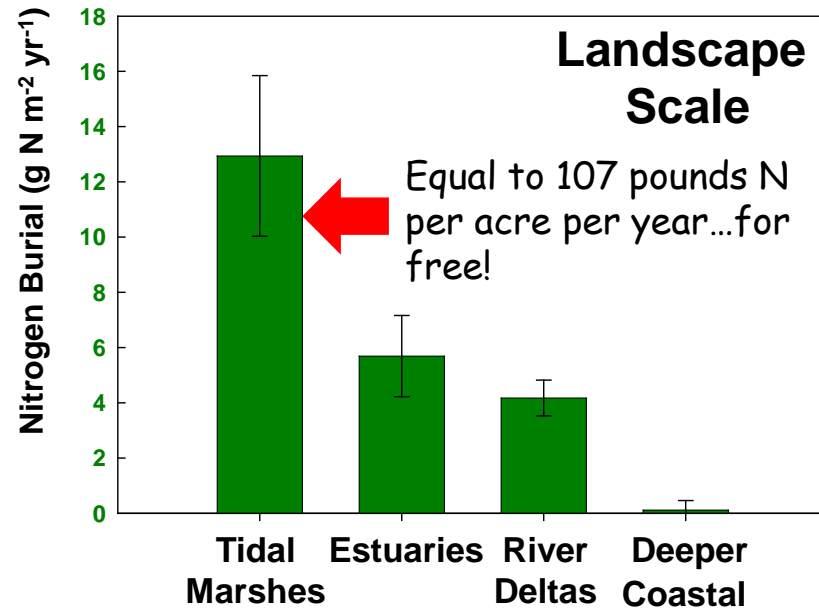


Lets look at Wetlands for a Moment



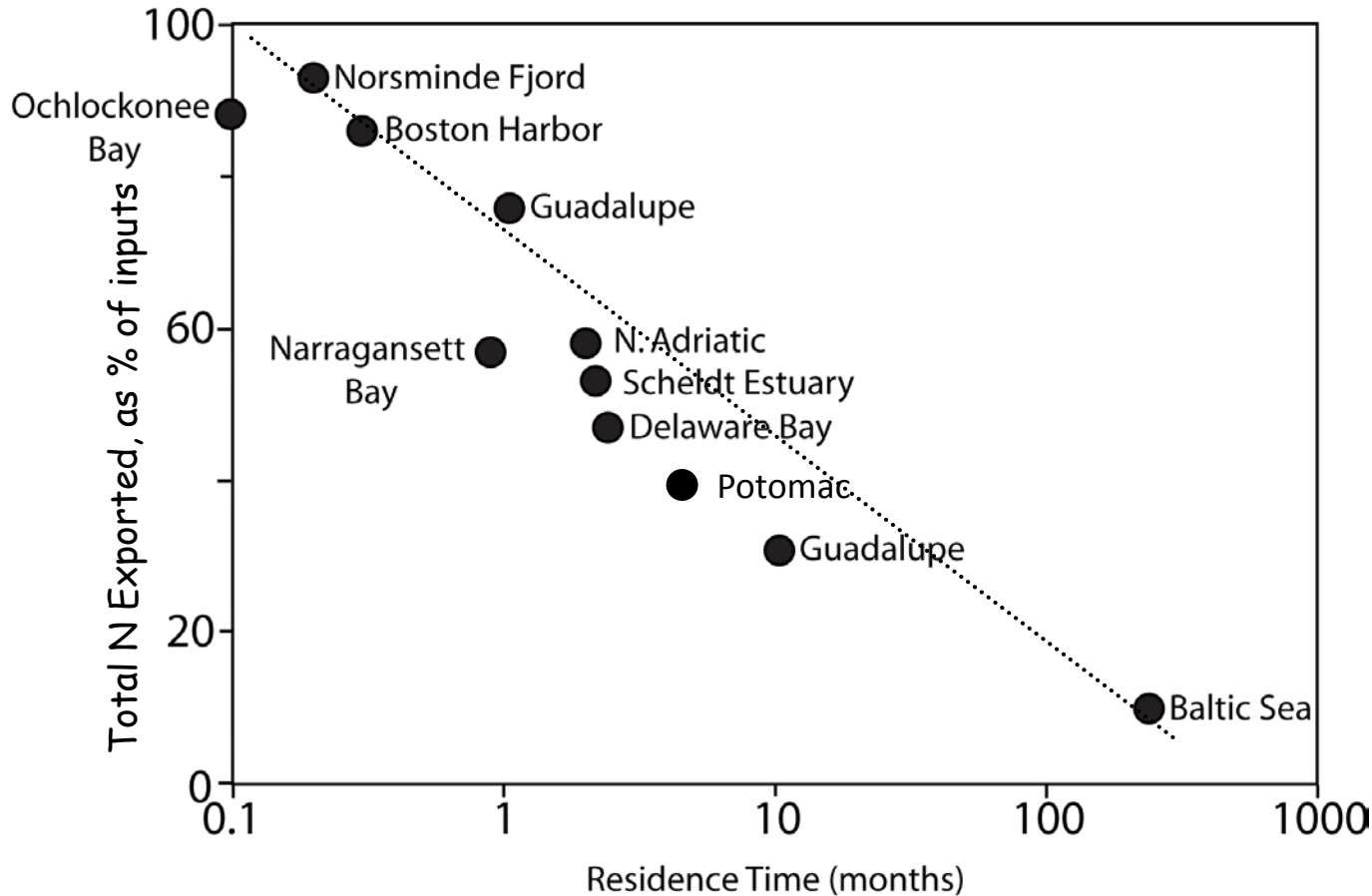
MARSH BURIAL of PARTICULATE NITROGEN

- Strong **GRADIENT** in burial across the land - sea interface
- Rates are **LARGE**
- Strong gradient in Patuxent marshes with highest burial close to marsh edge



A Synthesis based on multiple Syntheses

Nitrogen Export: For these estuaries, the percent of TN input exported was inversely related to water residence time

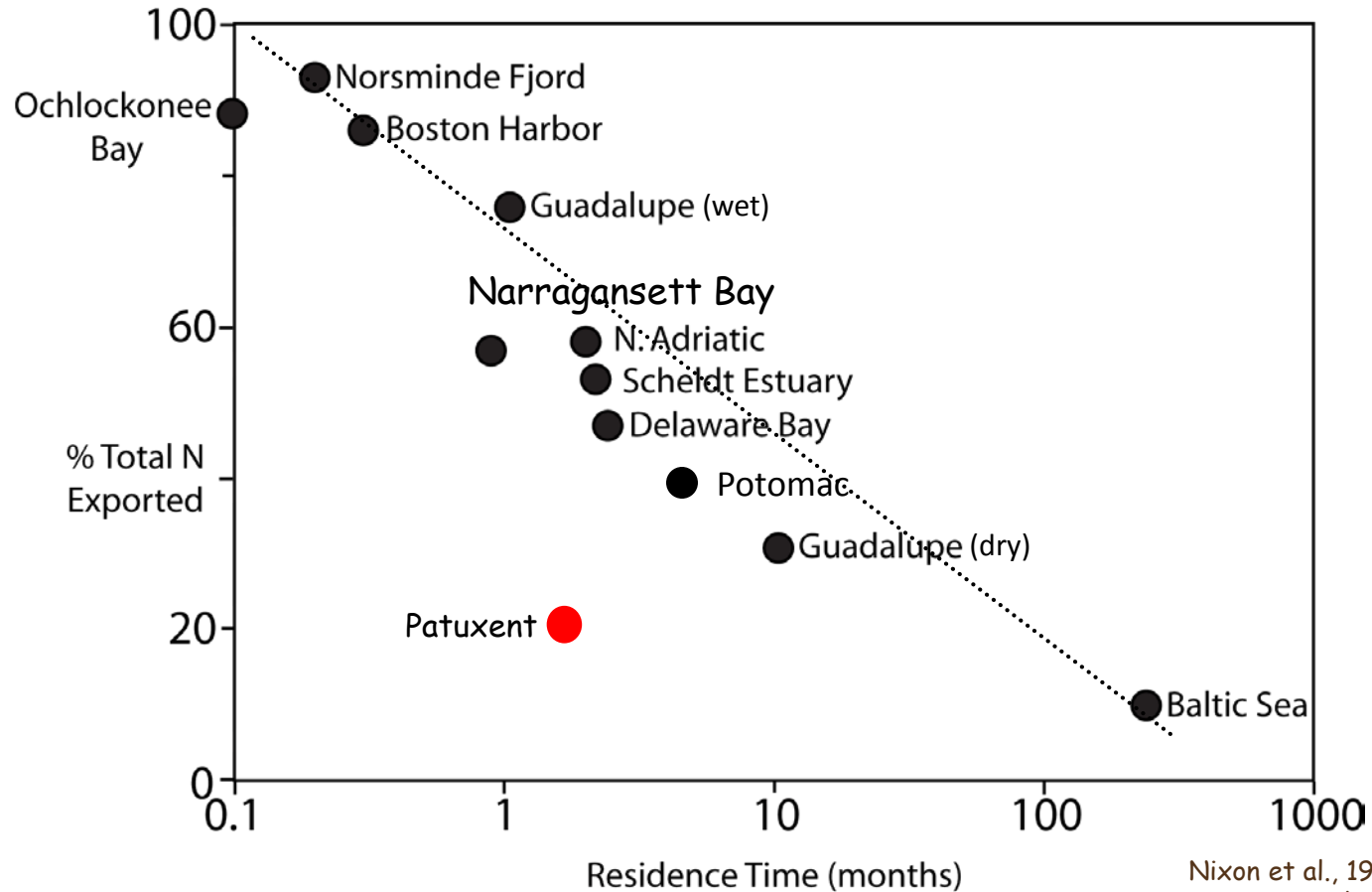


- "Give the bugs enough time and they will use and get rid of it" *Scott Nixon*

- In these budgets internal N losses were via denitrification and long-term N burial...fish extraction losses were small

Synthesis Revised?

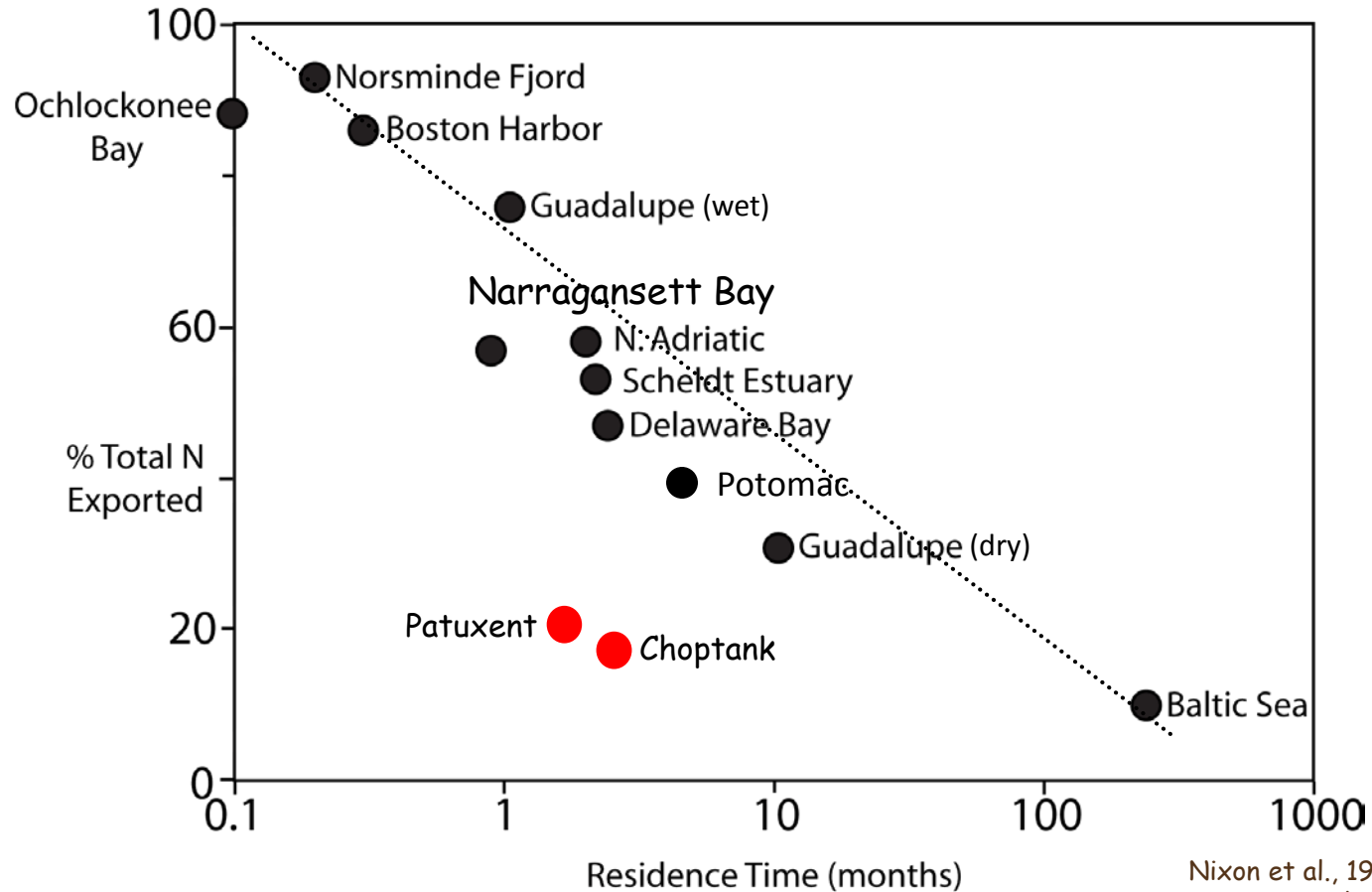
Nitrogen Export: Results from the Patuxent strongly diverged from other sites not characterized by extensive wetlands



Nixon et al., 1996
Boynton et al. 2008

Synthesis Revised

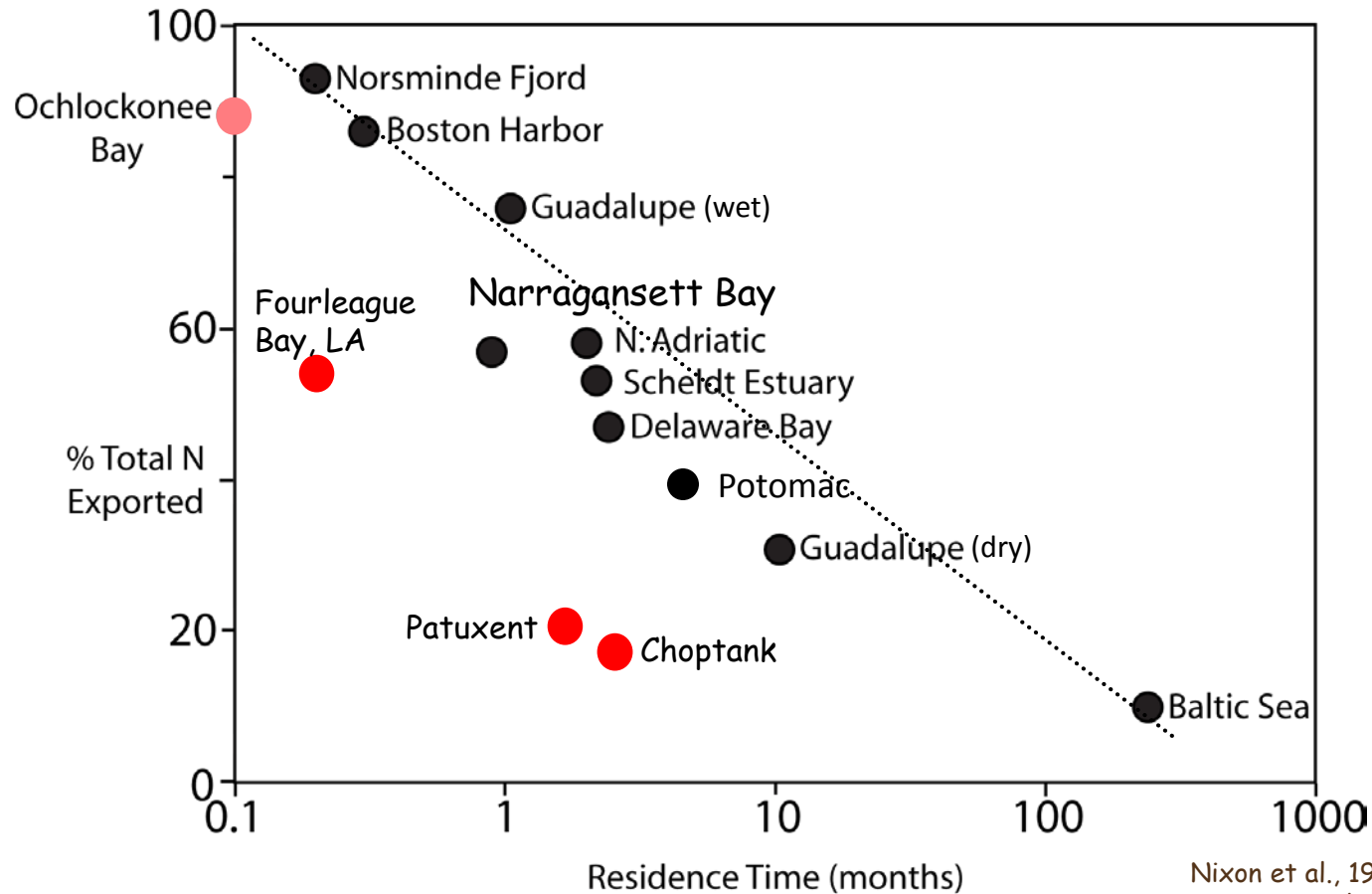
Nitrogen Export: And then aother Chesapeake system diverged, also having extensive wetlands at the land-sea margin



Nixon et al., 1996
Boynton et al. 2008
Fisher and Cornwell, pers comm

Synthesis Revised

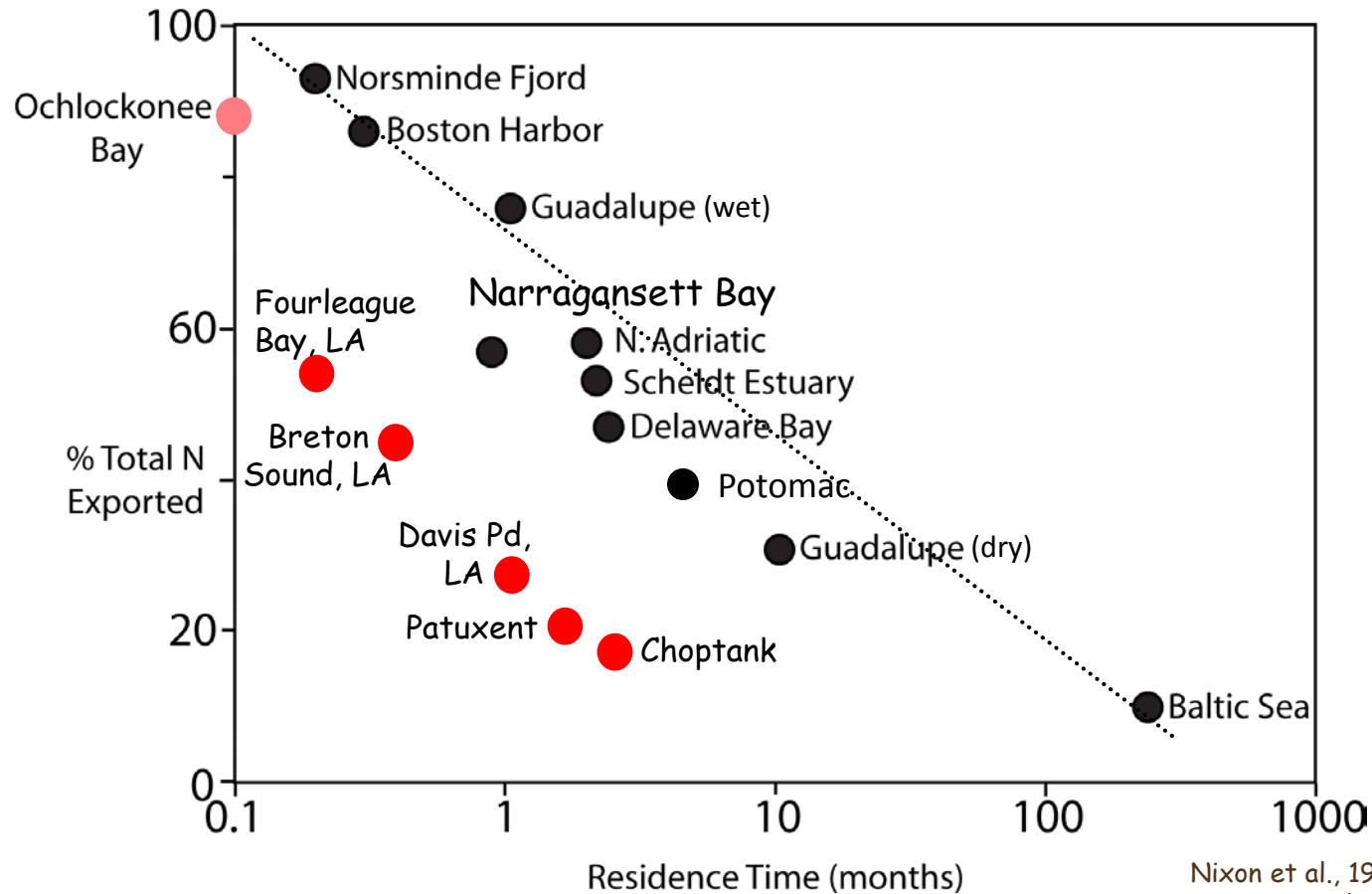
Nitrogen Export: And then more systems diverged, all with extensive wetlands



Nixon et al., 1996
Boynton et al. 2008
Fisher and Cornwell, pers comm
Justic and Day, pers comm
Perez et al (2001); Lane et al (2004)

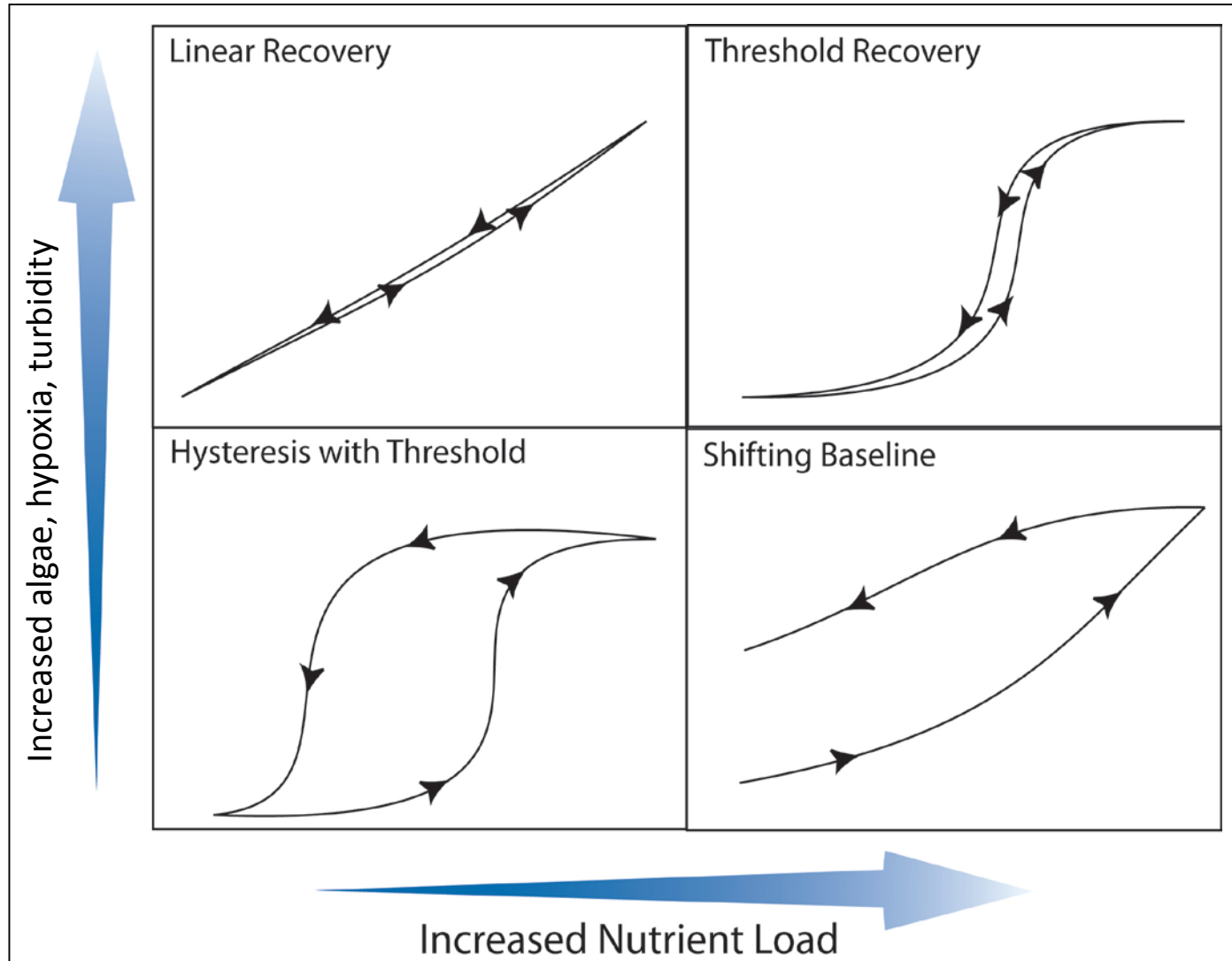
Synthesis Revised,,, might be something here

Nitrogen Export: And then more systems diverged, all with extensive wetlands at the land-sea margin

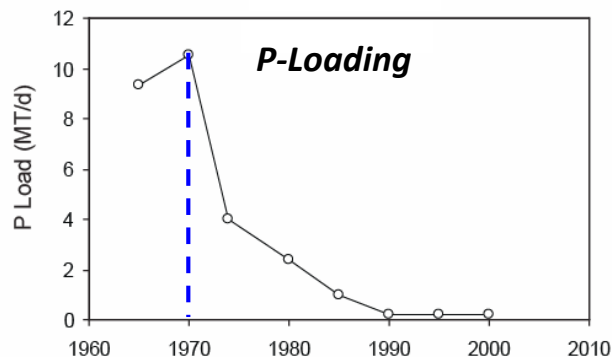


Nixon et al., 1996
Boynton et al. 2008
Fisher and Cornwell, pers comm
Justic and Day, pers comm
Perez et al (2001); Lane et al (2004)

Ecosystem Responses to Nutrient Degradation and Remediation



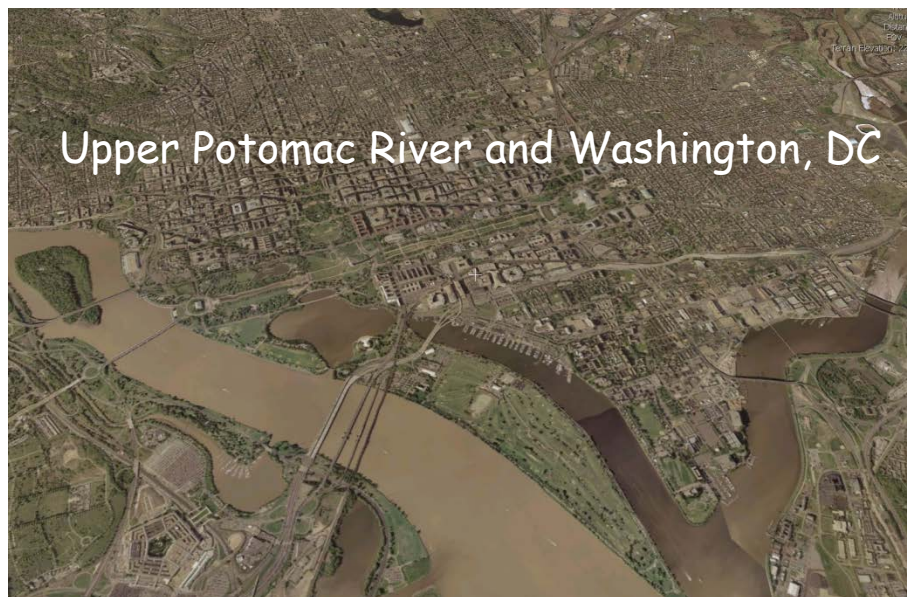
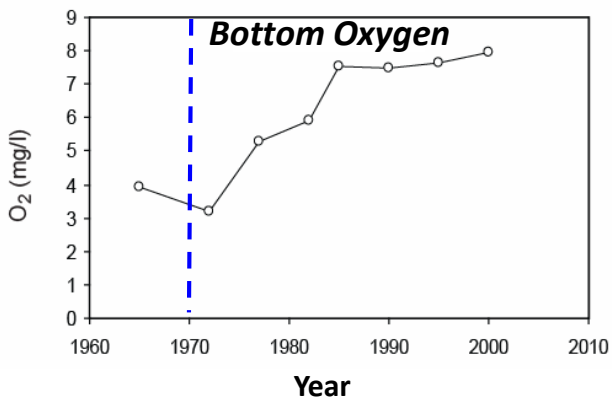
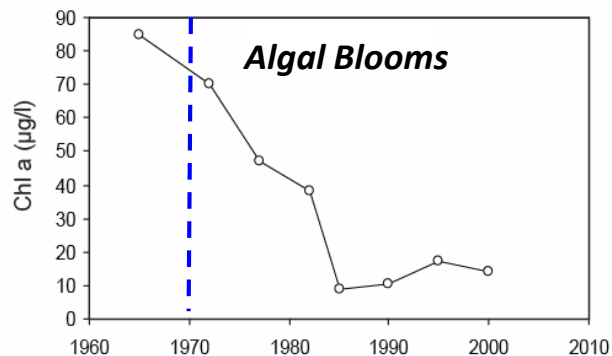
A "Simple" Response to Nutrient Load Reduction



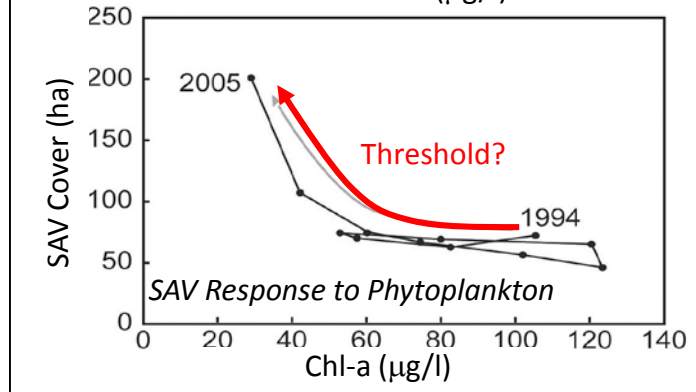
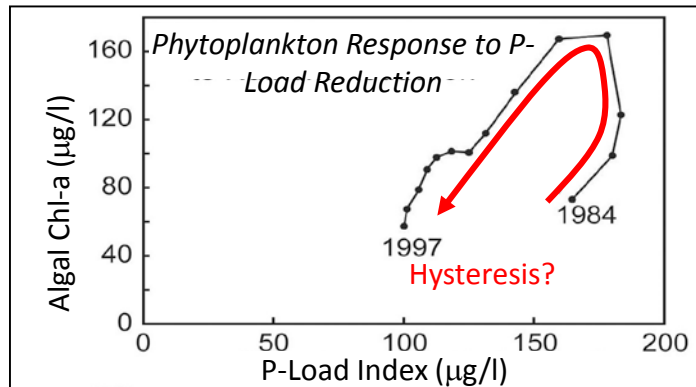
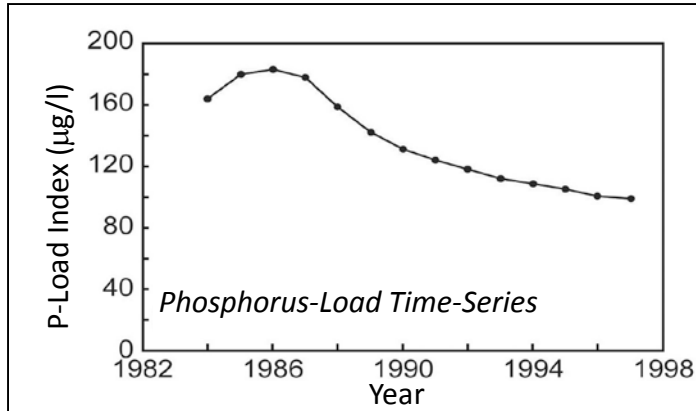
- Waste water treatment plants reduced P-loads by >90% in 30 years

- Algal blooms and bottom O₂ responded rapidly

- Underwater grasses also responded in a favorable fashion



Complex Response to P-Load Reduction



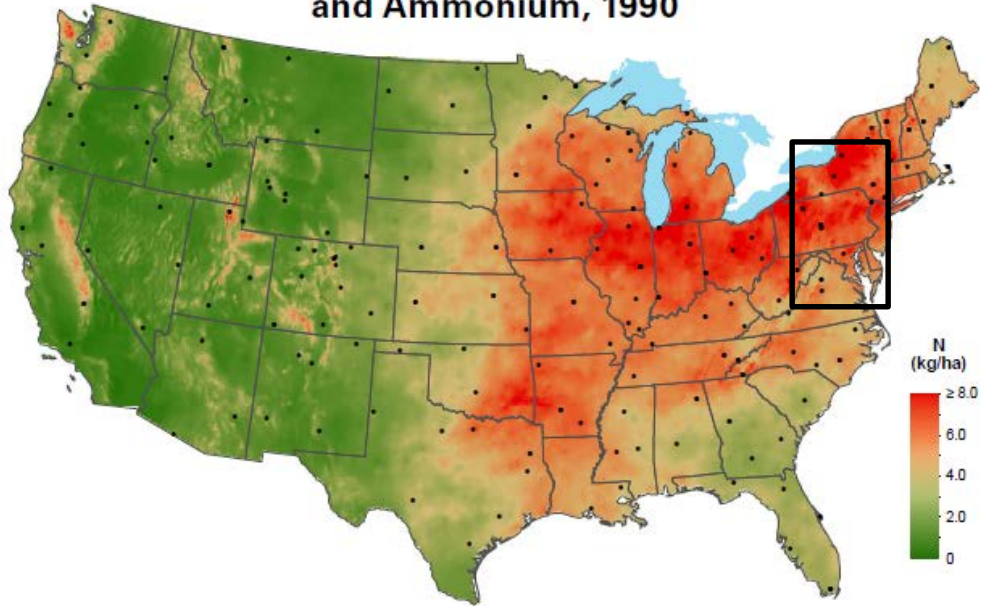
- Potomac River tributary
- Time-series of P-loading index includes periods of brief increase and gradual decline
- Phytoplankton chl-a shows response to P-load reduction after decade delay, probably due to slow purging of sediment DIP pools (hysteretic response pattern?)
- Reductions in phytoplankton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

Success Indicators

- Air
- Nutrient Loads
- Water Quality
- Habitat

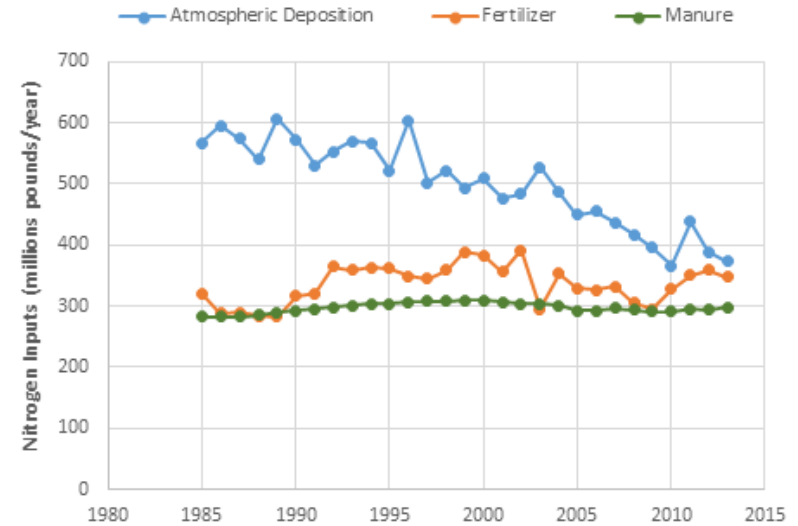
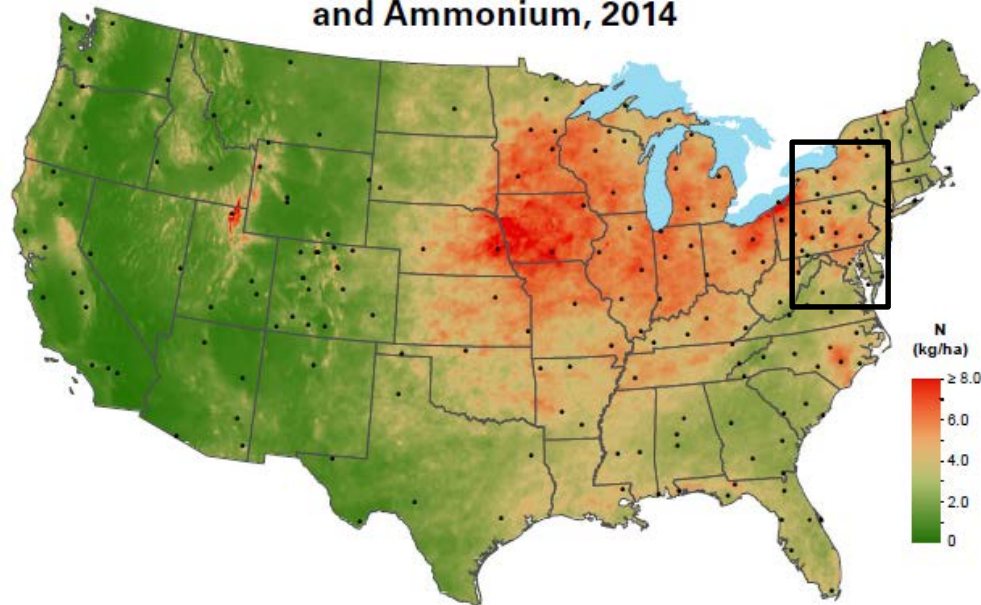


Inorganic Nitrogen Wet Deposition from Nitrate and Ammonium, 1990

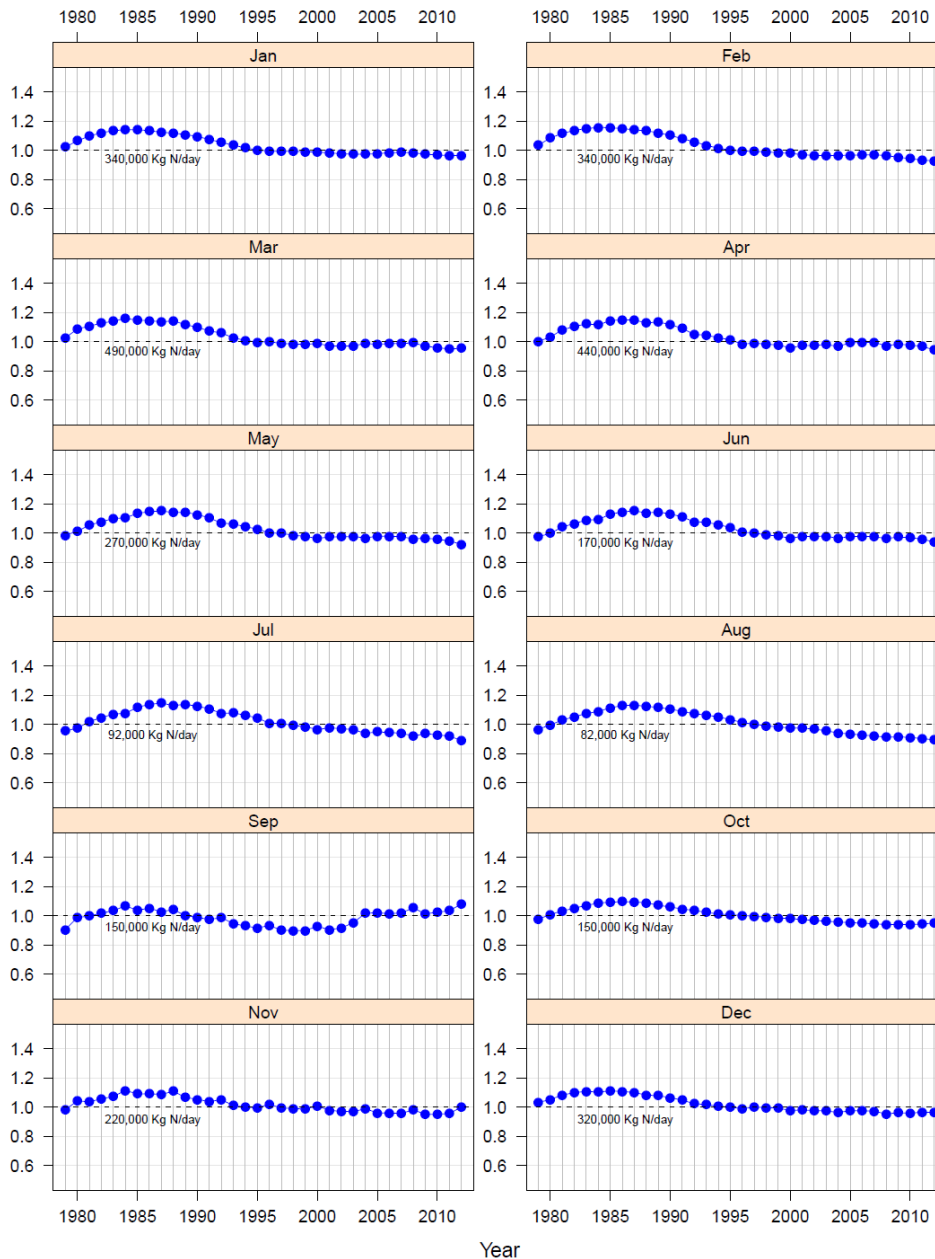


Declining Nitrate (NO_3) and Ammonia (NH_3) deposition concentrations across the Bay watershed

Inorganic Nitrogen Wet Deposition from Nitrate and Ammonium, 2014



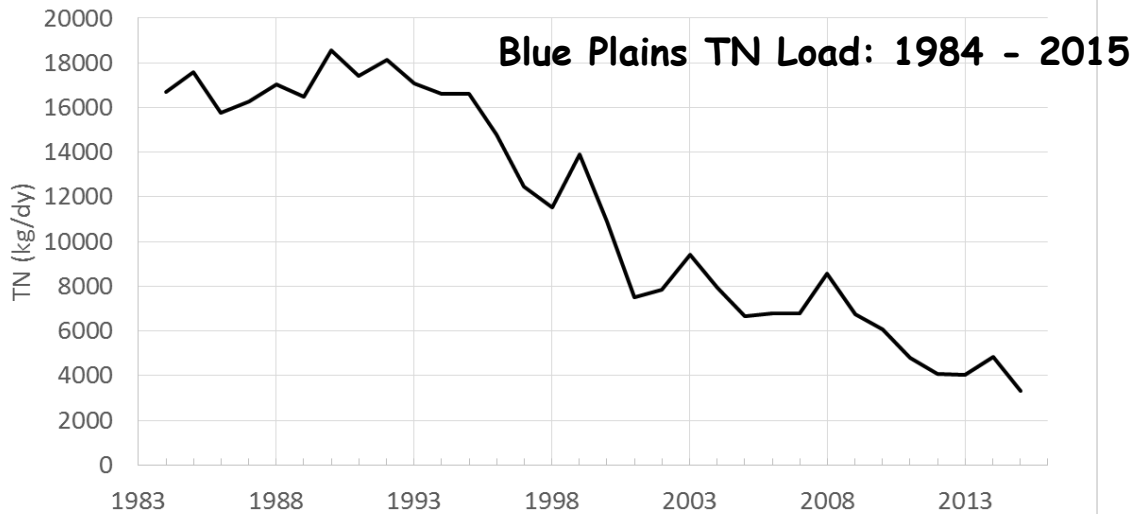
Total Nitrogen Loads from full CB Watershed



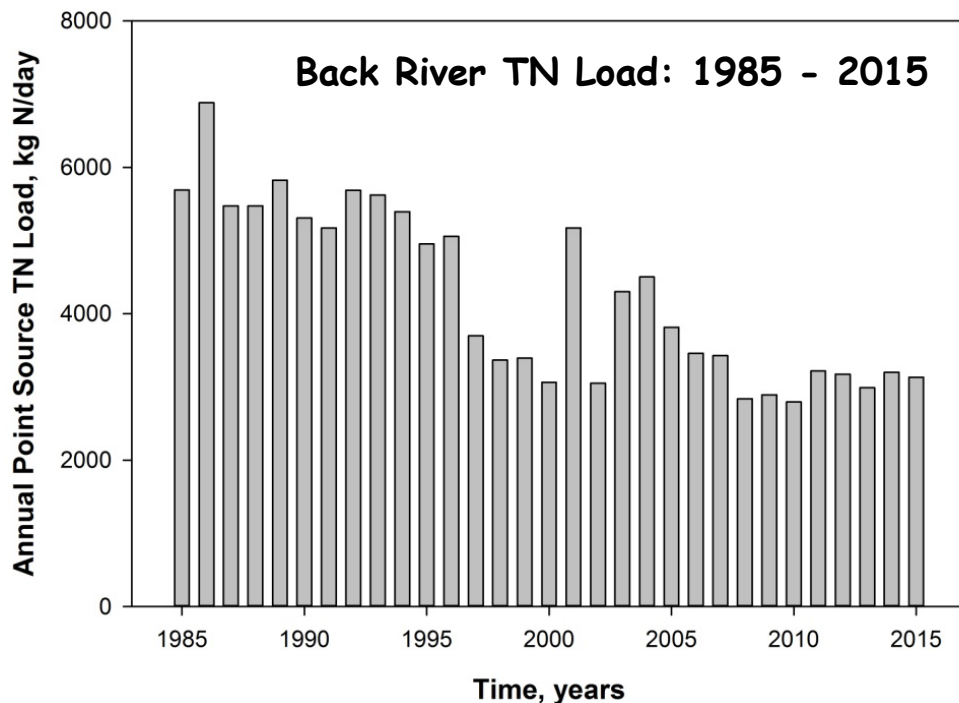
Monthly Total Nitrogen Loads from all Major Tributaries

- Loads decreasing post 1990 in all months except September
- Loads decreasing even in high flow months (Feb - Mar)
- Load declines have slowed in recent years

Point Source N and P Loads are Decreasing



- Huge decline in both TN and TP loads to the Potomac River from Blue Plains
- Back River (Baltimore, MD) TN loads reduced by ~ 50%
- In January, 2017 Back River loads will again be reduced by a further 50%
- Most P loads were reduced before N loads were reduced



Total Nitrogen per Acre Loads and Trends: 2005-2014

Trend Direction

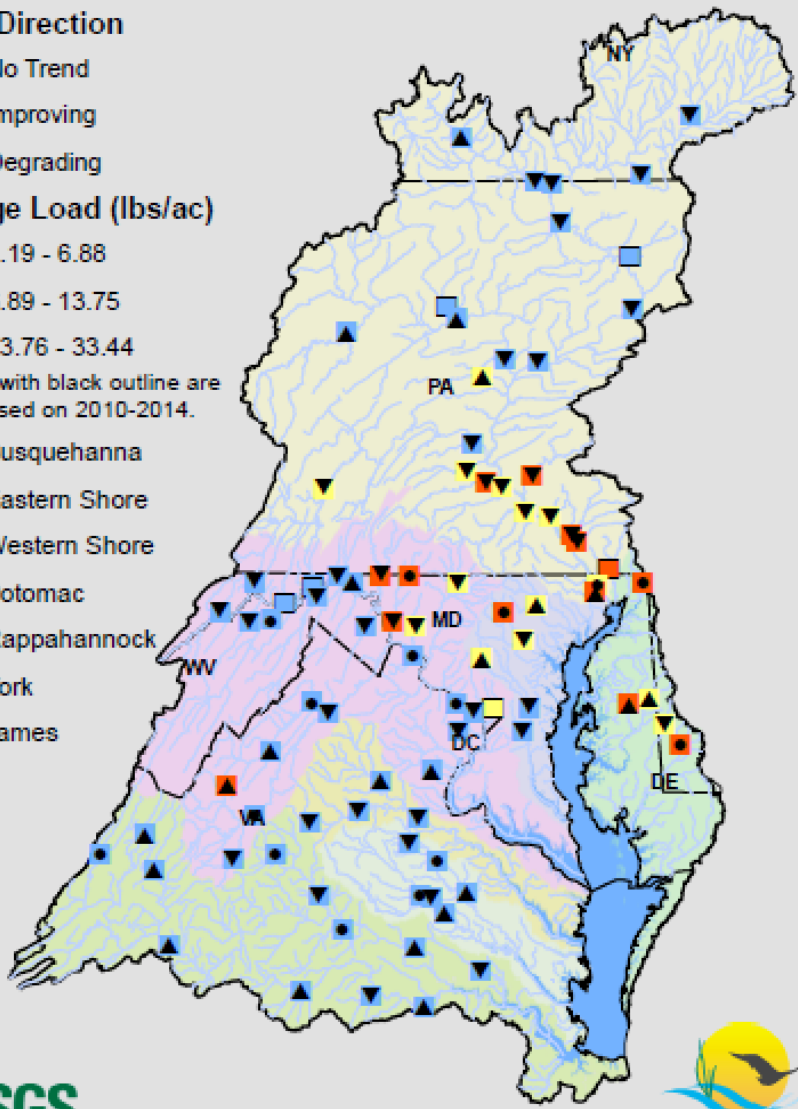
- No Trend
- ▼ Improving
- ▲ Degrading

Average Load (lbs/ac)

- 1.19 - 6.88
- 6.89 - 13.75
- 13.76 - 33.44

Squares with black outline are yields based on 2010-2014.

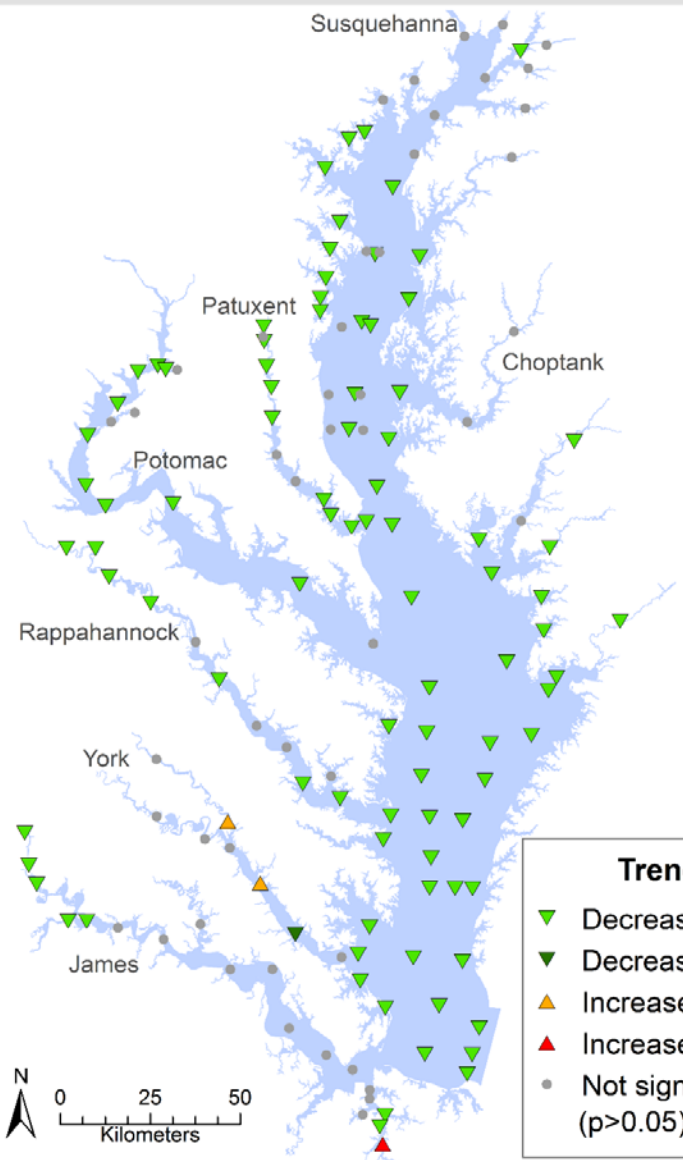
- Susquehanna
- Eastern Shore
- Western Shore
- Potomac
- Rappahannock
- York
- James



Prepared on 10/20/15

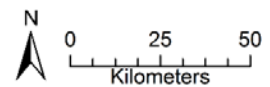


Trends for Surface Total Nitrogen in the Chesapeake Bay: 2005-2014



Trend

- ▼ Decrease 0-50%
- ▼ Decrease >50%
- ▲ Increase 0-50%
- ▲ Increase >50%
- Not significant (p>0.05)



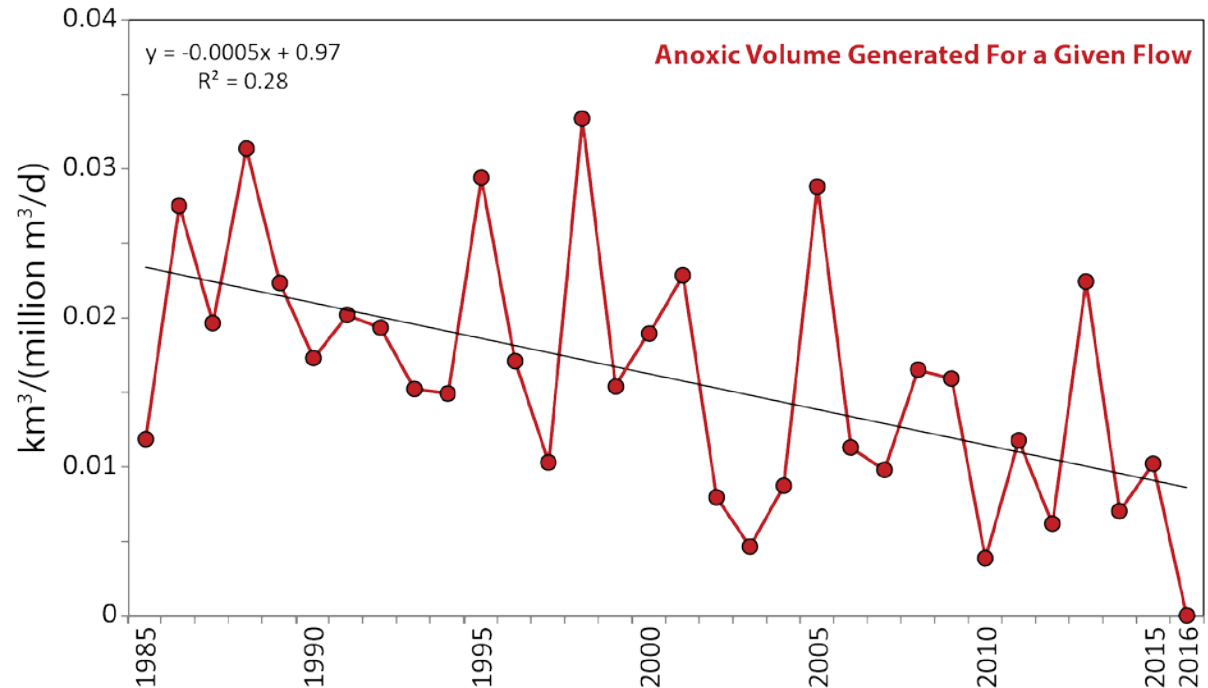
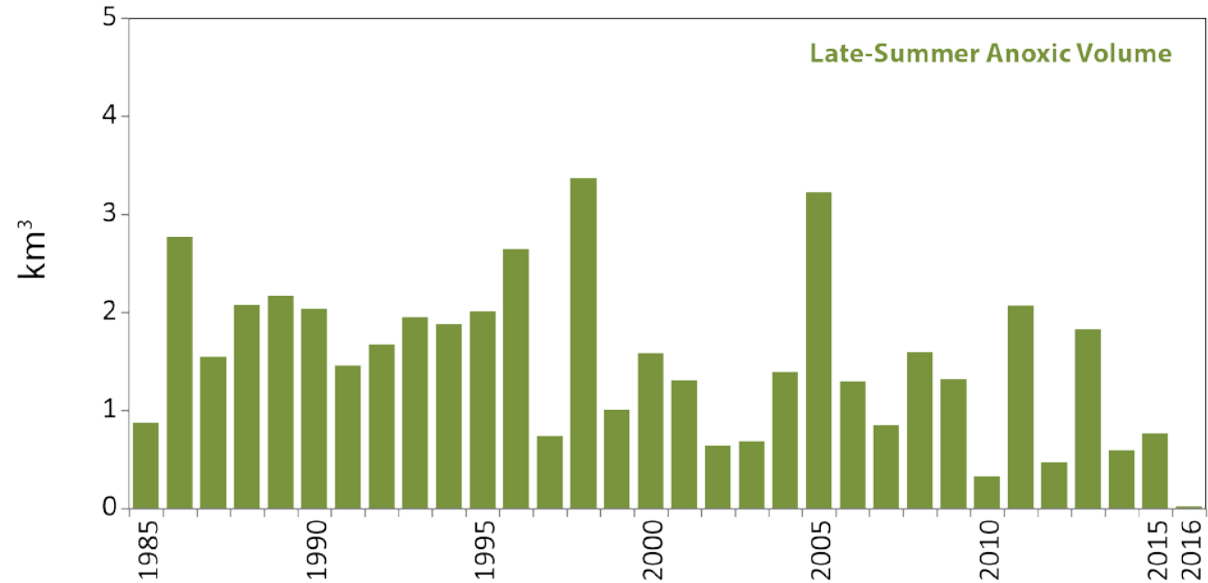
GAM Method Preliminary Results, Subject to Review

Late Summer Anoxia *Declining in Mainstem Bay*

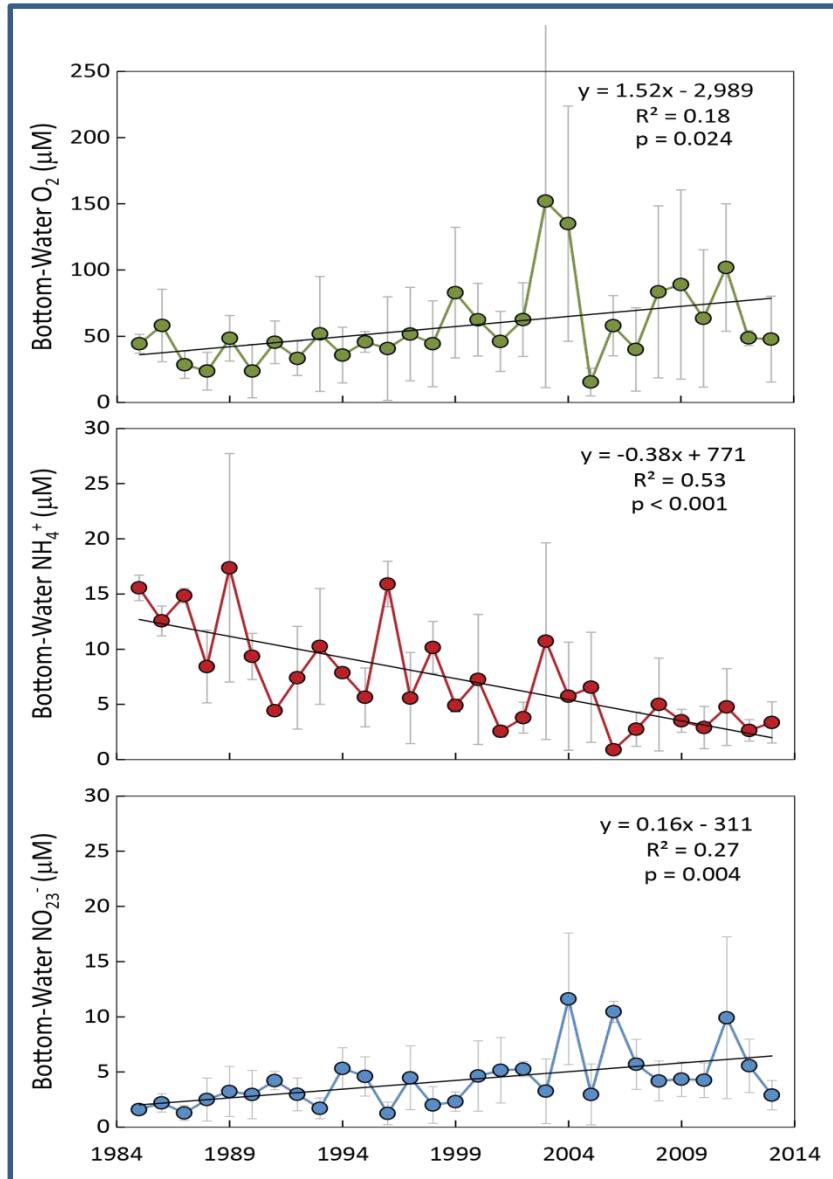
- Long-term decline in late summer anoxia ("no oxygen")

- This decline larger than expected from modest declines in load

- Clear explanation remains elusive



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



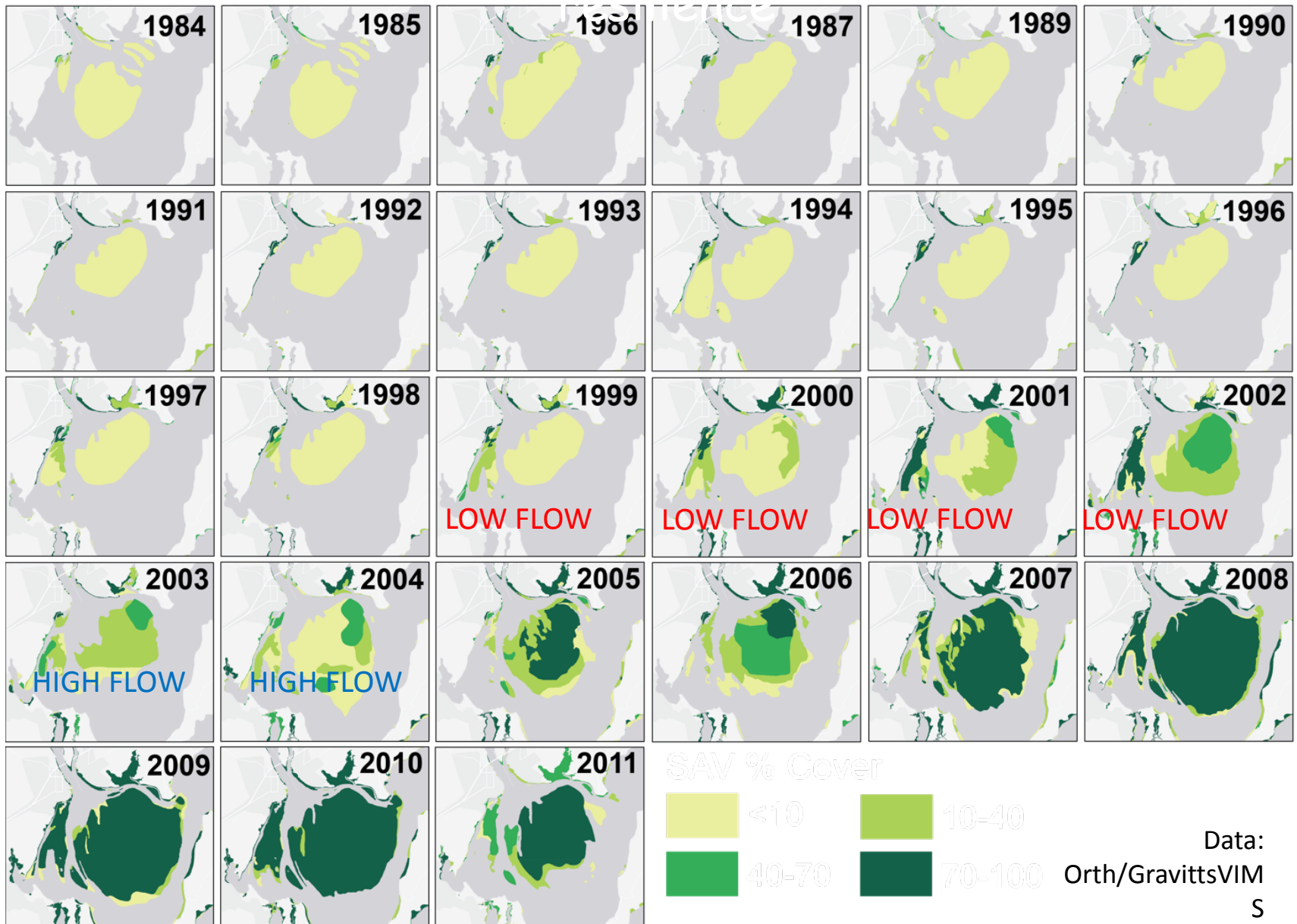
- Significant trends over 3 decades
- Late-summer mean values
- Increasing **dissolved oxygen**
- Decreasing **ammonium**
- Increasing **nitrate**
- Hypoxic region of Bay is becoming less hypoxic...an important sign of recovery

Now...this is a SAV bed!

- Huge expanse ~ 20 square miles (13,000 acres)
- Clear water
- Resilient to major storms; recovery from major storm = several years (not decades!)

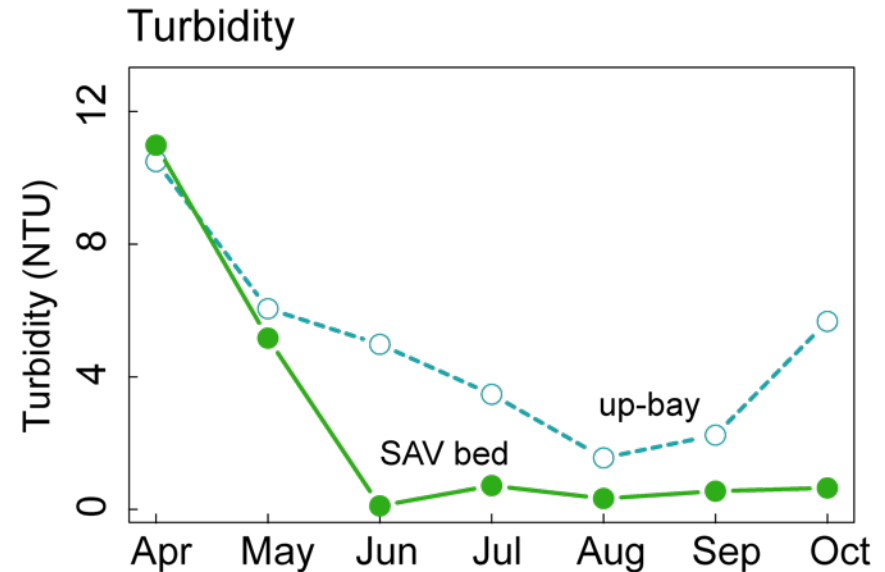
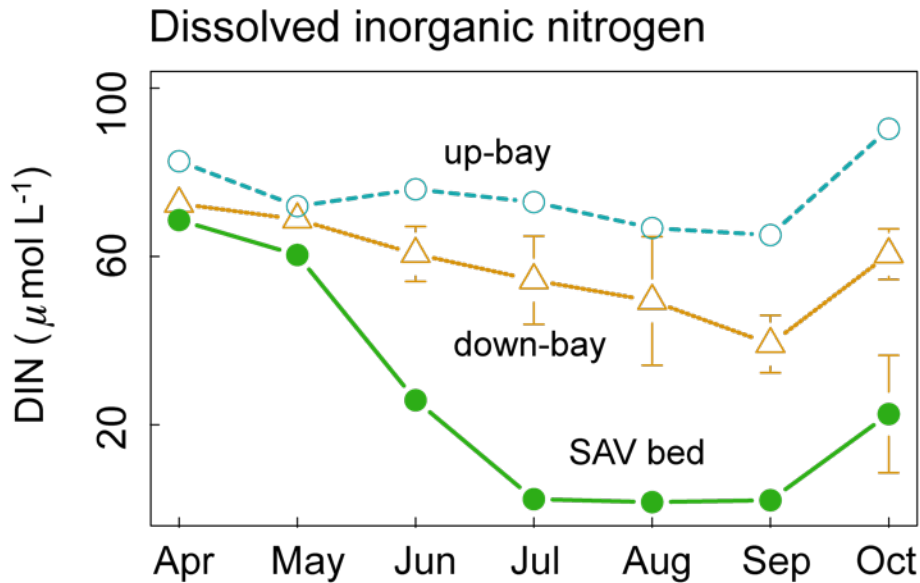


Susquehanna Flats SAV Time-Series



Strong Feedbacks Influence Tipping Points

- SAV bed strongly reduces nutrients in the bed and even reduces nutrients downstream of the bed
- Likewise, water clarity is better in the bed than up-stream of the bed
- Such “feedbacks” help the Bay “get better”...and it's free!



What are some major Challenges?

- (1) Water Clarity
- (2) Keep Reducing Nutrient Inputs!
- (3) Patterns of Growth in the basin
- (4) Climate Change
- (5) Maintain Monitoring and Analysis
- (6) Ecosystem-Based Fisheries
Management...related to nutrient
input levels

Water Clarity

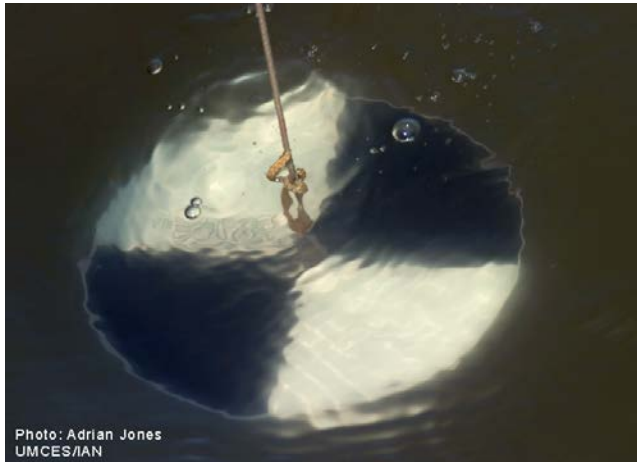
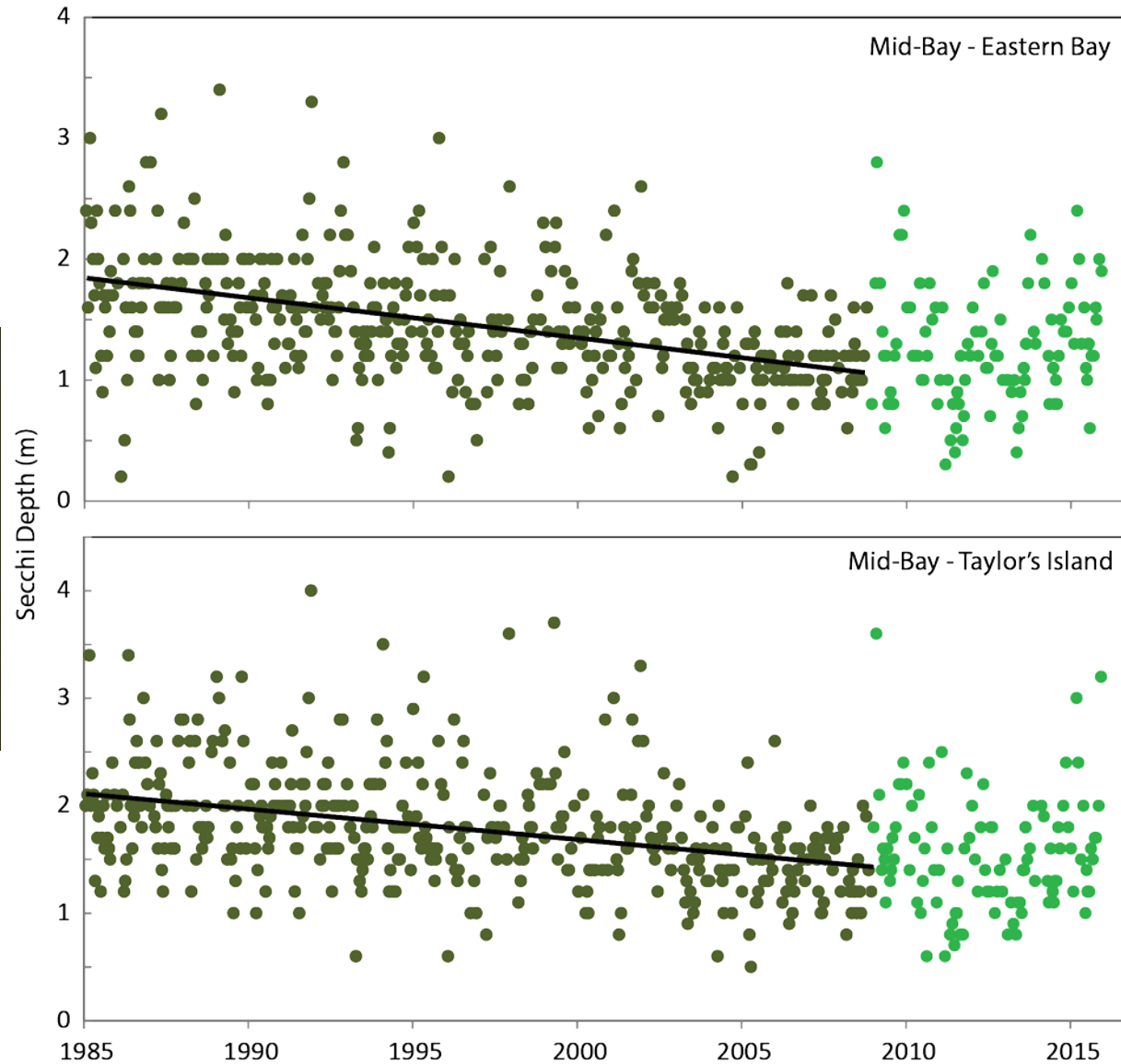


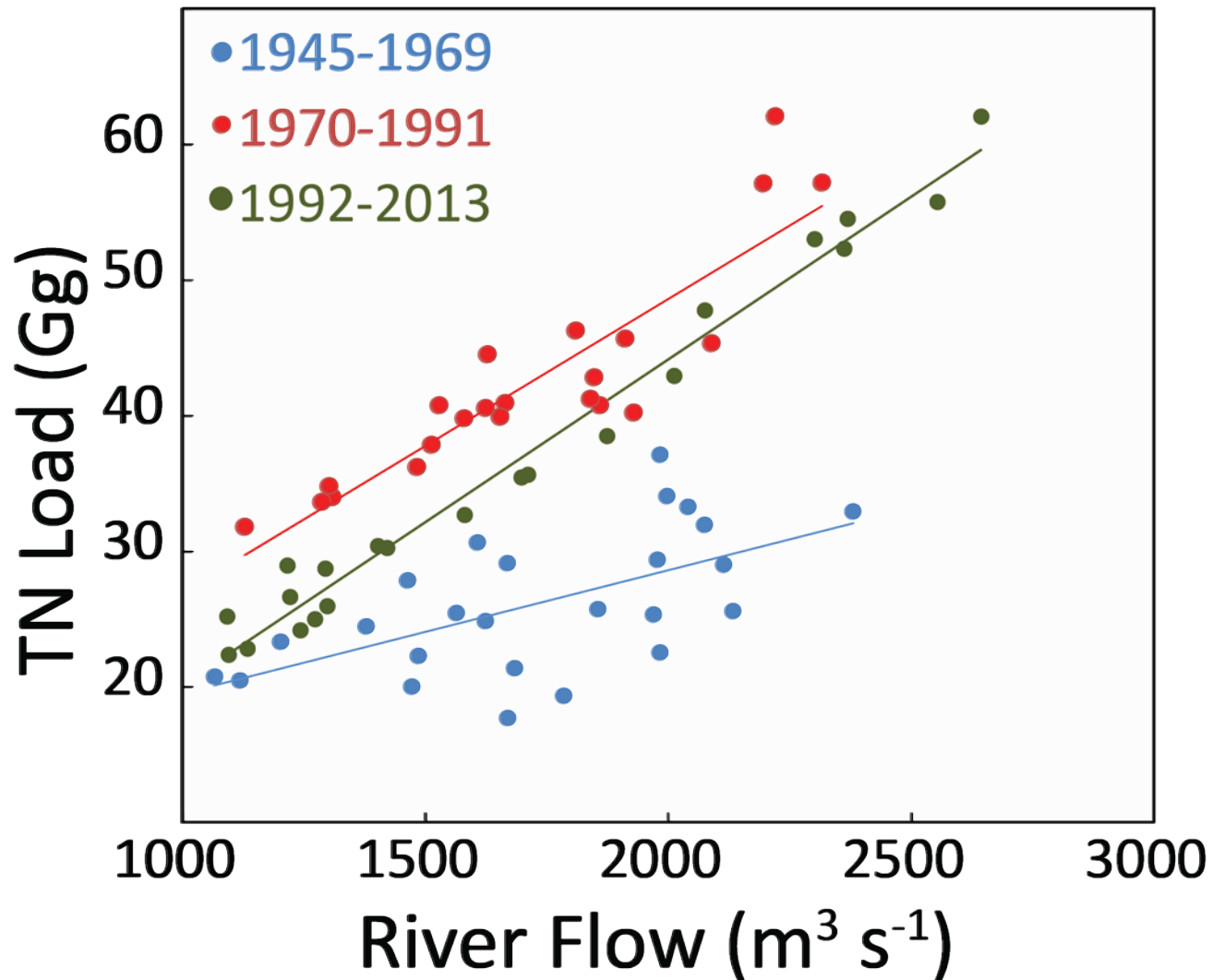
Photo: Adrian Jones
UMCES/IAN



- Secchi Depth measure the light available for SAV - but it is also an index of nutrient and sediment loading problems

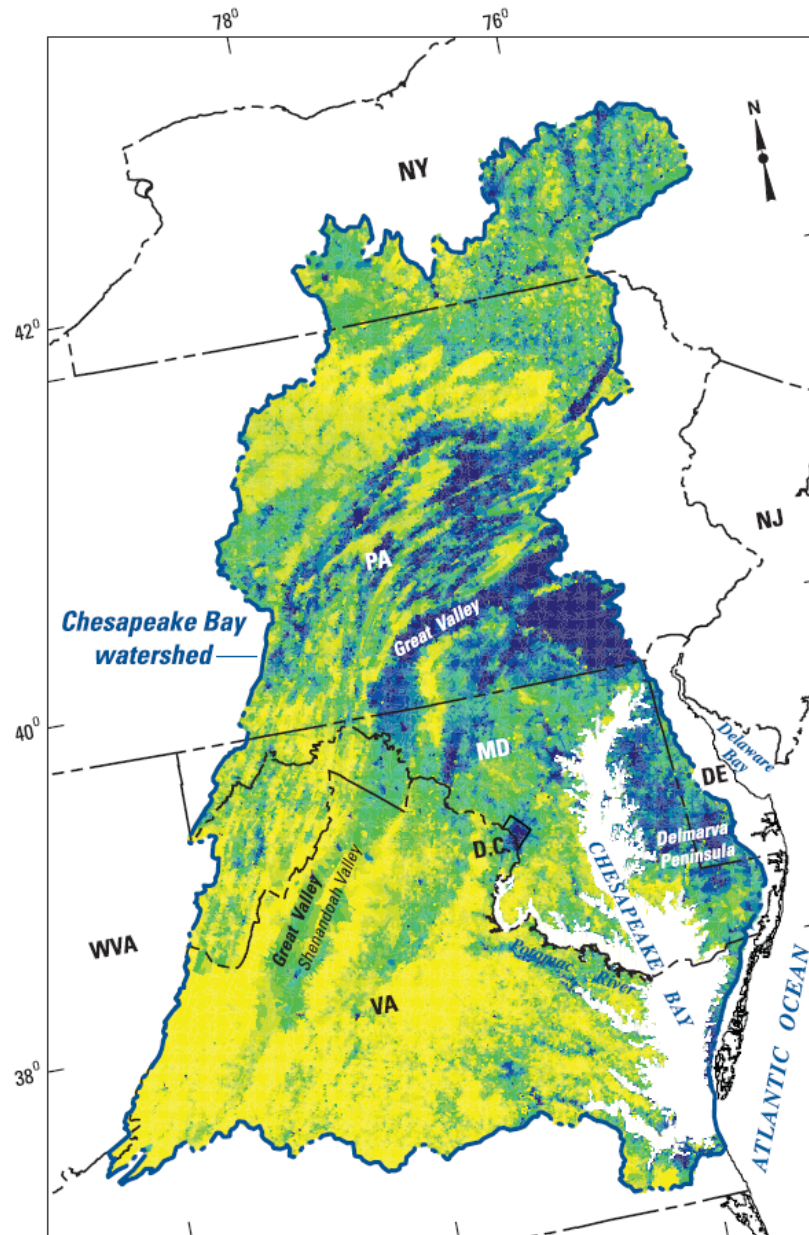
Testa et al. unpubl.

Changing Susquehanna River TN Load



Nitrogen Hotspots in the Landscape

- For the mainstem Bay, focus on lower Susquehanna Basin
- Tributaries are a more "local issue".



BASE FROM U.S. GEOLOGICAL SURVEY 1:2,000,000
STATE BOUNDARY DIGITAL LINE GRAPH, ALBERS
EQUAL AREA PROJECTION, NAD 1983

0 50 MILES
0 50 KILOMETERS

**ESTIMATED ANNUAL
YIELD OF TOTAL NITROGEN,**
in kilograms per square kilometer
(high value in pounds per acre)

0-152 (1.4)
152-221 (2.0)
221-297 (2.6)
297-398 (3.6)
398-526 (4.7)
526-683 (6.1)
683-887 (7.9)
887-1,186 (11)
1,186-1,710 (15)
GREATER THAN 1,710

Dark Blue = > than
15 pounds of N
acre per year

Cover Crops

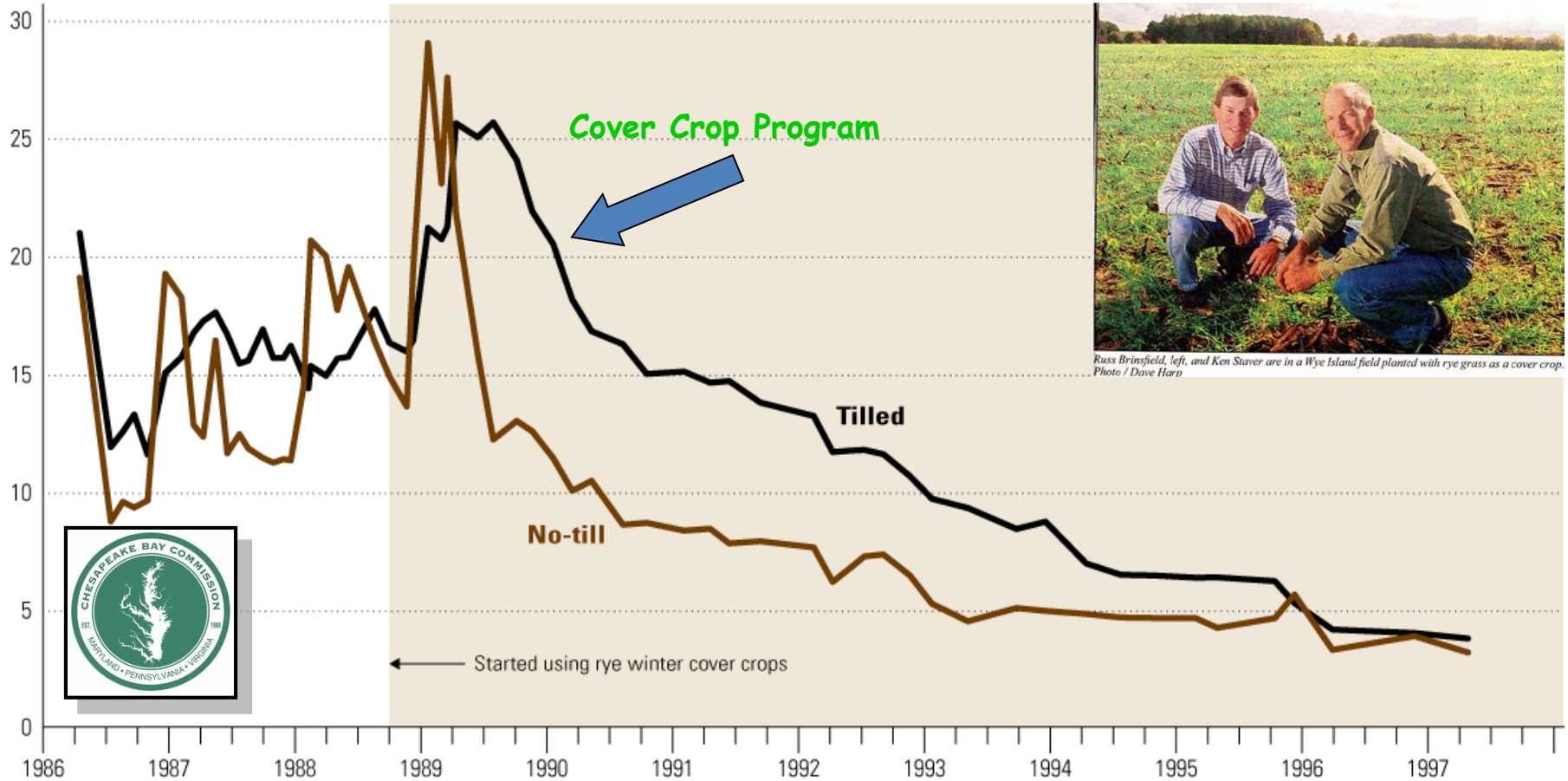


Conservation Practices Deliver Water Quality Benefits

Persistence and Patience Matters

Average Nitrate-N concentrations in shallow groundwater under two field watersheds planted continuously with corn at 140 lbs. N/acre, 1986-1997.

Groundwater Nitrate-N (mg/L)

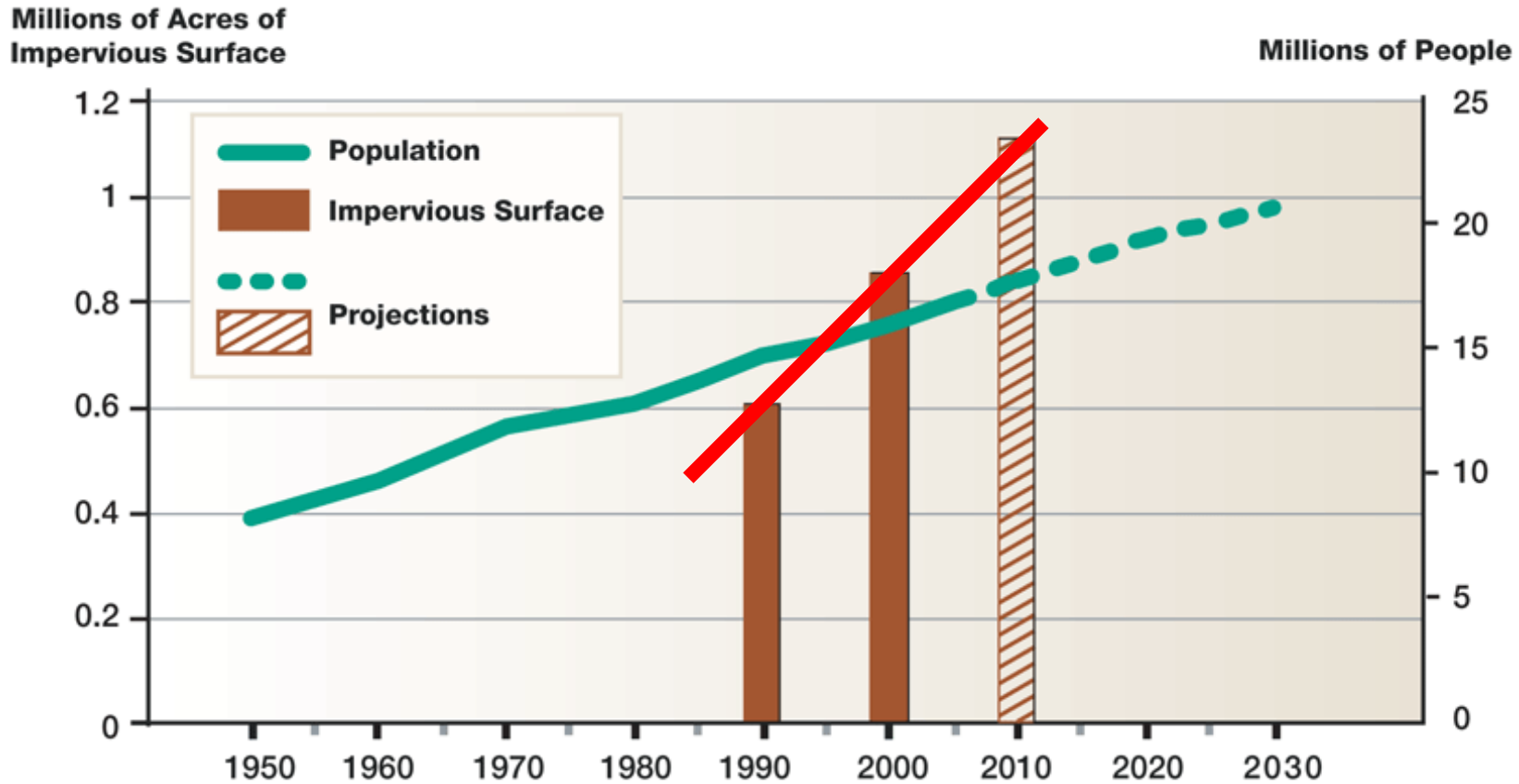


Russ Brinsfield, left, and Ken Staver are in a Wye Island field planted with rye grass as a cover crop. Photo / Dave Harp



SOURCE: STAVER AND BRINSFIELD. J. SOIL AND WATER CONS. 53: 230-240, 1998.

Bay Watershed Population, Impervious Surfaces and Stormwater Pollution Loads



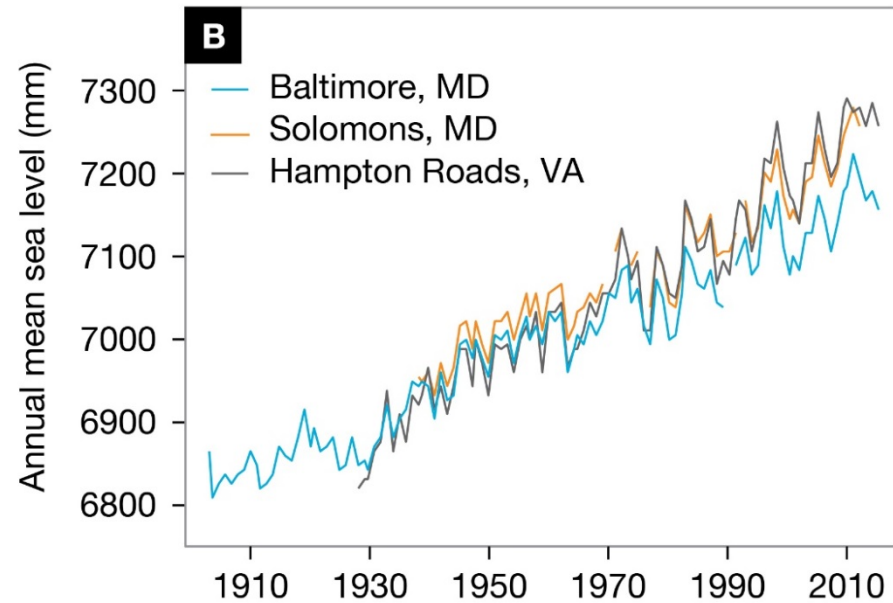
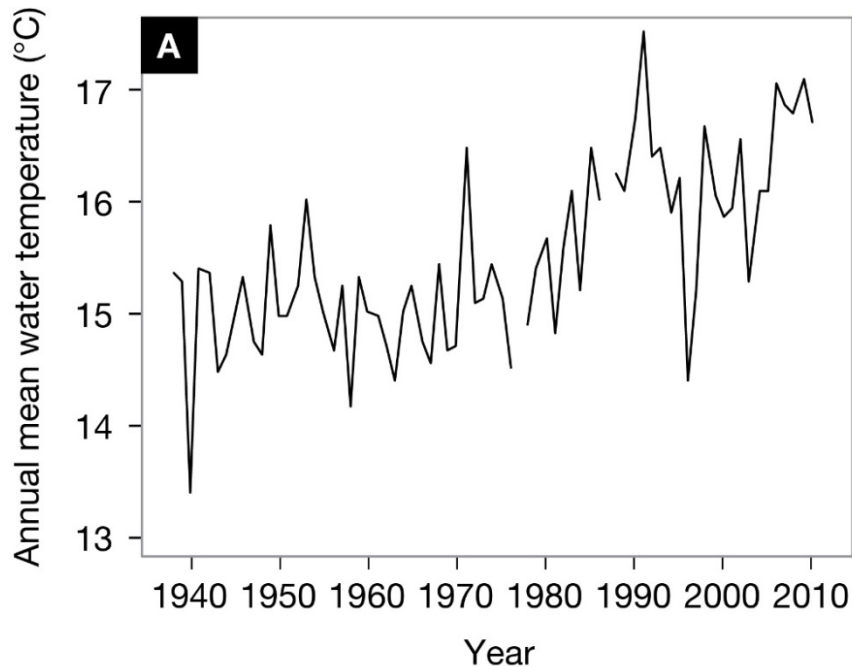
Data and Methods: www.chesapeakebay.net/status_population.aspx

Conversion of land for DEVELOPMENT since 1970 has grown at double the rate of housing and triple the rate of population

Climate Change

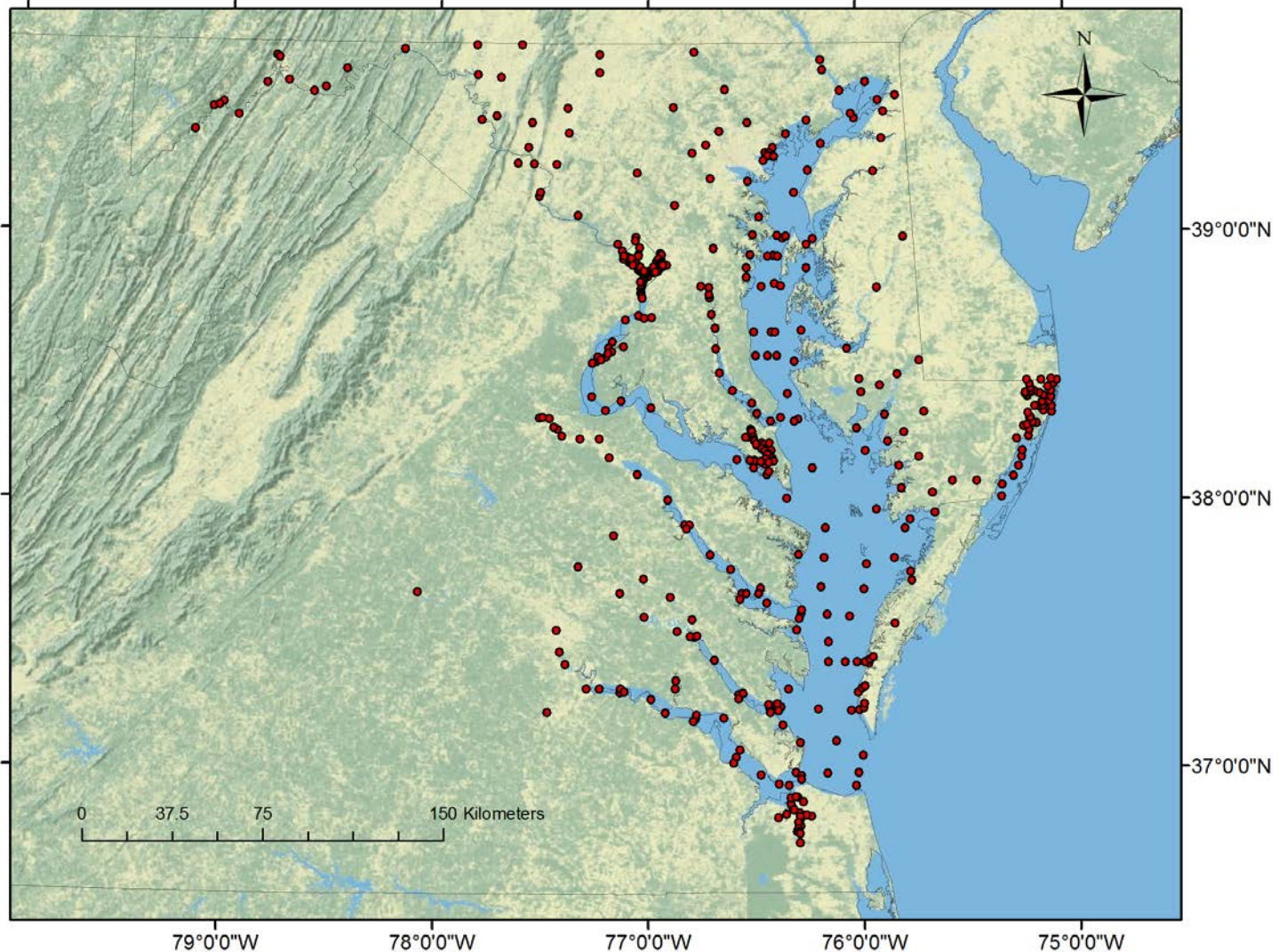
Temperature and sea level rise both clearly observed

- Temperature increases will influence hypoxia, plants and animal function and distribution and other processes as well
- Sea level rise will also have multiple effects including shoreline and tidal marsh erosion
- BUT, don't take your eye off the 800 pound gorilla...**nutrient load reduction**



Monitoring and Analysis

Keep core going; be adaptive; utilize new technologies when proven (e.g. nutrient sensors)



**Chesapeake Bay Program water quality monitoring sites (Cole 2011).
These sites represent a compromise between SCIENCE, MANAGEMENT AND POLITICS.**

Another Major Challenge: Fine tuning nutrient loading rates with ecosystem secondary production



- Currently we manage nutrients and sediments so as to meet water quality criteria and that's a good plan
- In the future we may well want to refine the loads to manage for some sort of optimum secondary production...a huge challenge.

Take-Home Points

- Basic ideas of enrichment and restoration are scientifically solid
- Substantial reductions of N and P result in improved water quality and better habitat conditions...the Bay is RESPONSIVE to load changes
- The pathways estuaries follow during degradation and restoration often involve time delays (lags), abrupt changes (thresholds) and other things not yet known or fully understood - or predictable!
- Restoration trends (and hints of trends) have been observed in both small and large Chesapeake systems...very good signs!
- Climate change and variability, continued and adaptive monitoring and analysis, control of diffuse sources all remain major challenges