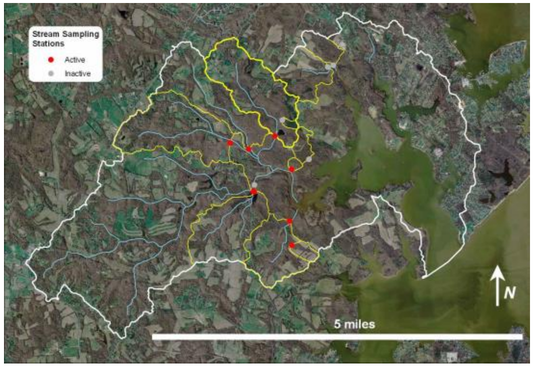
The Subestuary Concept: A Powerful Paradigm for Land-water Interactions in Estuaries



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Smithsonian Environmental Research Center

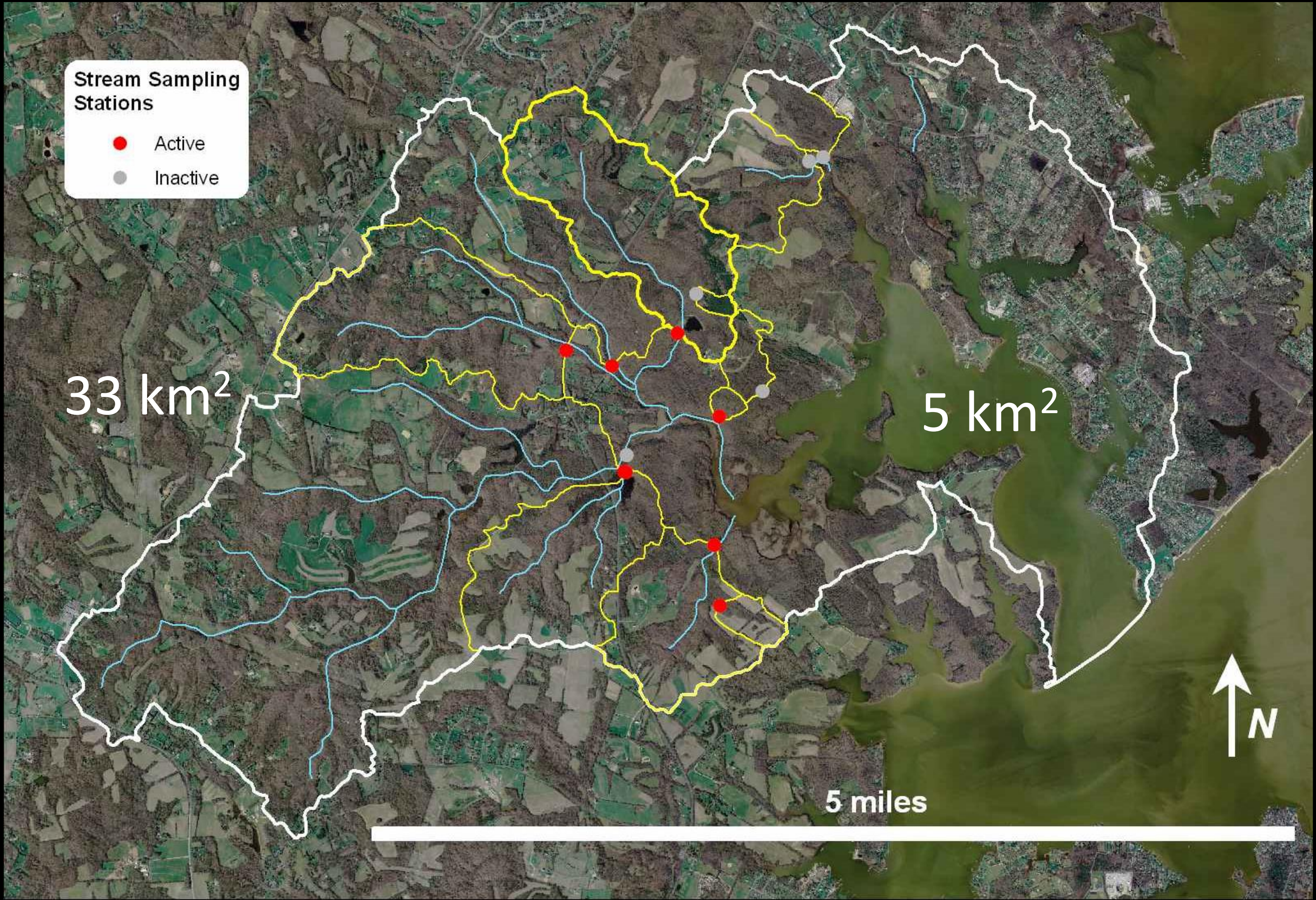
Subestuary concept

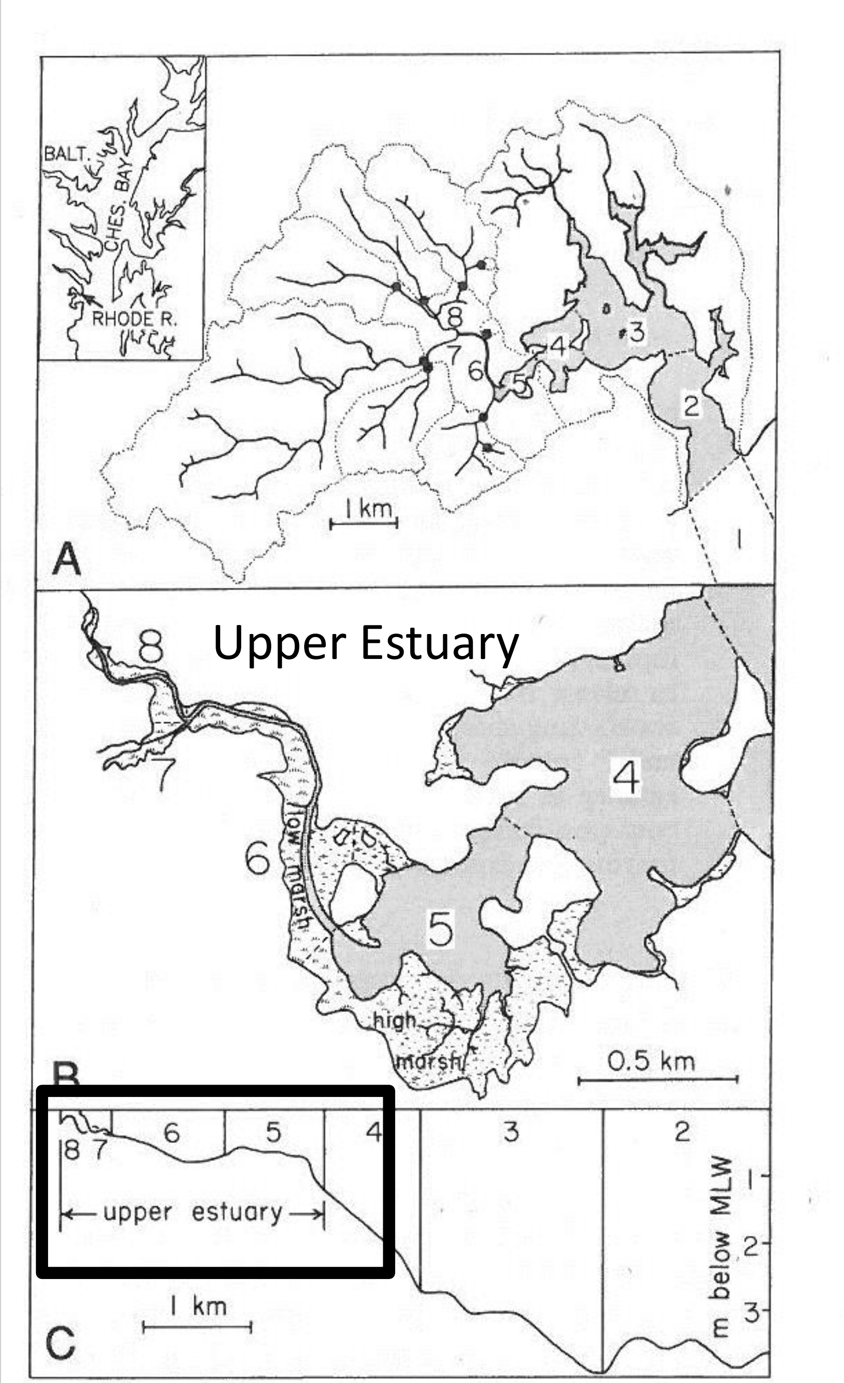
- Characteristics
  - Shoreline encloses a fairly distinct body of water
  - Identifiable mouth at the connection to Bay
  - One or more tributary streams
  - Distinct local watershed with associated land uses
  - "Mama bear" size watershed
- Disproportionate importance
  - SAV habitat & wetlands
  - Nursery and refuge areas
  - First to process land runoff
  - Close to human activities
  - Highly visible and accessible to people

Subestuary concept

- Advantages
  - Dozens in Chesapeake Bay
  - Convenient, replicated study units
  - Many in each salinity zone
  - Differ widely in local watershed land use
  - Reveal effects of watershed stressors on estuarine responses
    - SAV abundance
    - Fish, blue crab, benthic fauna abundance
    - PCB contamination of fish
    - Bird community health
  - Ecologically relevant, yet small enough for local management action

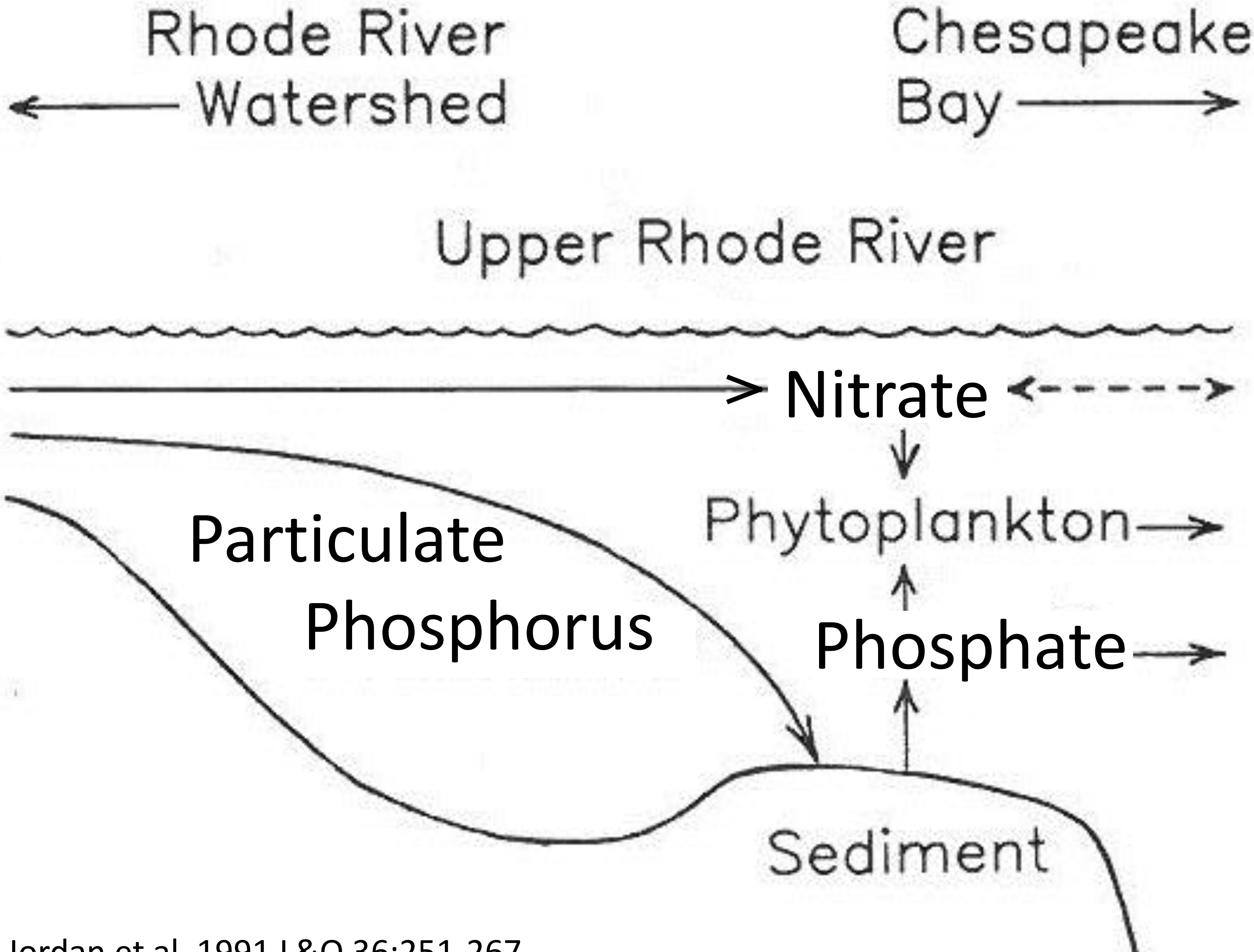
The Rhode River: Subestuary of Chesapeake Bay





Rhode River Estuary

- Traced mixing between segments based on changes in salinity
- Measured tidal exchanges of nutrients from marshes
- Remote (Susquehanna) vs. local watershed effects distinguished by time lag.
- Local watershed only effects upper estuary

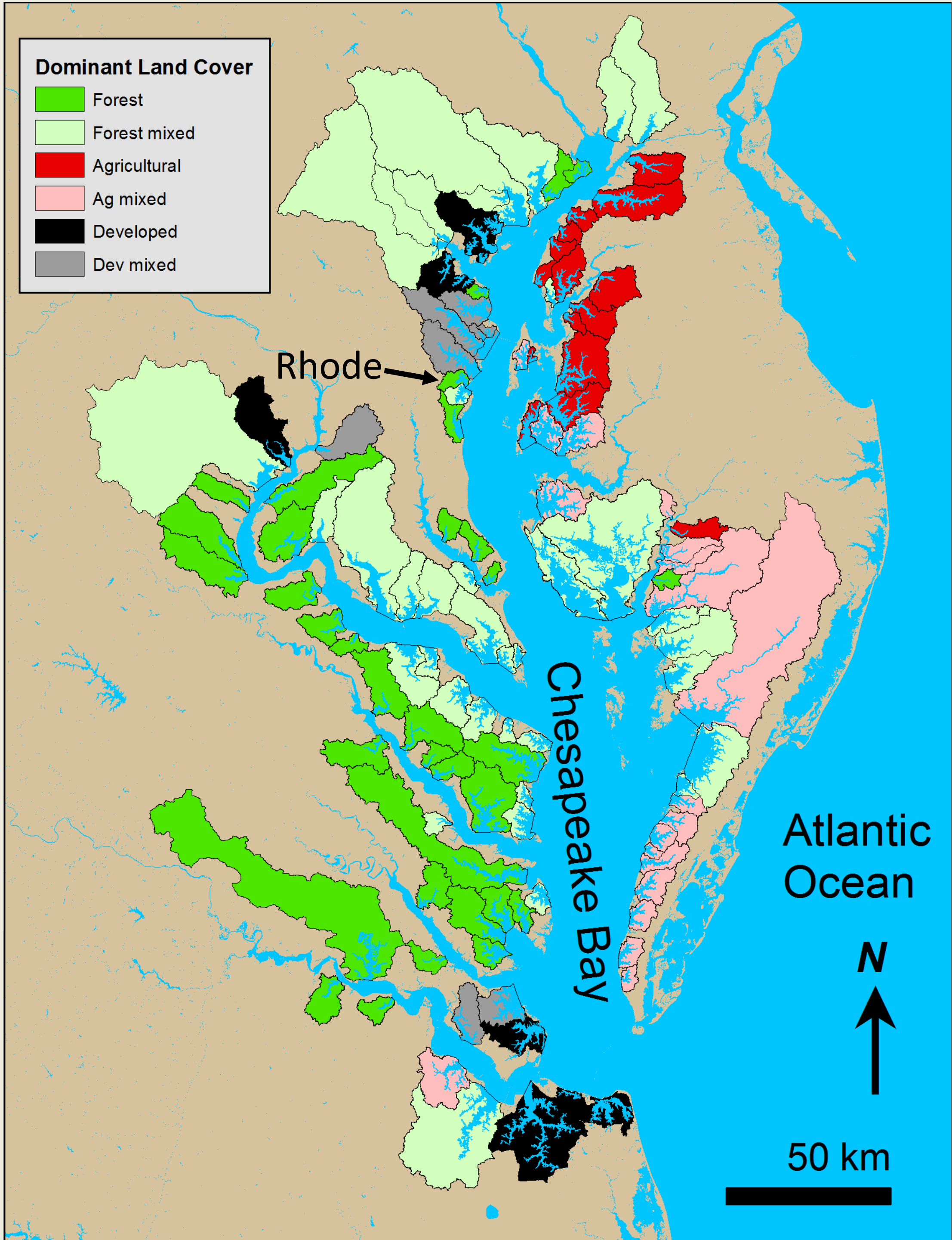


Jordan et al. 1991 L&O 36:251-267

~100 study subestuaries

- Shallow hot spots
- Broad range of land cover:

Forest	2-63%
Developed	3-91%
Crop	0-64%
Wetland	1-72%



The NOAA Shorelines Project

Approach: Compare shoreline types…


Native Marsh


Phragmites Marsh


Rip-Rap


Bulkhead


Beach

…in bays subestuaries with watersheds that have differing land use.

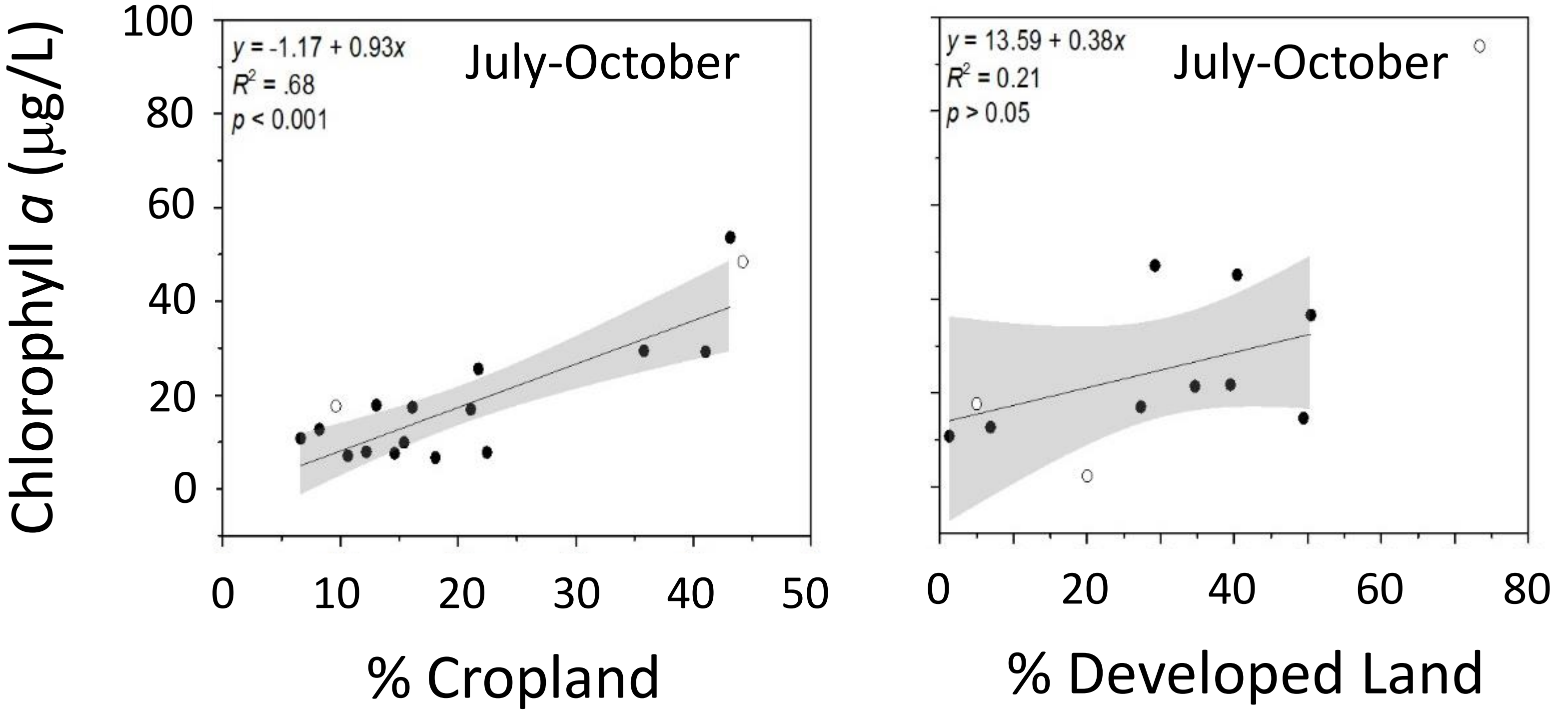

Forested


Developed

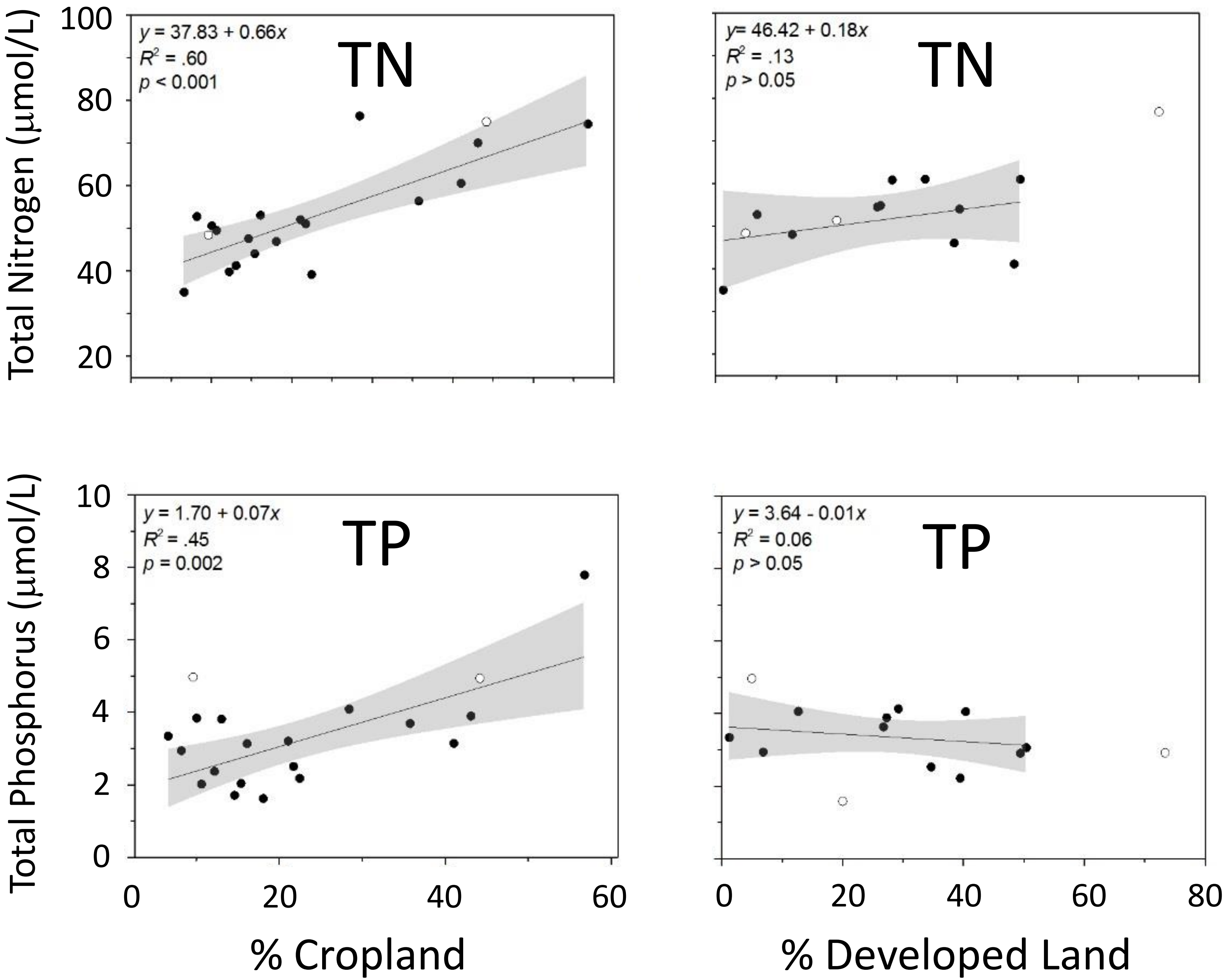

Agricultural

Forty nine subestuaries compared to investigate the effects of land cover on water quality:

Chlorophyll *a*

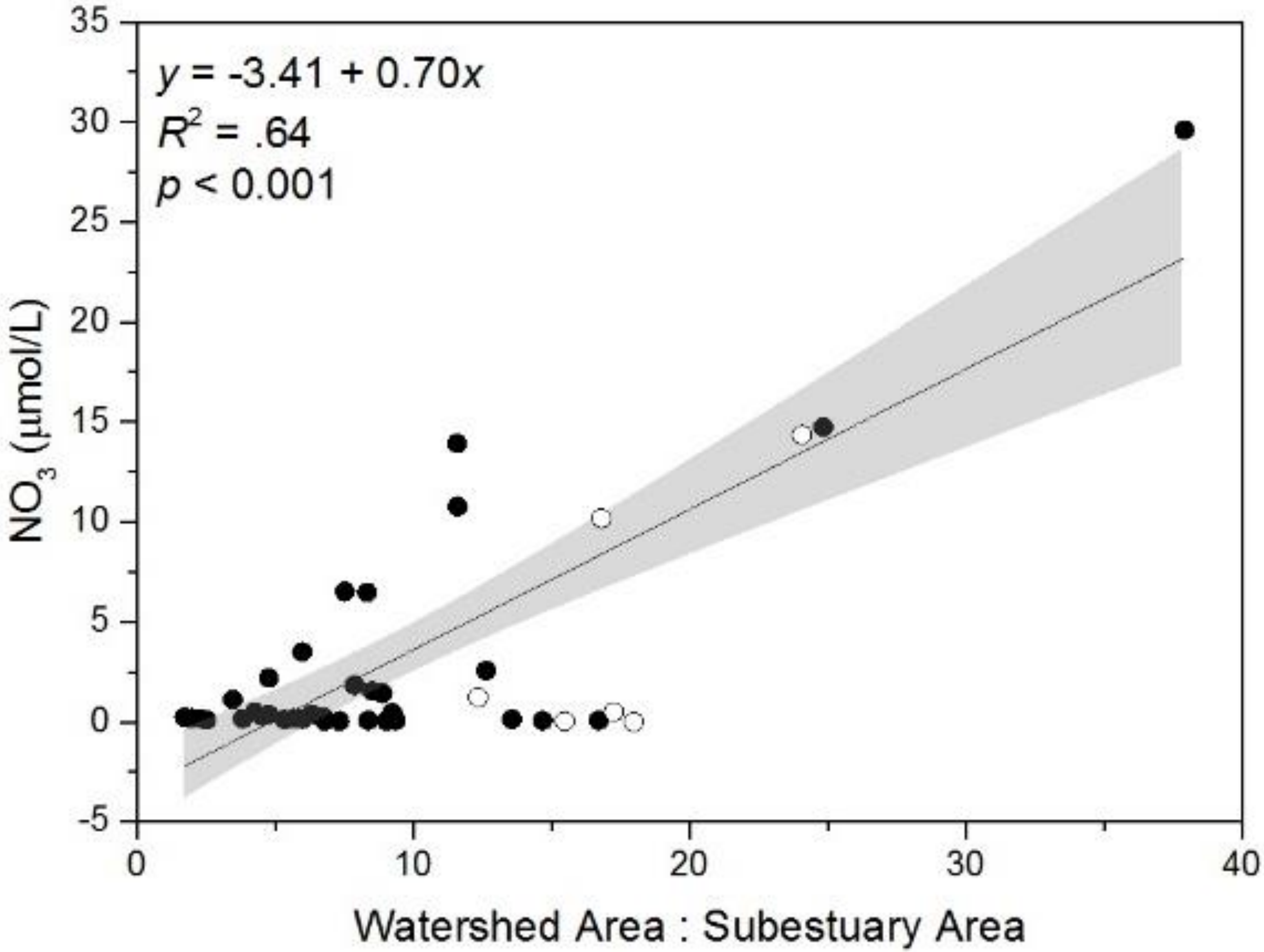


Jordan et al. 2017. Estuaries and Coasts.

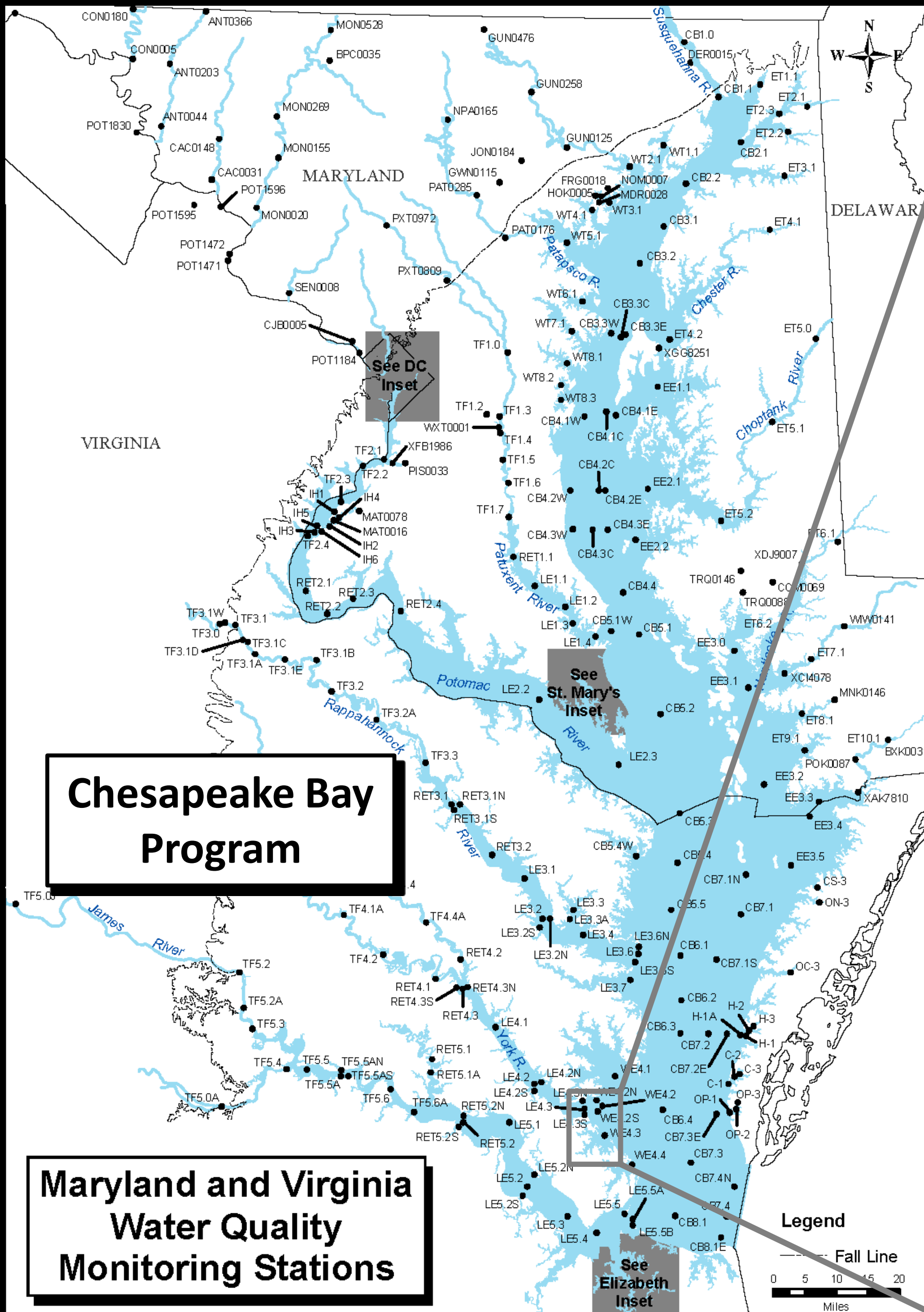


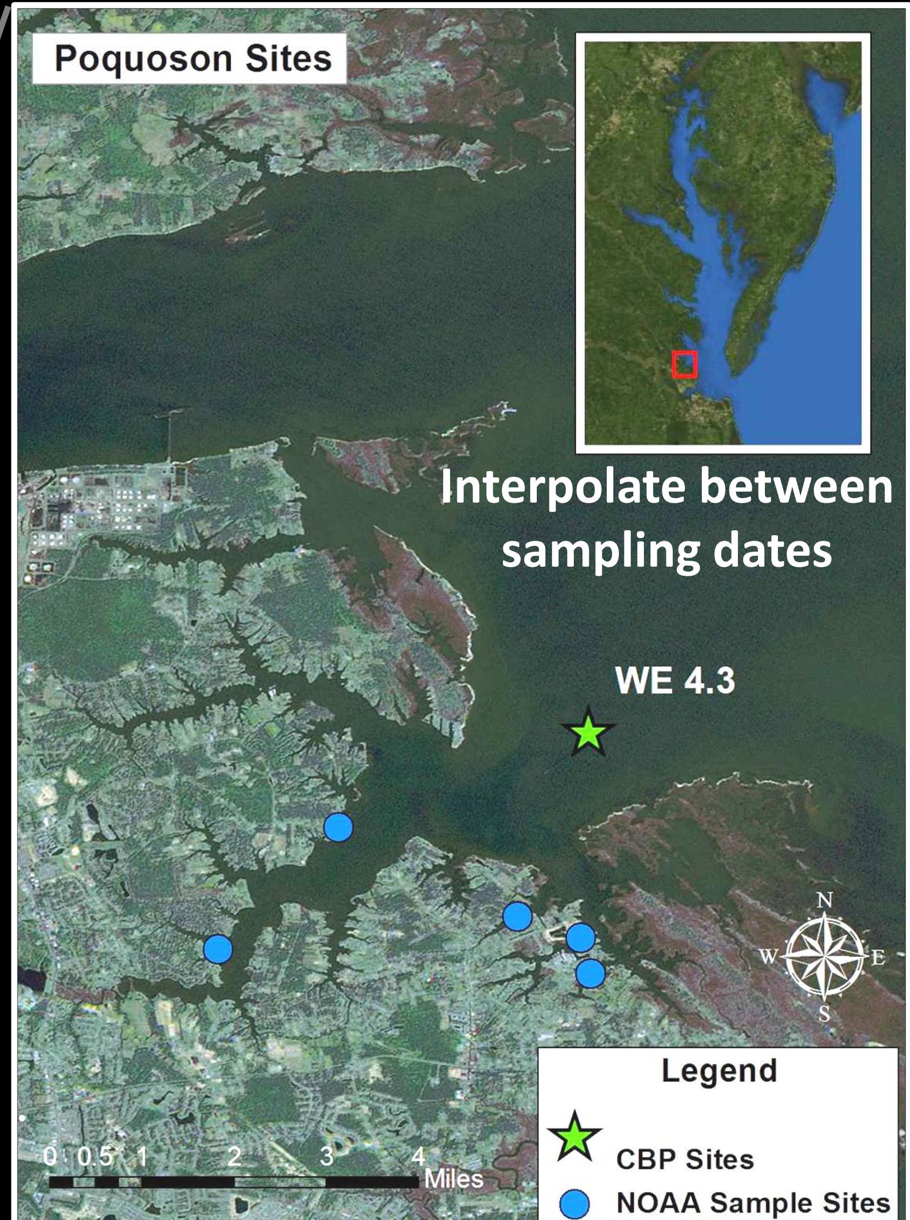
Total Nitrogen (μmol/L)
Total Phosphorus (μmol/L)
y = 37.83 + 0.66x
R² = .60
p < 0.001
TN
y= 46.42 + 0.18x
R² = .13
p > 0.05
TN
y = 1.70 + 0.07x
R² = .45
p = 0.002
TP
y = 3.64 - 0.01x
R² = 0.06
p > 0.05
TP
% Cropland
% Developed Land

Nitrate vs. Ratio of Watershed Area : Subestuary Area



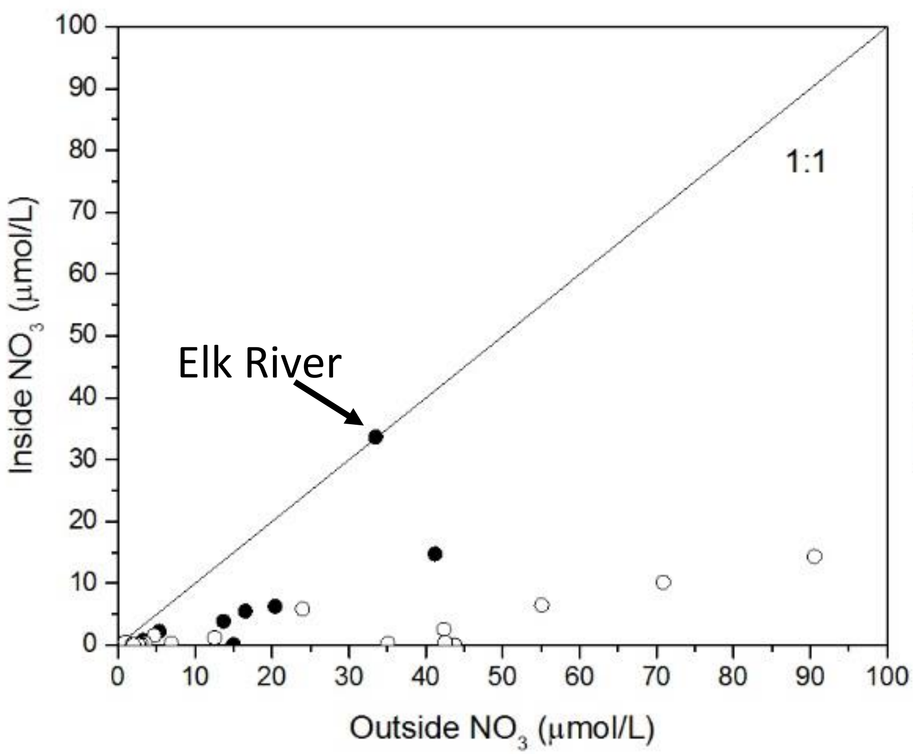
Inside vs. Outside Subestuaries



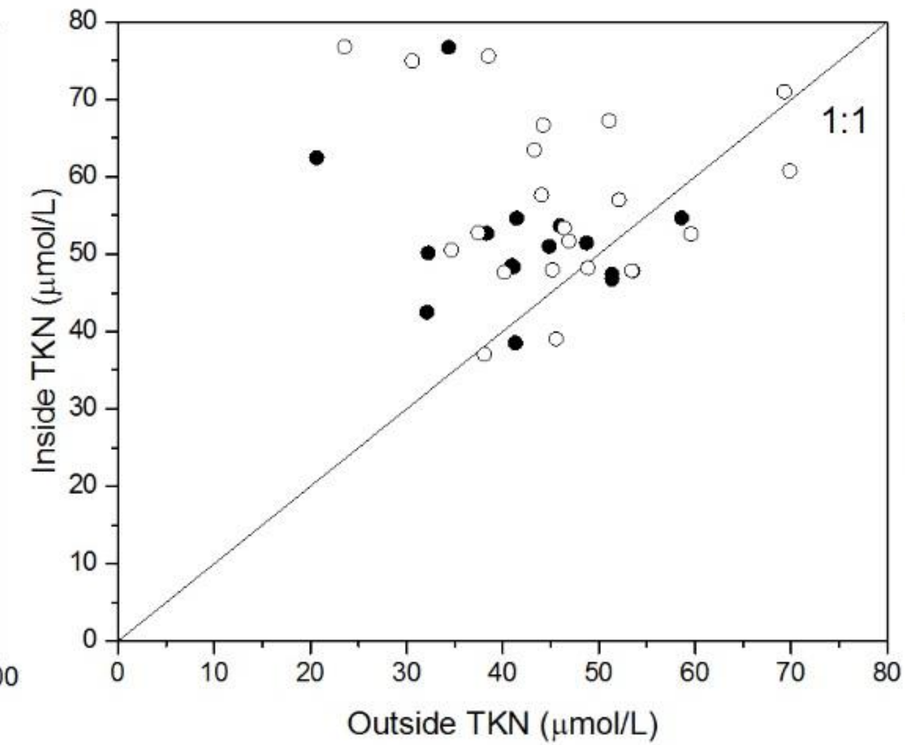


Concentration Inside vs. Outside the Subestuary

Nitrate (μmol/L)

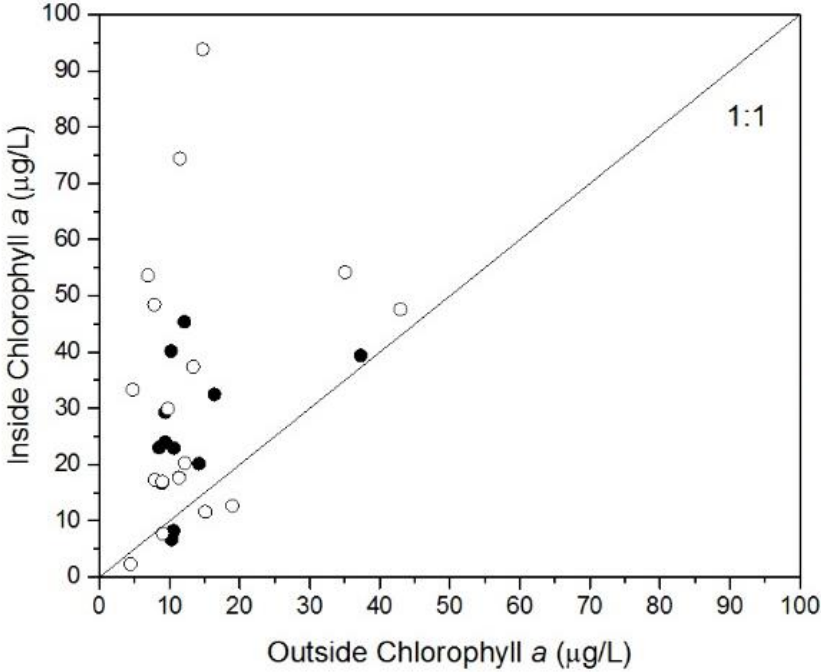


TKN=
Ammonium Plus Organic N (μmol/L)

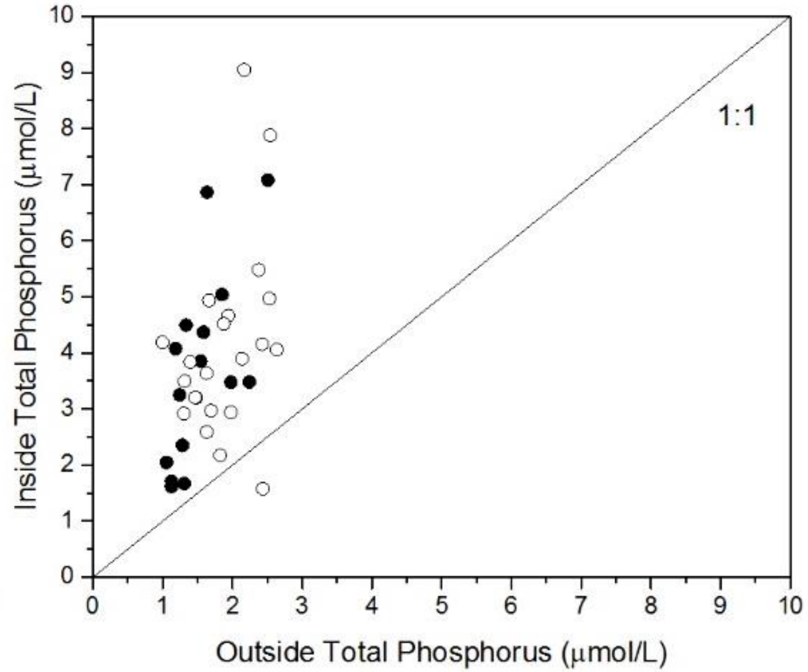


Concentration Inside vs. Outside the Subestuary

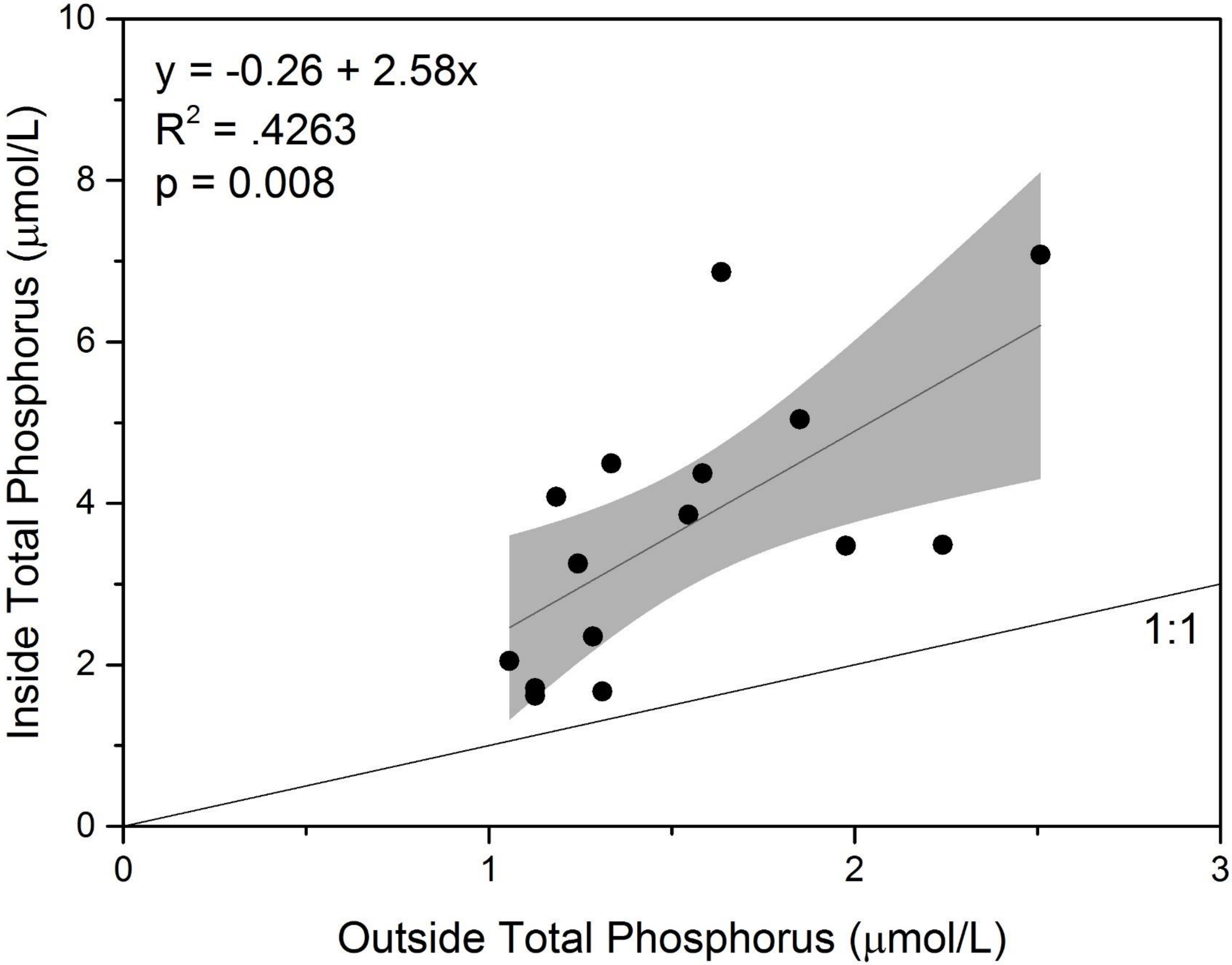
Chlorophyll *a* (μg/L)



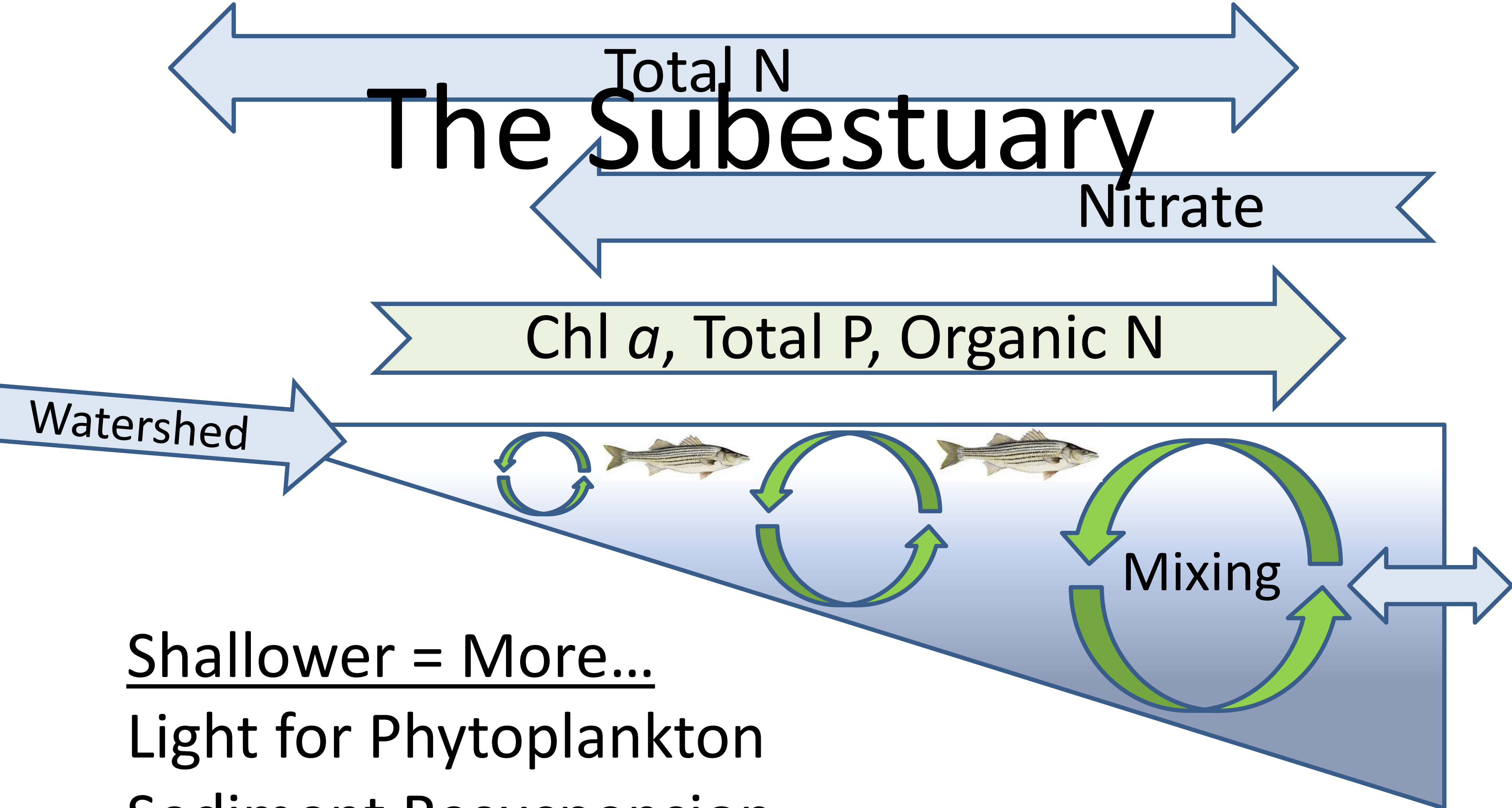
Total Phosphorus (μmol/L)



Total Phosphorus: Inside vs. Outside the Subestuary



The Subestuary



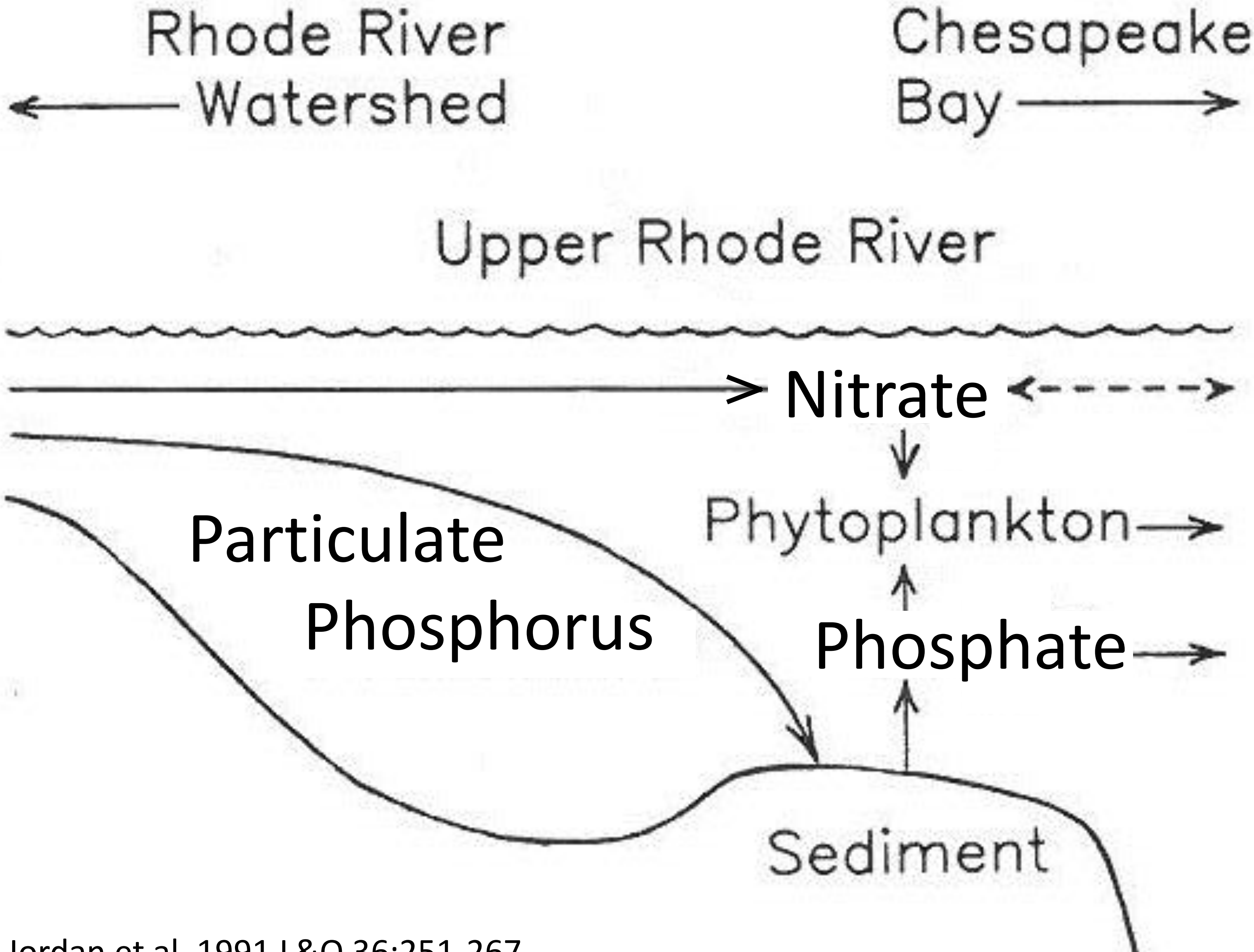
<u>Shallower = More…</u>

Light for Phytoplankton

Sediment Resuspension

(Sediment Surface)/(Water Volume)

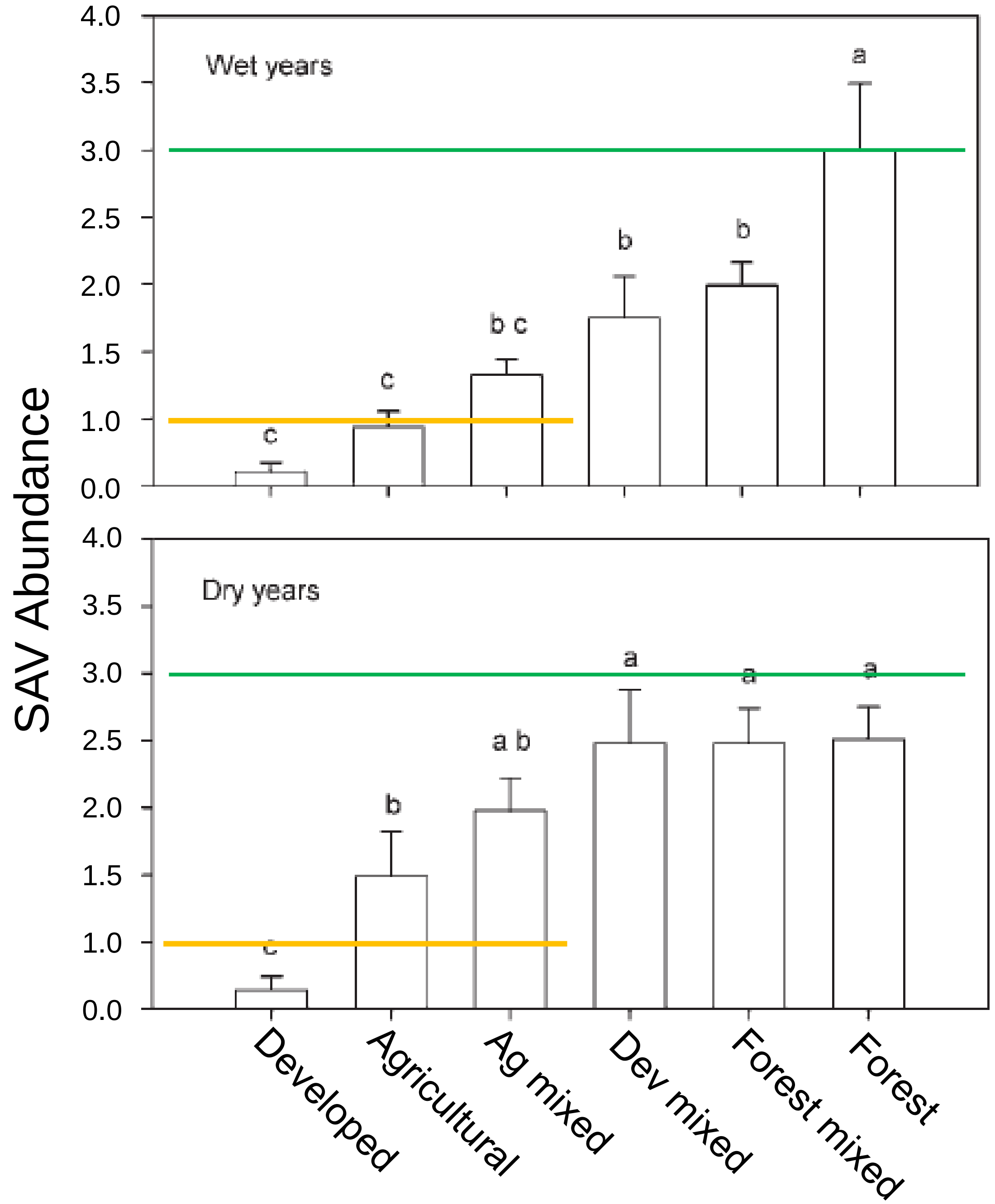
Benthic Denitrification and Nutrient Release



Jordan et al. 1991 L&O 36:251-267

Interacting effects of land cover and weather

- SAV area normalized to habitat area & density weighted
- RM ANOVA
- Dev always low
- Ag better in dry years
- Forest better in wet years



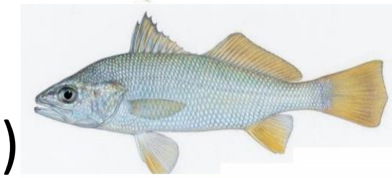
Li et al. 2007. Estuaries & Coasts 30:840-854

Negative correlation with % cropland, especially % cropland <100m from shore

Blue Crab
(*Callinectes sapidus*)

Atlantic Croaker
(*M. undulatus*)

Silver Perch
(*Bairdiella chrysoura*)



Hogchoker
(*Trinectes maculatus*)

Spot
(*Leiostomus xanthurus*)

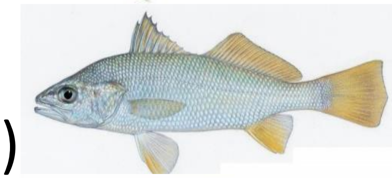
Kornis et al. 2017. Estuaries and Coasts 40:1464-1486.

Negative correlation with
% developed land and
% hardened shoreline

Blue Crab
(*Callinectes sapidus*)

Atlantic Croaker
(*M. undulatus*)

Silver Perch
(*Bairdiella chrysoura*)



Hogchoker
(*Trinectes maculatus*)

Spot
(*Leiostomus xanthurus*)

American Eel
(*Anguilla rostrata*)

Grass Shrimp
(*Palaemonetes pugio*)

Kornis et al. 2017.

Management Implications

- Nutrient management in the local watershed can improve water quality in subestuaries.

- Water quality is distinct in shallow nearshore waters. Sampling outside the subestuary will not characterize nearshore water quality.

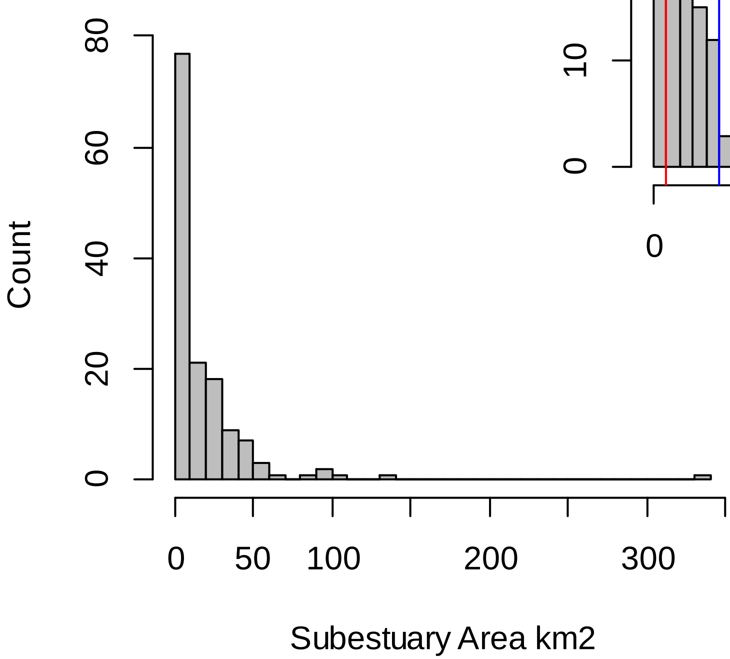
- Comparisons of estuaries with contrasting nutrient sources can provide insights into nutrient fluxes, nutrient limitation, and factors affecting abundance of SAV, fish, and other macrofauna.

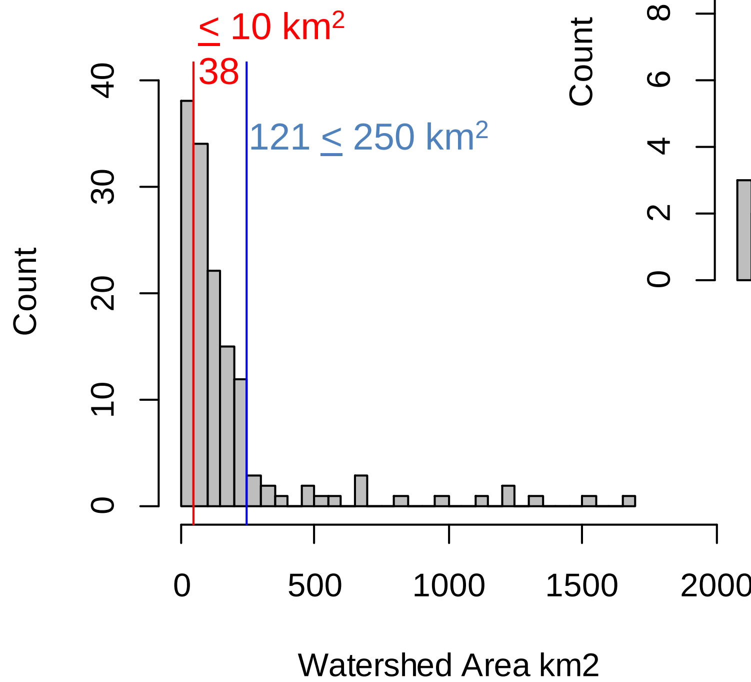
Acknowledgements

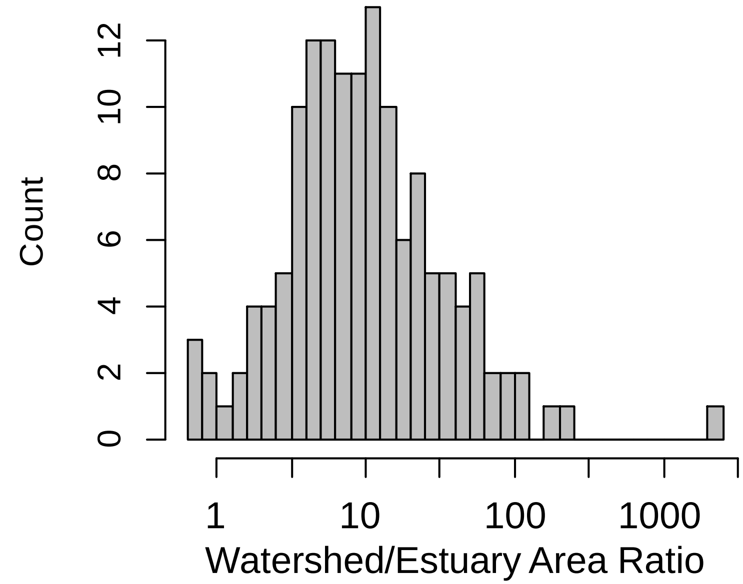
- Since the 1970s SERC research on subestuaries has been funded mainly by: The Smithsonian Institution, NSF, EPA, and NOAA.

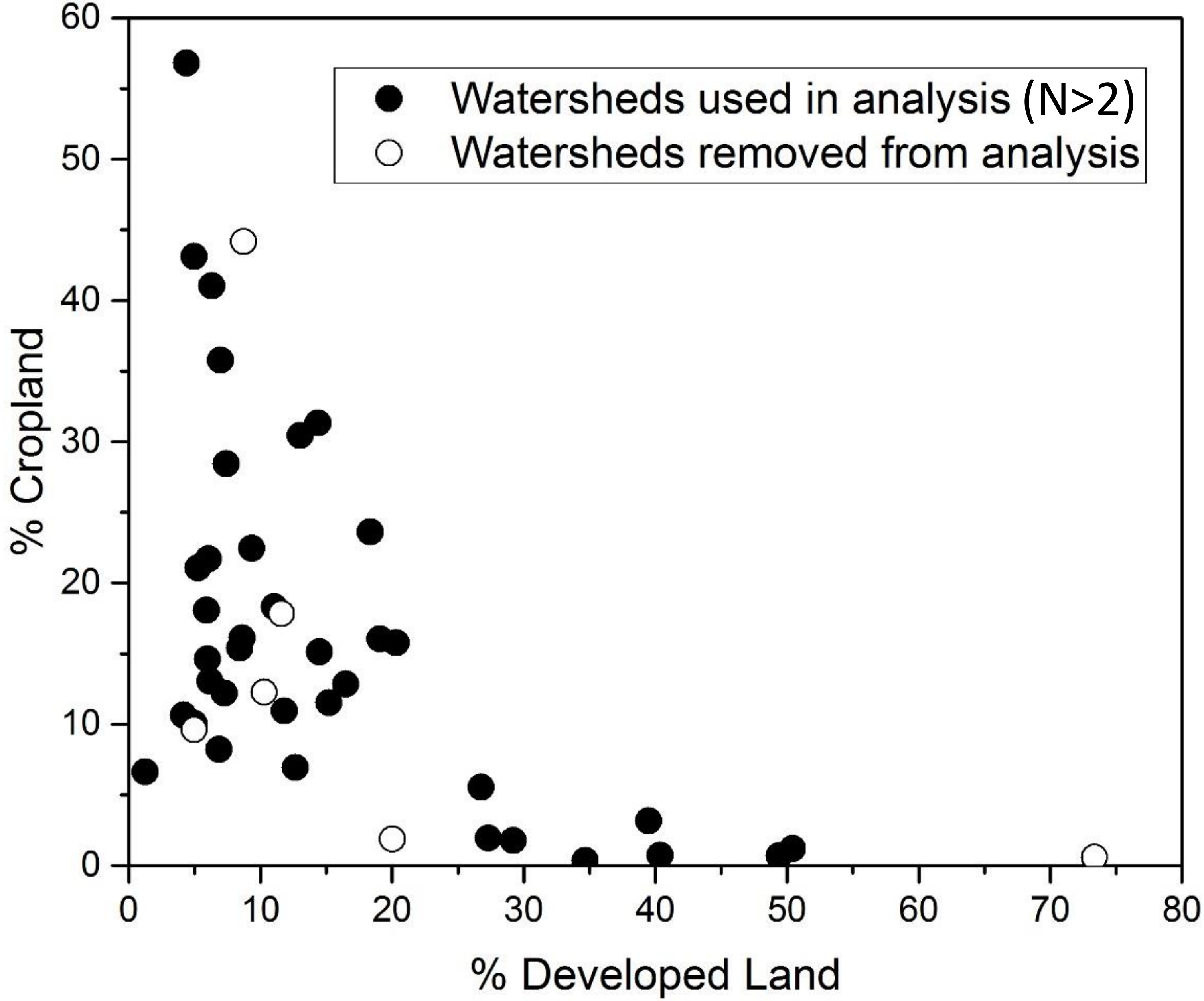
- The Shorelines Project (2009-2016) involved 17 principal investigators from 8 institutions and was funded by: NOAA Center for Sponsored Coastal Ocean Research.

Subestuary size distributions



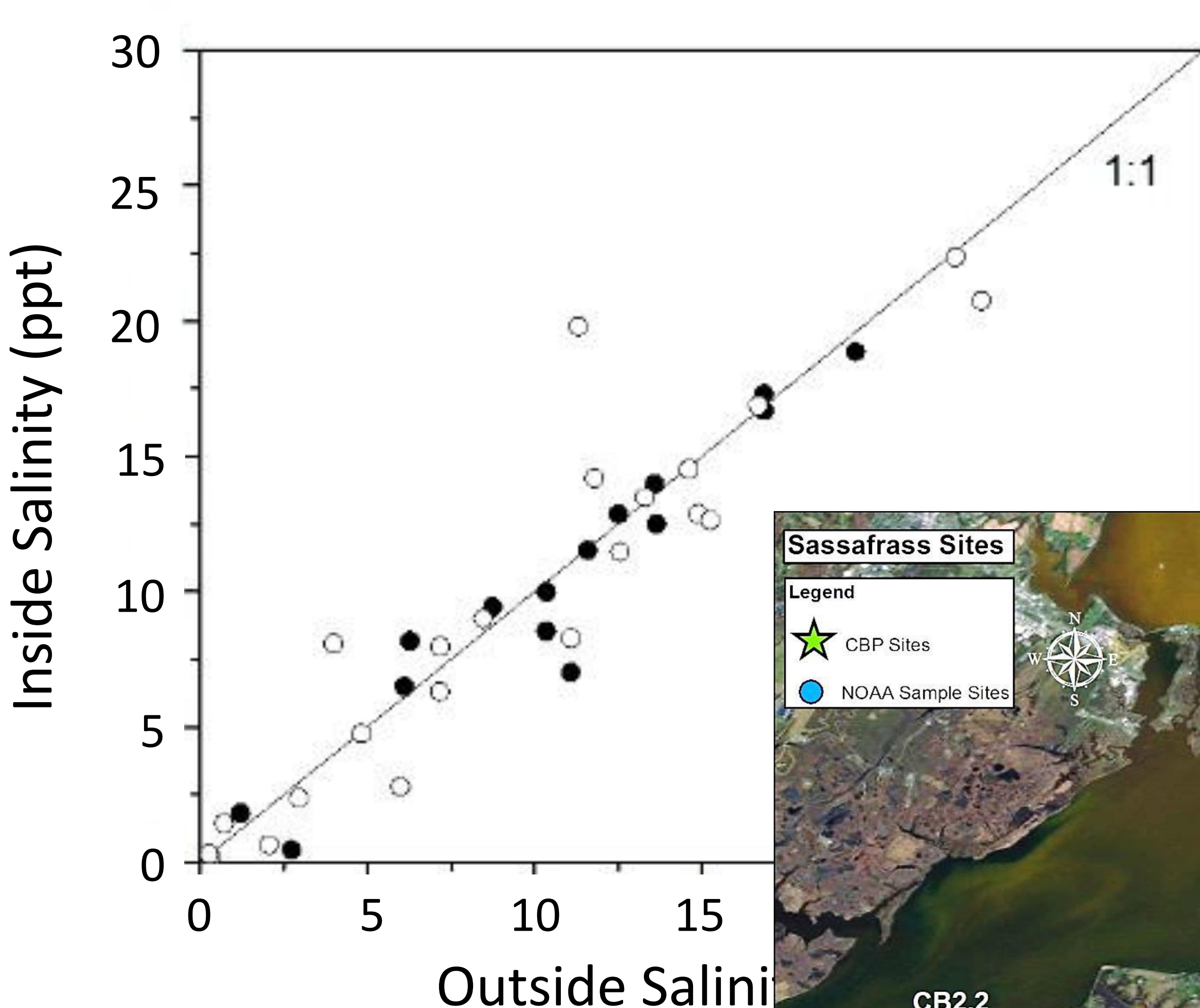


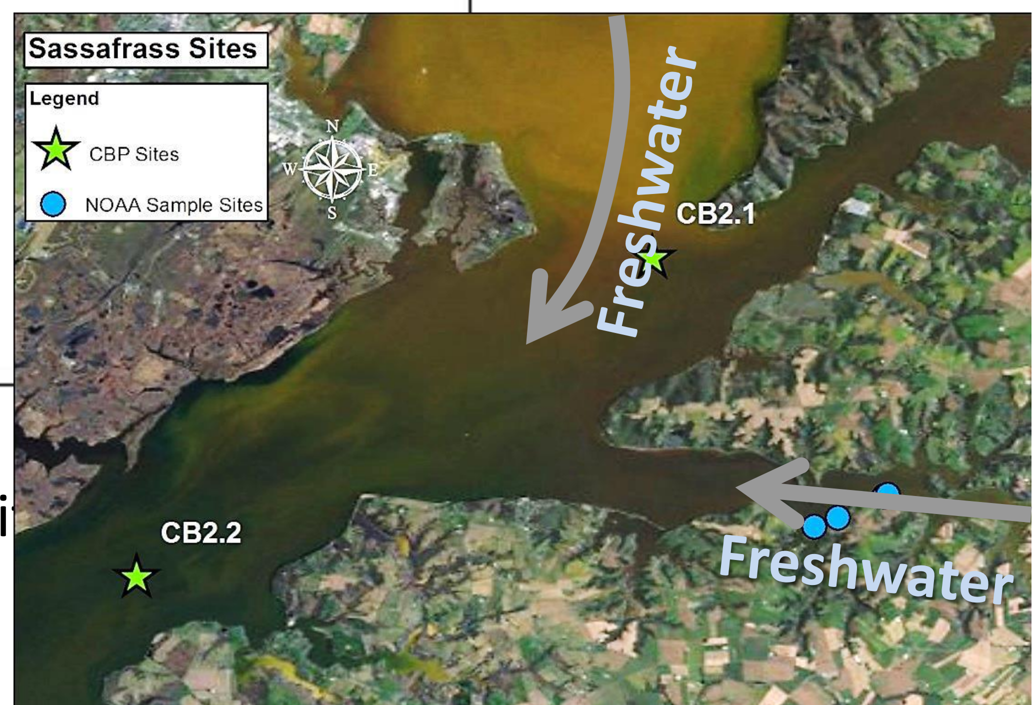




Watersheds used in analysis (N>2)
Watersheds removed from analysis
% Cropland
% Developed Land
0
10
20
30
40
50
60
70
80

Salinity Inside vs. Outside the Subestuary





What are the sources of nutrients: Agricultural vs. Urban?

- Both N and P increase with % Cropland
- Only N increases with % Developed land
- Cropland has a bigger effect per acre than Developed land
- Consistent with previous studies of watershed discharges (e.g. Jordan et al. 1997, 2003)

What are the sources of nutrients: Local vs. Remote Watersheds?

- Local watershed land use makes a difference.
- It’s not just the Susquehanna River or the Conowingo (for example) although remote sources can contribute.
- Local watersheds of subestuaries might contribute to total P concentrations in adjacent waters.

How does depth and proximity to shore affect concentrations of nutrients and phytoplankton?

- Chlorophyll, organic N, and total P concentrations are higher nearshore inside subestuaries than in adjacent water outside.

- Nitrate concentrations are lower inside nearshore than outside.

Which is the limiting nutrient N or P?

- N seems to limit July-October when chlorophyll concentrations were highest.

- N and P increased with % cropland but only N increased with % developed land. However, chlorophyll increased with both land types, suggesting that the addition of N alone was sufficient to increase chlorophyll.

Local vs. Remote Watersheds:

- E.g., what controls eutrophication in subestuaries of upper Chesapeake Bay: nutrients from the Susquehanna River or from the local watersheds of the subestuaries?

- Nitrate and chlorophyll in the Rhode River subestuary respond mostly to variations in Susquehanna discharge (Jordan et al. 1991)

- It has been suggested that sediment releases from the Conowingo Dam may negate efforts to reduce nutrients in Chesapeake Bay (e.g. reports in Washington Post and Baltimore Sun, 2017)

How could depth affect nutrients and phytoplankton?

Shallower water has more:

- Light throughout the water column
- Sediment resuspension
- Surface area of bottom sediments per water volume, which increases the importance of exchanges between the sediment and water column

Subestuary concept

- Recent studies have exploited the natural division of the Chesapeake Bay into dozens of subestuaries to explore and quantify the effects of nearby land use on estuarine responses. Each subestuary, an embayment at the mouth of a tributary stream, has its own local watershed with associated land use activities (Fig. xx); and each of the major salinity zones (polyhaline, mesohaline, oligohaline, and tidal fresh) contains many subestuaries. The subestuaries of the Chesapeake Bay and Atlantic coastal bays are convenient, replicated study units for comparing systems dominated by different land uses and salinity regimes (Li et al. 2007; Patrick et al. 2014). The subestuaries can serve as replicate study units for analyzing the effects of watershed stressors on estuarine responses, and this approach has been applied to studies of blue crab abundance, polychlorinated biphenyl (PCB) contamination of fish, bird community health, and other measures of estuarine condition (DeLuca et al. 2004; King et al. 2004, 2005). Studies of Chesapeake Bay SAV have examined stressor-response relationships across 100 subestuaries (Li et al. 2007; Patrick et al. 2014, 2016; Patrick and Weller 2015). Subestuaries differ widely in the proportions of human land uses in their local watersheds. Watersheds range from having little or no forest, development, wetlands, or cropland to having as much as 79%, 77%, 51%, and 57%, of each category respectively (see Table 2 in Patrick et al. 2014). These ranges highlight how strongly land use varies near the Chesapeake Bay--some subestuaries have mostly natural land uses in their local watersheds, while others have watersheds dominated by row-crop agriculture or high-density development.