Constructing Probability Surfaces of Ecological Changes in Coastal Aquatic Systems Through Retrospective Analysis of *Phragmites australis* Invasion and Expansion

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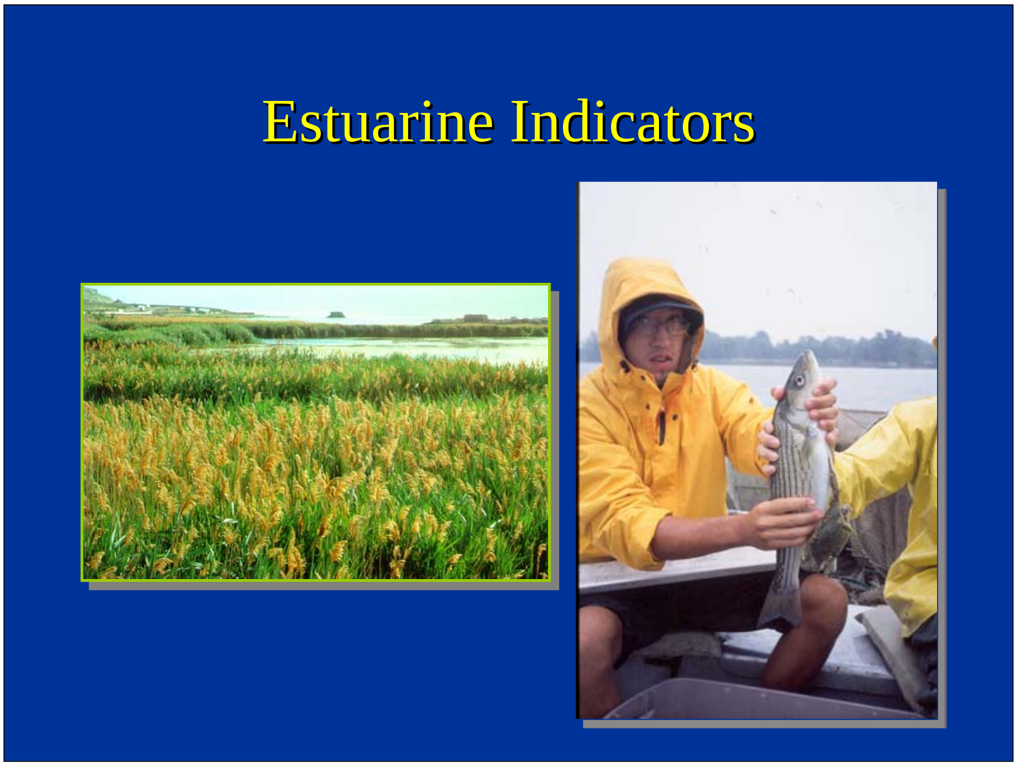
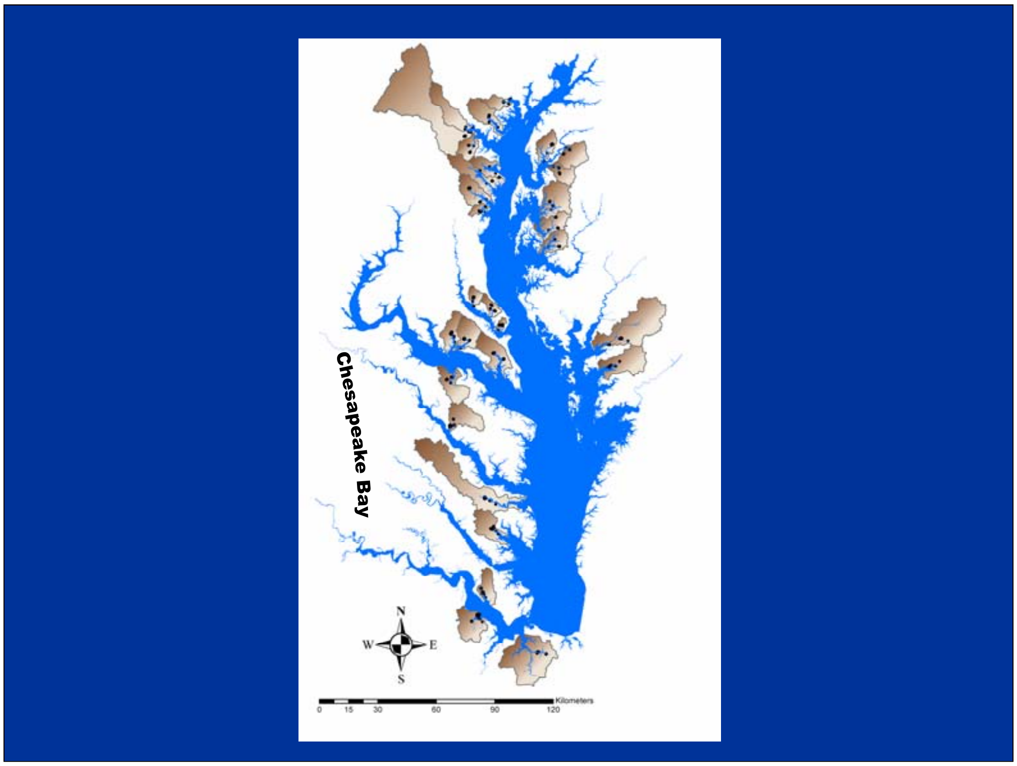
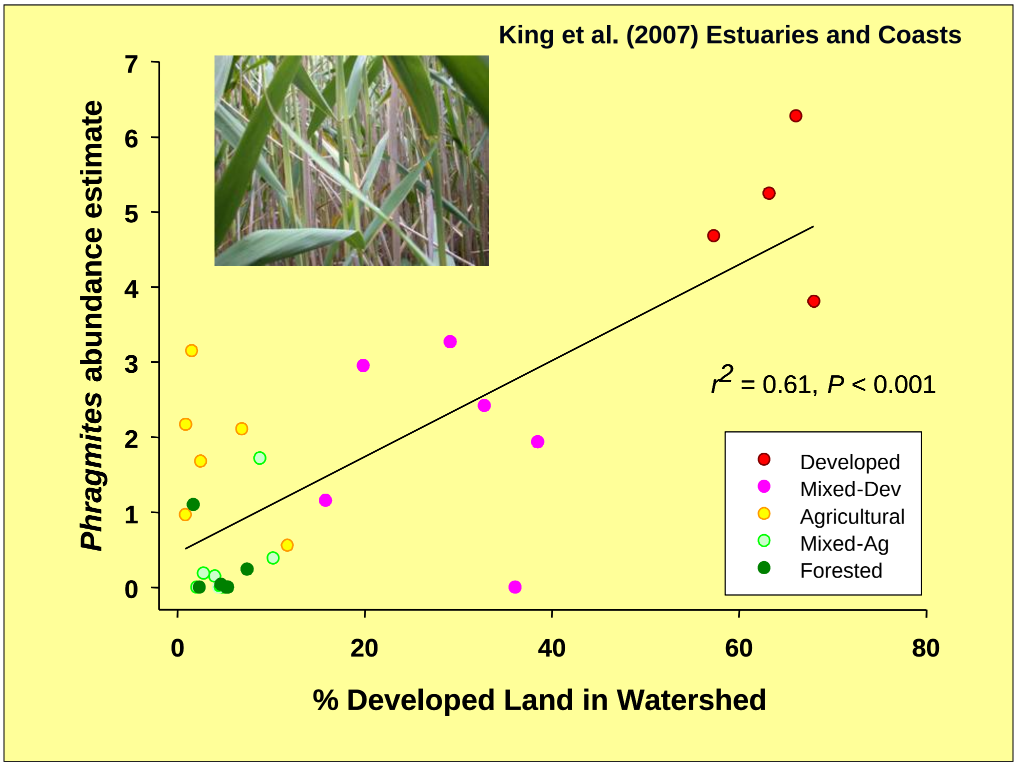


The Chesapeake Bay is highly monitored. While there are many indicators of changes in the Bay, it is difficult to link these indicators to what is occurring on land. This project is working to link these indicators to the land. The hope is that the researchers will be able to identify linkages and detail how those linkages occur.

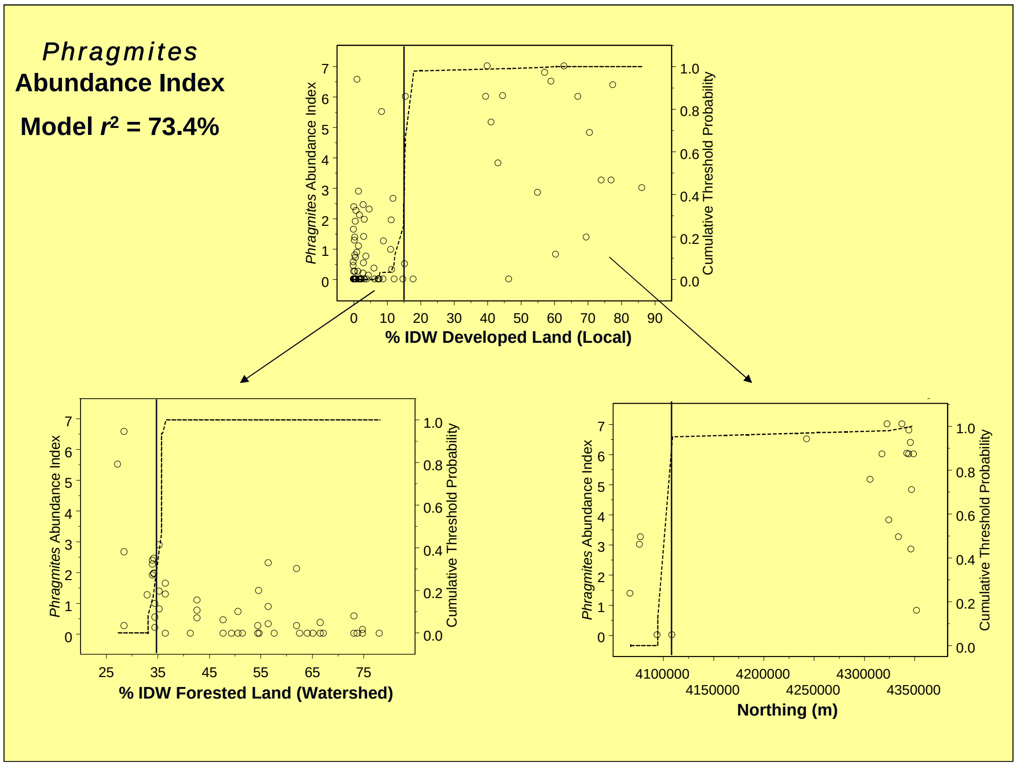


The researchers sampled the Chesapeake Bay from north to south, focusing on estuarine segments. An estuarine segment is a watershed that is large enough to have a perennial stream flowing into the subestuaries of the Chesapeake Bay. A broad range of indicators that responded to land use patterns was identified. In particular, there appeared to be a strong association between an invasive plant species called *Phragmites* and land use.

The dots on the map represent the places where the researchers sampled the water for *Phragmites*. Estuarine segments were chosen using GIS data to represent the three dominant land use types: development, agriculture, and forest (reference condition).



There was a significant correlation between the amount of development on the watershed and the abundance of *Phragmites*.



The three most important variables affecting *Phragmites* are: developed land; northing (location of the subestuary in the Chesapeake Bay), which has shown that the invasion front is moving from the north to the south in the Chesapeake Bay; and forested land.

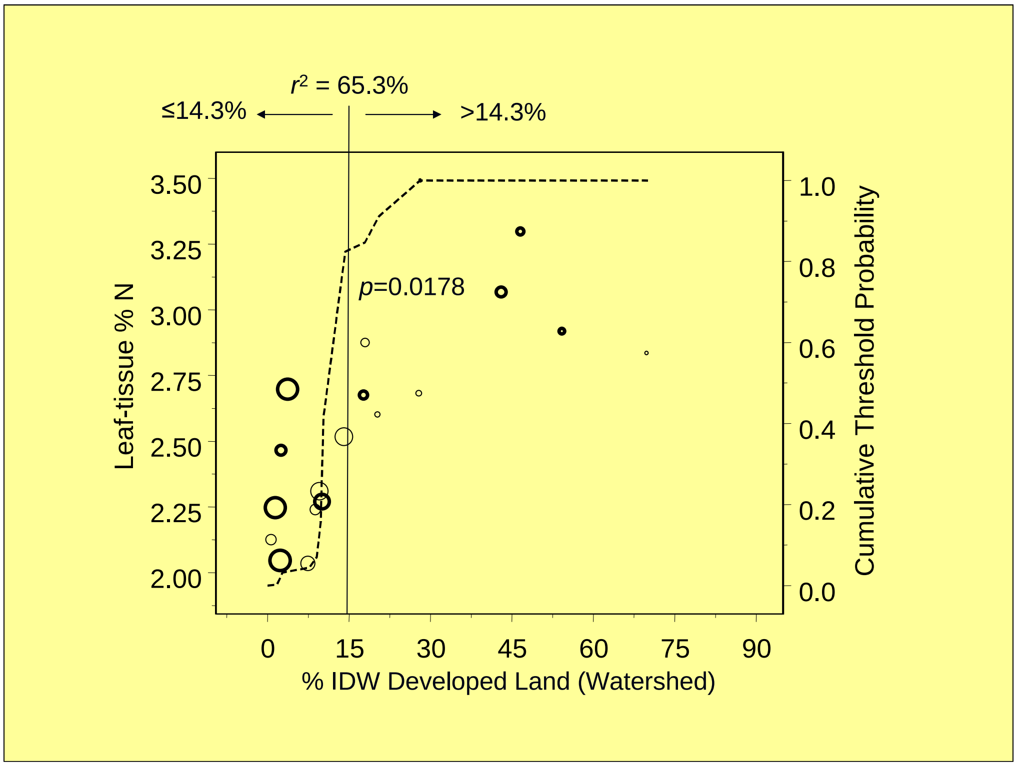
The researchers identified a threshold using these indicators. The data show that only a small amount of development is needed to reach the threshold and, once a certain point is reached, change occurs very quickly.

Developed land is the most important variable related to the abundance of *Phragmites*. Although the amount of developed land along the watershed is important, where the developed land is occurring along the watershed also is very important. The closer the disturbance to the water, the stronger the relationship.

Category	Adaptations	Dispersal distances		Representative species (terminal velocity in m/s)
Species with low terminal velocity seeds	Low terminal velocity seeds (terminal velocity ≤ 0.3 m/s) and relatively high release heights, often in combination with selective release mechanisms	Upper limit is at least several kilometres under highly convective or stormy conditions	Several kilometres ↓	Typha latifolia (0.1) Phragmites australis (0.1) Epipactis palustris (0.2) Liparis loeselii (0.2) Epilobium hirsutum (0.2) Epilobium palustre (0.2) Eriophorum angustifolium (0.2) Dactylorhiza species (0.3) Cirsium palustre (0.3) Aster tripolium (0.3)
Species with low terminal velocity seeds	Low terminal velocity seeds (0.3 m/s < terminal velocity < ± 2 m/s) and relatively high release heights, often in combination with selective release mechanisms	Upper limit ranges from at least several kilometres to at least several tens of metres under stormy conditions.	Several tens of metres ↓	Cirsium dissectum (0.38) Eupatorium cannabinum (0.4) Narthecium ossifragum (0.6) Senecio paludosus (0.6) Valeriana dioica (0.6) Leontodon autumnalis (0.9) Holcus lanatus (1.1) Anthoxanthum odoratum (1.4) Filipendula ulmaria (1.7) Molinia caerulea (1.8) Cardamine pratensis (1.9) Succisa pratensis (2.14)
Wind ballists	Selective release mechanisms	Upper limit several metres under stormy conditions	Several metres	Luzula campestris (2.5) Centaurea jacea (4.33)

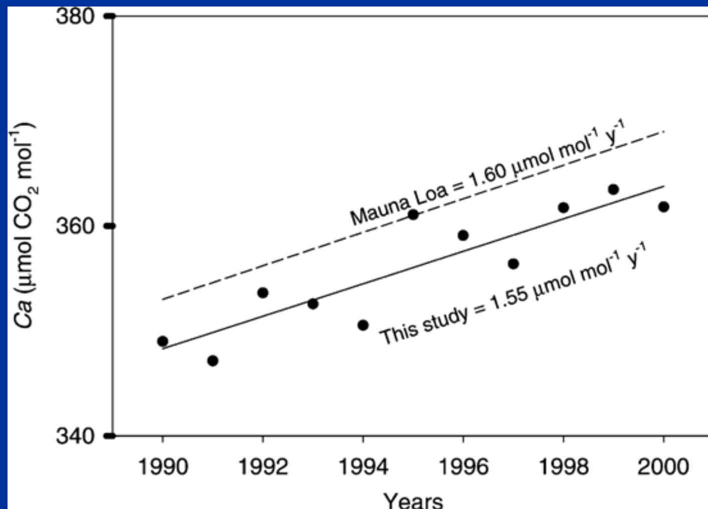
Source: Sooms (Applied Veg. Sci.)

Phragmites can spread rapidly and colonize a large area. In fact, their seeds can disperse up to several kilometers.



The concentration of nitrogen in the leaves of the plant showed the same pattern. As more development close to the wetland occurs, the percentage of nitrogen in the leaves begins to increase rapidly. Thus, there may be a second important factor: the nutrient status of the ecosystem of the subestuaries.

The researchers initially hypothesized that there were two important factors in the establishment and spread of *Phragmites*: (1) a disturbance was needed to establish *Phragmites* in a new area, and (2) nutrient enrichment in the system was needed to allow *Phragmites* to spread.



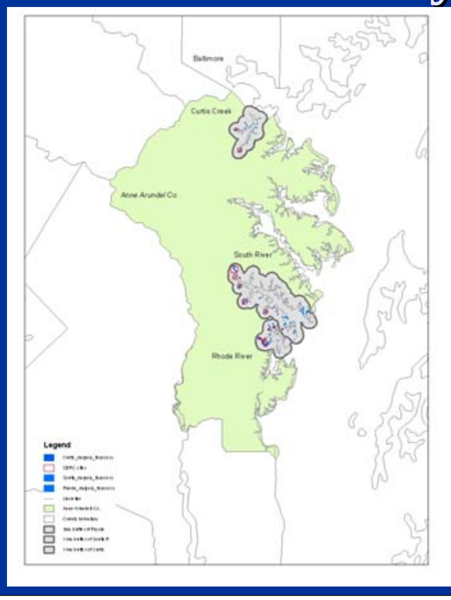
Patterns of canopy-air CO2 concentration in a brackish wetland: analysis of a decade of measurements and the simulated effects on the vegetation.

Daniel P. Rasse, Stavroula Stolaki, Gary Peresta, Bert G. Drake
Agricultural and Forest Meteorology 114 (2002) 59–73

Objectives

- Choose an aquatic ecosystem with clearly identifiable alternative states, and define a limited number of variables that are considered to be the driving factors in state changes
- Establish the database of explanatory and response variables over both a spatial and temporal extent. A retrospective analysis is the most powerful if performed over a truly temporal extent, instead of a "space for time" experimental design.
- Construct a probability surface of state change over the n-dimensional space of selected explanatory variables
- Describe thresholds in terms of the probability surface

Selection of Anne Arundel County, MD



- Abundance of historical data
- Rapid development
- Invaded/uninvaded marshes
- Existing management infrastructure

Prioritized Slow Variables

Accumulating potential for an alternative ecosystem

1. Flooding
2. Organic vs. mineral soil
3. Presence of non-native haplotype
4. Genetic variation in population
5. Drought
6. Developed Land Cover
7. Agricultural Land Cover
8. Forested Land Cover
9. Nitrogen from septic systems
10. Nitrogen from point sources
11. Hydrologic connectivity to Bay
12. Salinity
13. Atmospheric CO_2
14. Atmospheric nitrogen deposition
15. Phosphorus
16. Precipitation and Climate

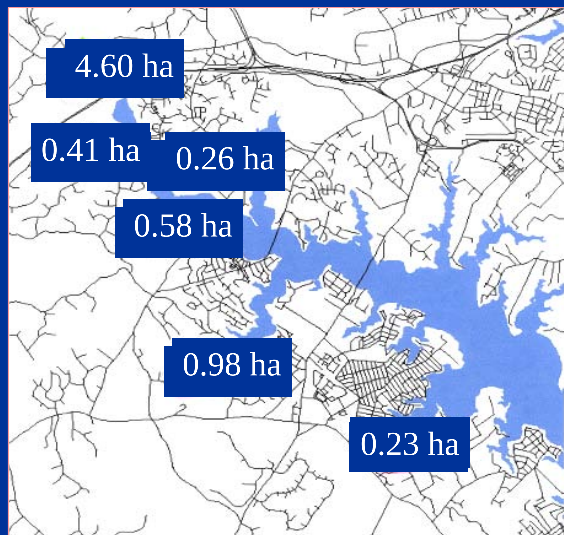
Prioritized Fast Variables
Events which precipitate a reorganization of the plant community

1. Aerial distance to nearest *Phragmites*
2. Water distance to nearest *Phragmites*
3. Sedimentation
4. Road/Bridge
5. Tidal Restrictions/ Bulkhead
6. Upland Fills/Construction
7. Marsh modification (Dock, Boardwalk)
8. Marsh surface water input
9. Storms
10. Fetch
11. Species composition of marsh
12. Ditches/Tidal Creek

Data Sources

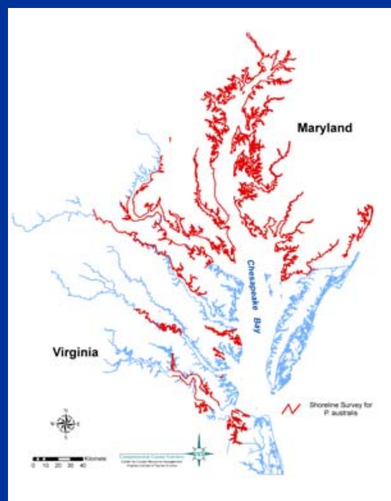
- Complete inventory, classification, and mapping of MD tidal marshes, 1970s (training set)
- Aerial photographs for 1970, 1977, 1984, 1992, 2001 (preliminary analysis for *Phrag* expansion)
- Remote sensing data for 1984, 1992, 2001
- Shoreline Survey for Maryland, completed in 2005 (1441 shoreline miles surveyed)
  - Immediate riparian zone
  - Bank
  - Shoreline

Phragmites Invasion in South River Marshes



- 1970: Present only in two marshes; < 2 ha
- 1977: Invades two additional marshes; expands to 3.2 ha
- 1984: Present in all six marshes; area increases to 4.1 ha
- 2000: Large increases in all marshes (38%-800% over 1984 areas); total area = 7.1 ha

Shoreline Situation Reports



- Immediate riparian area for land use
- Height, stability, and natural protection of bank
- Recreational and access structures on shoreline

Red represents sites where shoreline surveys have been completed.

Rhode River. 1-km buffer in yellow; SERC sites in red; DNR wetland polygons in blue; VIMS Phrag in bright pink; VIMS unknown in pale pink: VIMS no Phrag in gray

Expansion of temporal/spatial data set

- Decision to “recreate” inventory, land cover, and shoreline survey for all available time periods, proceeding from 2005 “backwards”
- Increases temporal datapoints from 5 to 15

Availability of Aerial Photography

Year	Rhode River	South River	Curtis Bay
1943	X	Incomplete	Complete
1952	Incomplete	Incomplete	Complete
1957	Complete	Complete	Complete
1962/3	Complete	Complete	Incomplete
1970	Complete	Complete	Incomplete
1977	Complete	Incomplete	Complete
1980	Incomplete	Incomplete	Incomplete
1984	Complete	Complete	Complete
1988	Incomplete	Incomplete	Incomplete
1990	Complete	Complete	Complete
1995	Complete	Complete	Complete
1998	Complete	Complete	Complete
2000	Complete	Complete	Complete
2002	Complete	Complete	Complete
2005	Complete	Complete	Complete

Explanatory Variables from Aerial Photography

- Aerial distance to nearest *Phragmites* population
- Water distance to nearest *Phragmites* population
- Land cover
- Shoreline disturbances
- Species composition of marsh

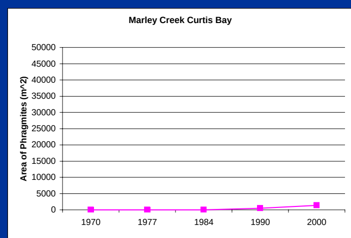
Historical Photo Interpretation:
Excerpt of Explanatory Variable Metrics, Temporal and Spatial Scale

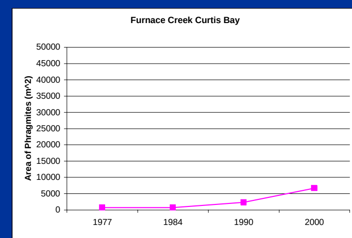
Variable	Variables Impacted	Metric of Measure	Temporal Period	Spatial Scale
Aerial Distance to Nearest Phragmites Population	Increase dispersal; within marsh: decrease anoxia and flooding (clonal Integration);	1) closest pixel with Phragmites, 2) % of pixel in Phragmites coverage	aerial photo time step; time steps before	pixels which include marsh
Land Cover: Developed, Agricultural, Forested	nitrogen in surface H_2O, sedimentation, flooding, salinity	1) % of land within a certain radius; 2) N load, 3) Sediment load (typical load determined from literature)	1) period of the aerial photo, 2) previous photos (period of 10, 20, 50 years ago?)	1) within 1 km of marsh, 2) within 200 m of marsh, 3) within 10m of marsh
Road/Bridge, Upland Fill/Construction, Marsh Modification (Dock, Boardwalk)	sedimentation, flooding, salinity, dispersal	linear m in pixel	aerial photo time step; time steps before	pixels which include marsh: in or within 10m (30m?) of marsh
Species Composition of Marsh	Salinity, Flooding, Anoxia tolerance; Response to N; Aggressiveness	% of species (plant community type) in pixel	1 measure (1970's)	pixels which include marsh

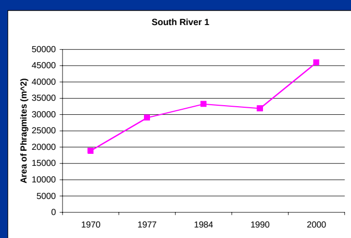
Additional Historical Data

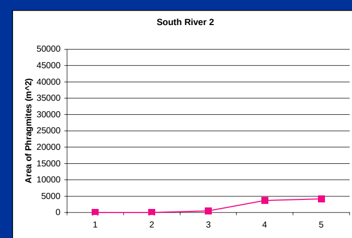
- Sedimentation
- Salinity
- Phosphorous
- Drought
- Precipitation
- Climate
- Flooding
- Mean Sea Level Rise
- Metonic cycles
- Nitrogen - Atmospheric deposition, point sources, septic systems, surface water

Curtis Bay and South River

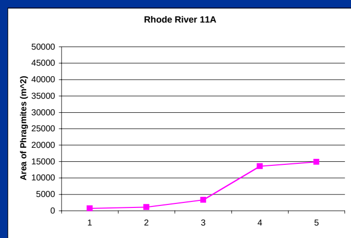


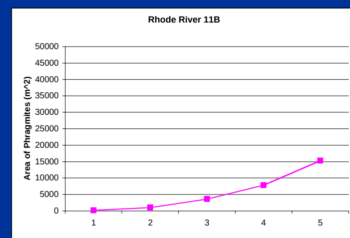


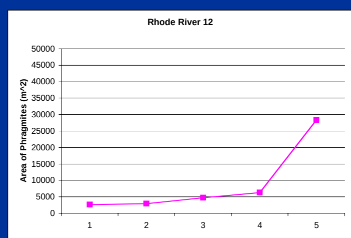


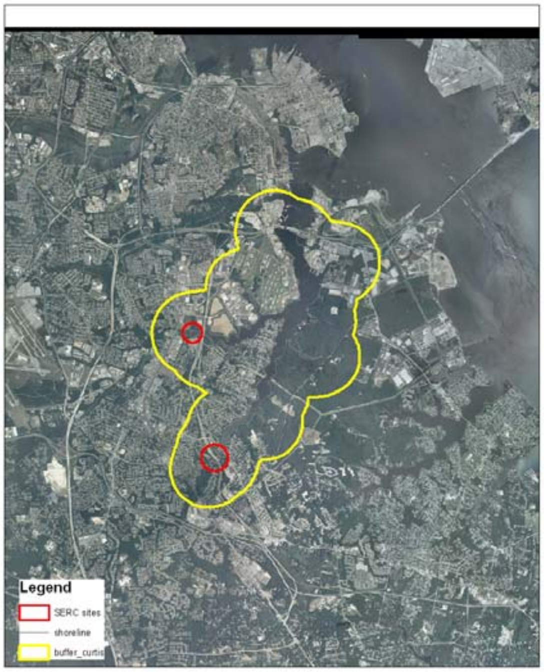


Rhode River


Rhode River 11A
Area of Phragmites (m^2)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1
2
3
4
5


Rhode River 11B
Area of Phragmites (m^2)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1
2
3
4
5


Rhode River 12
Area of Phragmites (m^2)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1
2
3
4
5

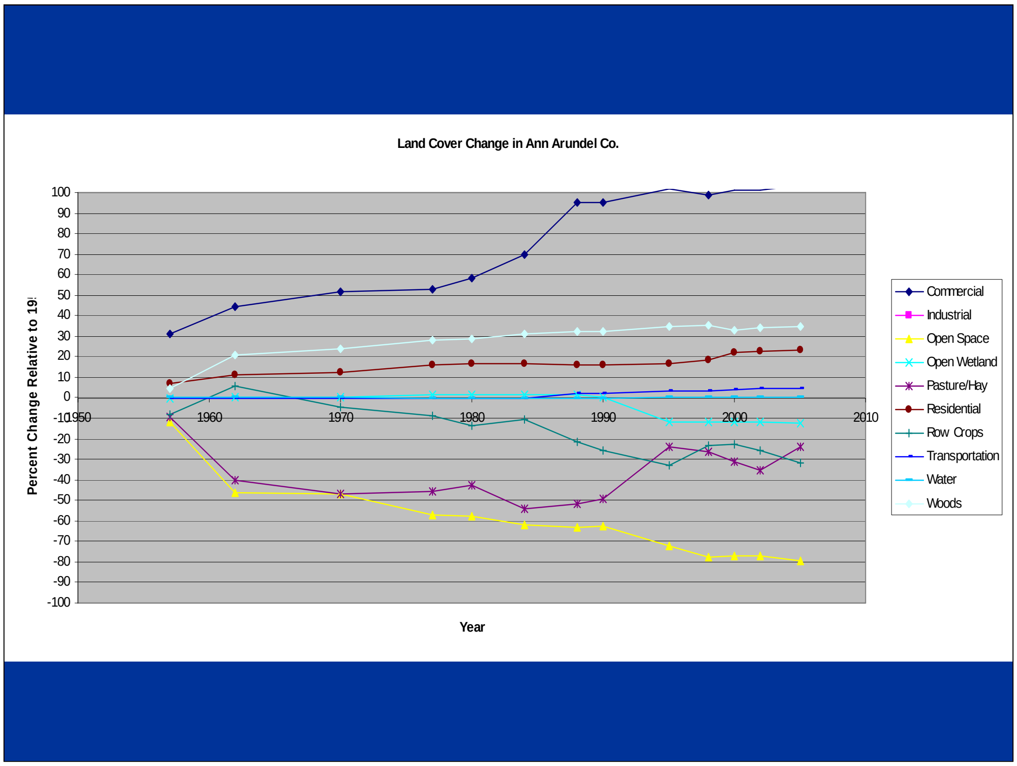


Curtis Bay sub-estuary, with the original SERC sites outlined in red, and the 1 km buffer of the shoreline outlined in yellow.

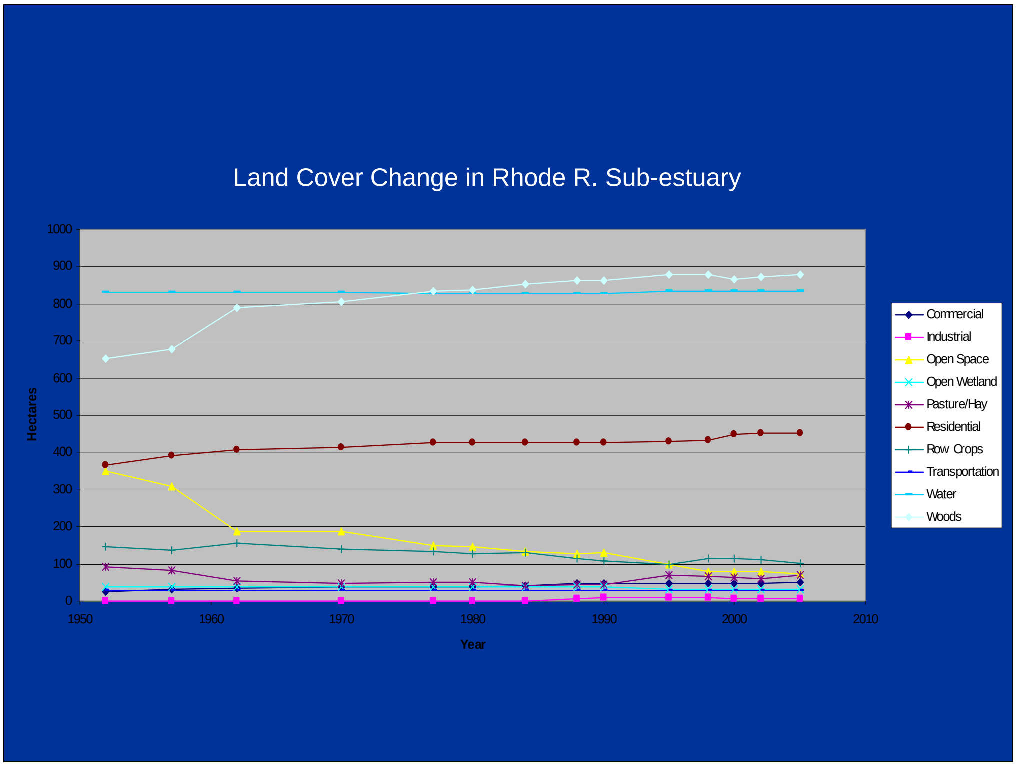
The researchers hypothesized that there was a correlation between nutrient increase and *Phragmites* increase, but they do not appear to be correlated.

AA Co. Land Cover Categories

- **Airport: Land designated or used for air traffic.**
- **Commercial: Retail and office uses.**
- **Industrial: Industrial and industrial parks.**
- **Utility: Corridors defined by electrical line paths. May be represented by clear-cuts in non-urban areas or cleared paths through urban areas.**
- **Residential 1/8-acre: Single or Mulit-Family Residential or Townhouses - 1/8 acre lot size.**
- **Residential 1/4-acre: Single Family Residential - 1/4 acre lot size.**
- **Transportation: Highway, road and railroad right of way.**
- **Residential 1/2-acre: Single Family Residential - 1/2 acre lot size.**
- **Residential 1-acre: Single Family Residential 1 - acre lot size.**
- **Residential 2-acre: Single Family Residential - 2 acre lot size.**
- **Open Space: Open, Recreational, or vacant space maintained in turf.**
- **Pasture/Hay: Cultivated land used for pasture or hay.**
- **Row Crops: Cultivated land used for crops. Includes orchards.**
- **Woods: All upland forested areas.**
- **Water: Open or standing water.**
- **Forested Wetland: Lowland forest.**
- **Open Wetland: Emergent, floating aquatic or shrub wetlands.**


Land Cover Change in Ann Arundel Co.
Percent Change Relative to 19
Year
Commercial
Industrial
Open Space
Open Wetland
Pasture/Hay
Residential
Row Crops
Transportation
Water
Woods

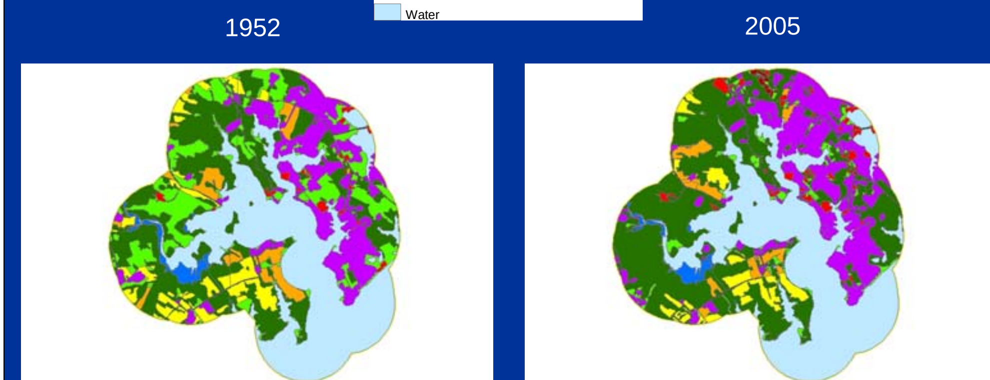
RHODE RIVER

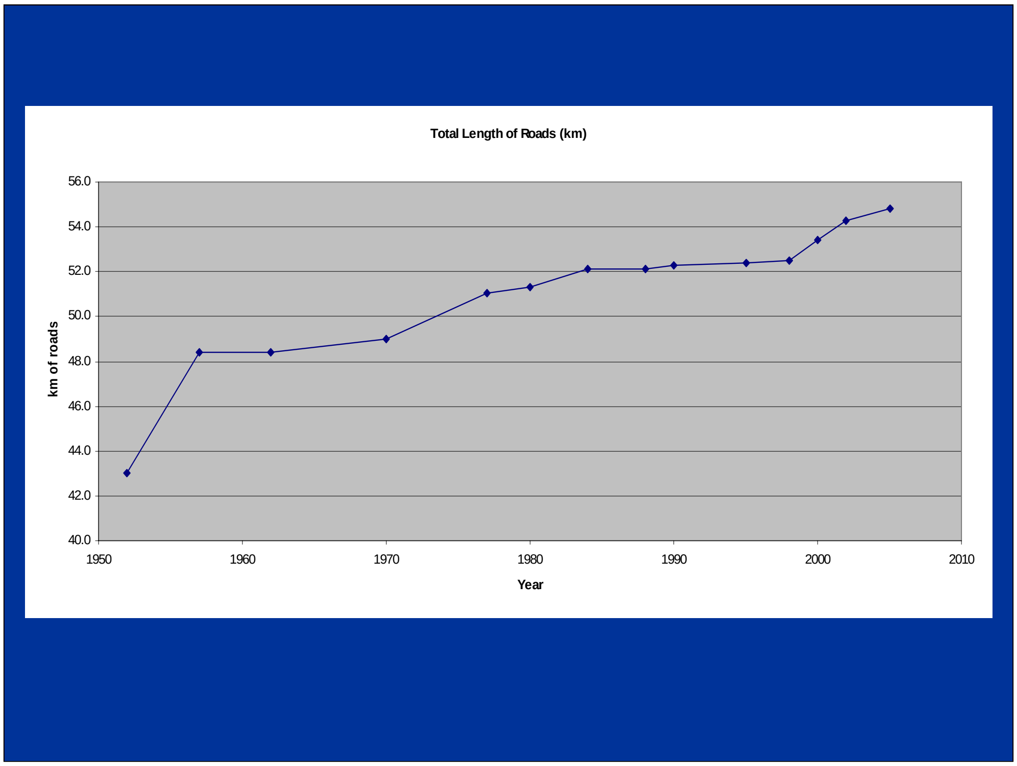


Land Cover Change in Rhode R. Sub-estuary
Hectares
Year
Commercial
Industrial
Open Space
Open Wetland
Pasture/Hay
Residential
Row Crops
Transportation
Water
Woods

Landcover in Rhode River Sub-estuary

CLASSNAME2
- Transportation
- Industrial
- Commercial
- Residential
- Pasture/Hay
- Row Crops
- Open Space
- Woods
- Open Wetland
- Water

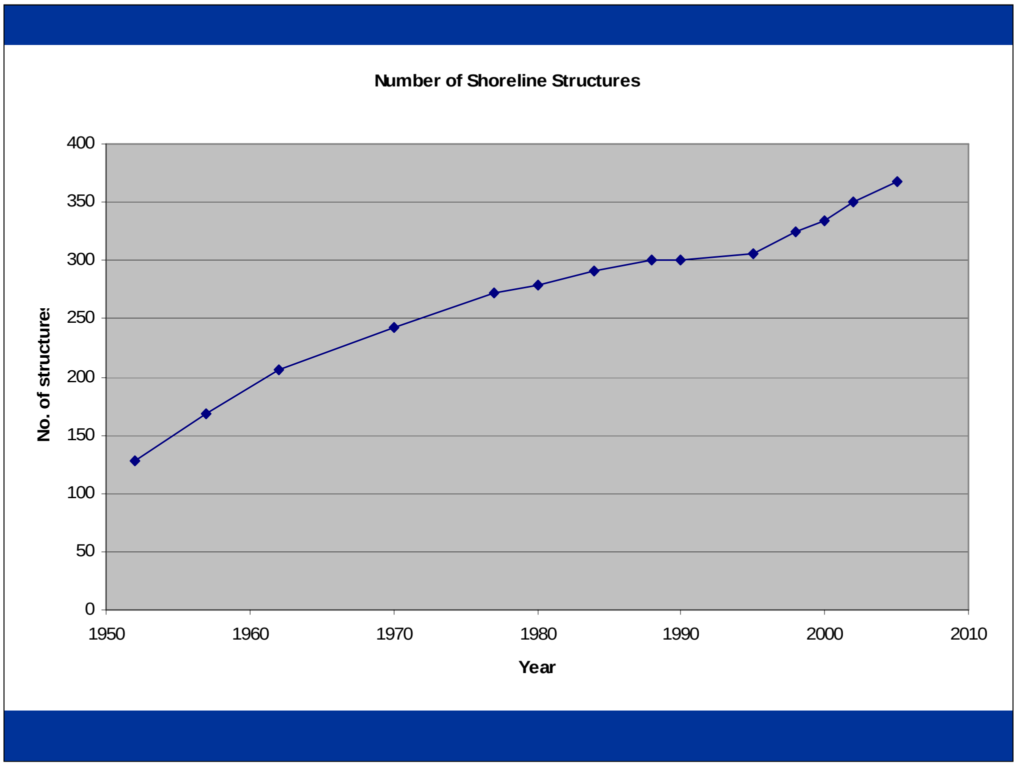



Total Length of Roads (km)
56.0
54.0
52.0
50.0
48.0
46.0
44.0
42.0
40.0
km of roads
1950
1960
1970
1980
1990
2000
2010
Year

Roads in Rhode River Sub-estuary

1952

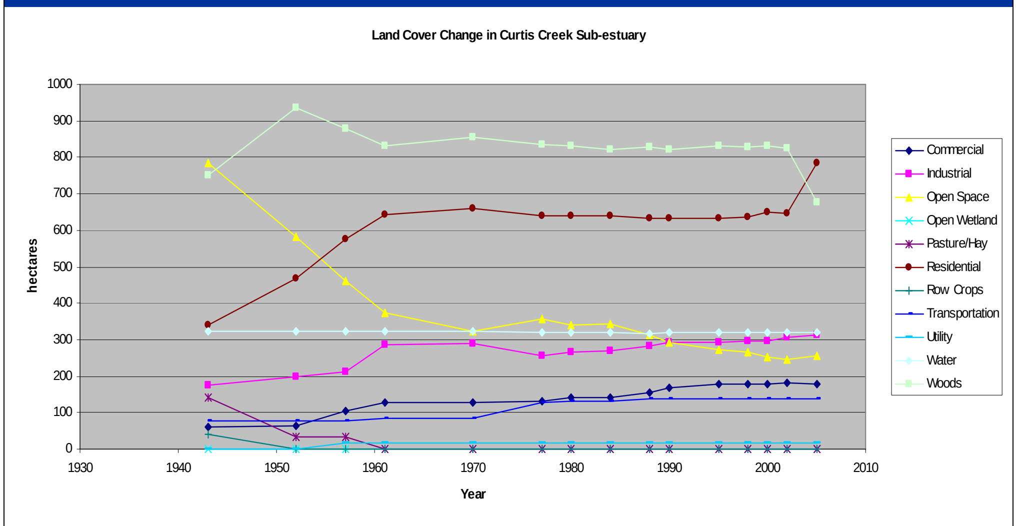
2005



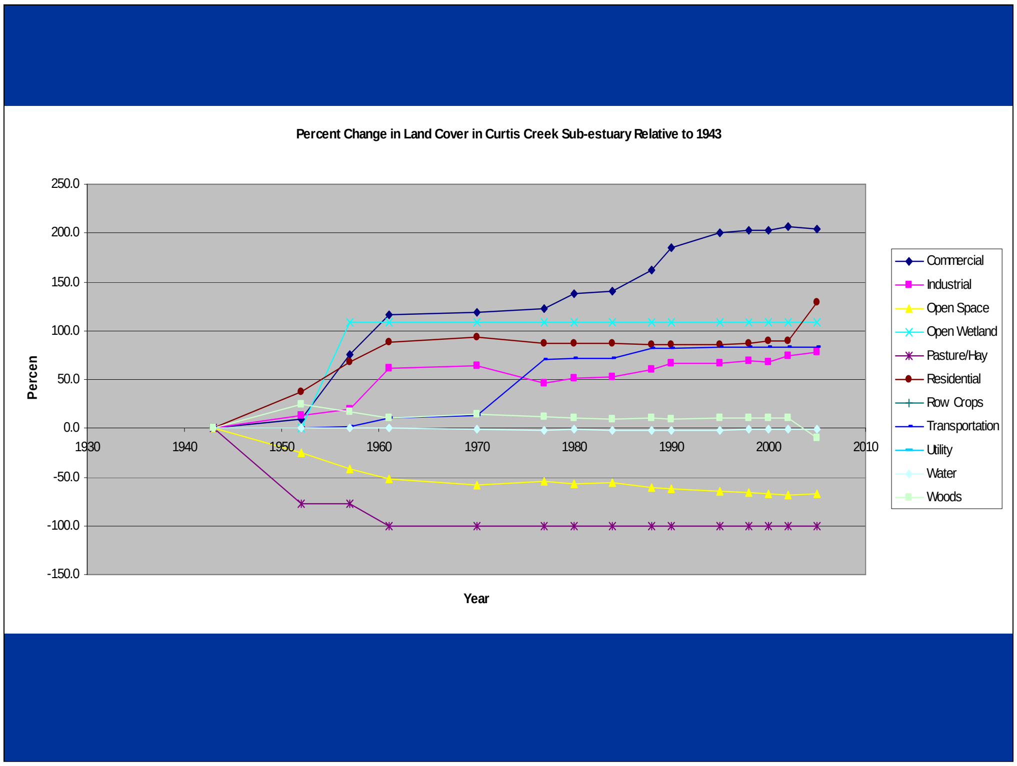
Number of Shoreline Structures
No. of structures
400
350
300
250
200
150
100
50
0
1950
1960
1970
1980
1990
2000
2010
Year


Shoreline Structures in Rhode River Sub-estuary
1952
2005

Curtis Creek

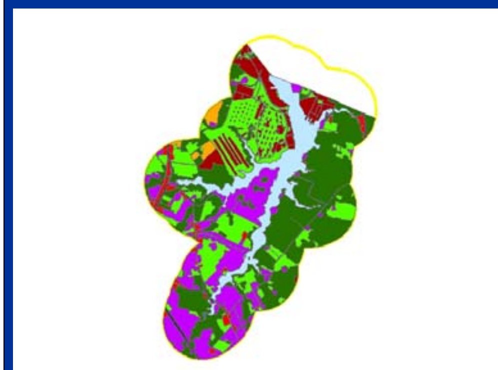


Land Cover Change in Curtis Creek Sub-estuary
hectares
Year
1000
900
800
700
600
500
400
300
200
100
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
Commercial
Industrial
Open Space
Open Wetland
Pasture/Hay
Residential
Row Crops
Transportation
Utility
Water
Woods

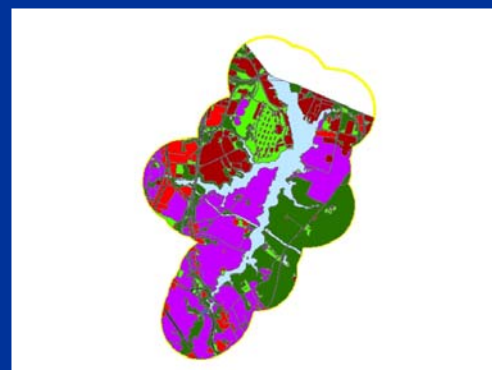

Percent Change in Land Cover in Curtis Creek Sub-estuary Relative to 1943
250.0
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
Percen
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year
Commercial
Industrial
Open Space
Open Wetland
Pasture/Hay
Residential
Row Crops
Transportation
Utility
Water
Woods

Curtis Creek Sub-estuary:
Land Use Change 1952 vs. 2005

1952



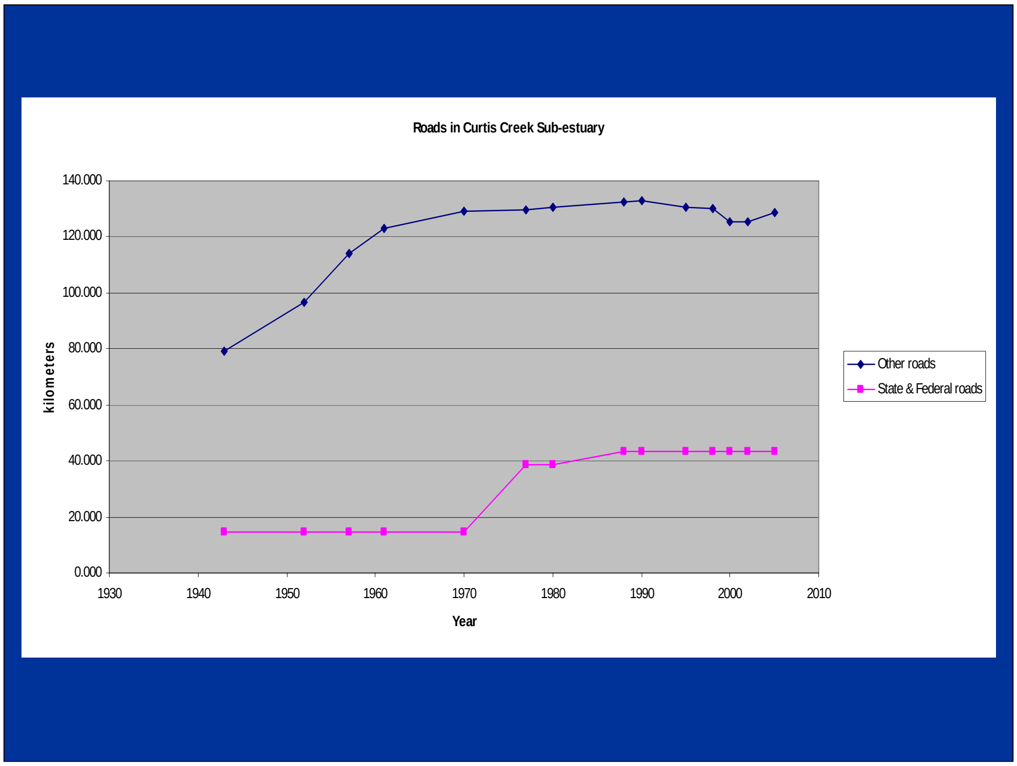
2005



Curtis Creek Sub-estuary:
Land Use Change During Initial 9-year Period of Record

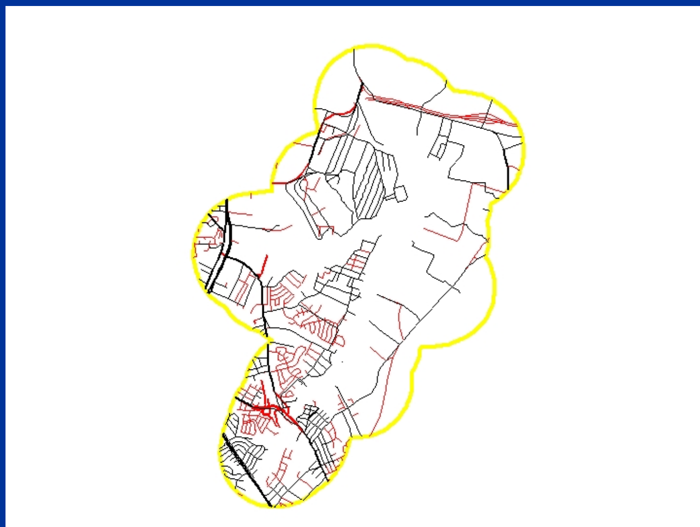
1943

1952


Roads in Curtis Creek Sub-estuary
140.000
120.000
100.000
80.000
60.000
40.000
20.000
0.000
kilometers
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year
Other roads
State & Federal roads

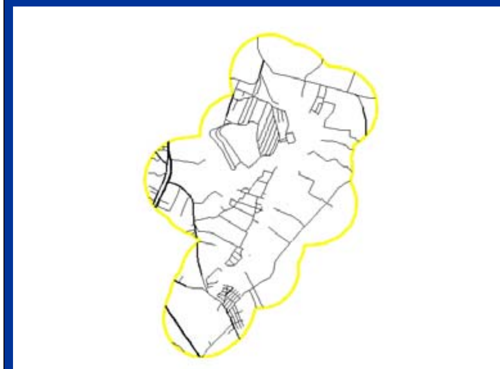
Roads – 1952 vs. 2005

Black roads were present in 1952;
red roads have been built since that
time

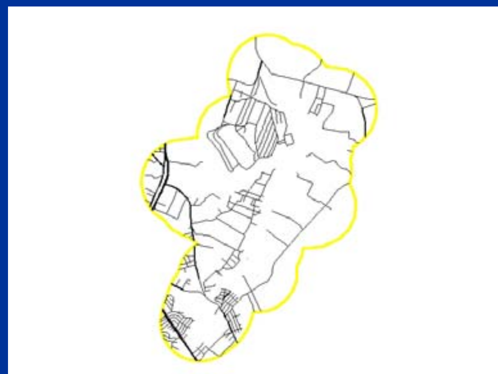


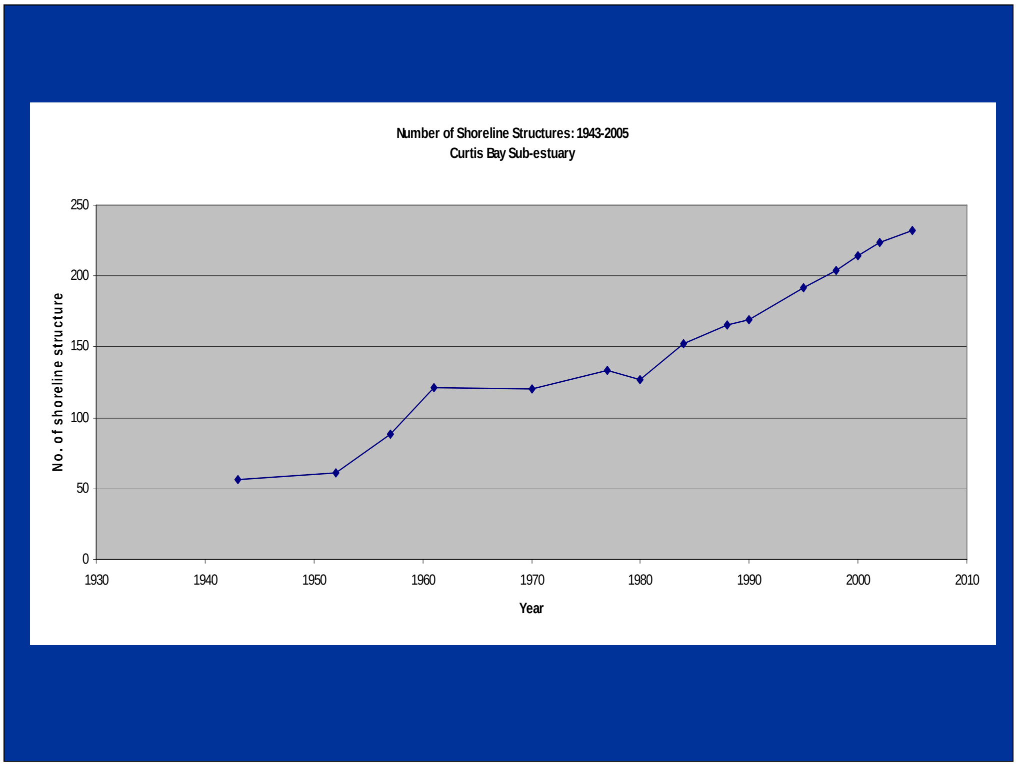
Curtis Creek Sub-estuary:
Road Change During Initial 9-year Period of Record

1943



1952

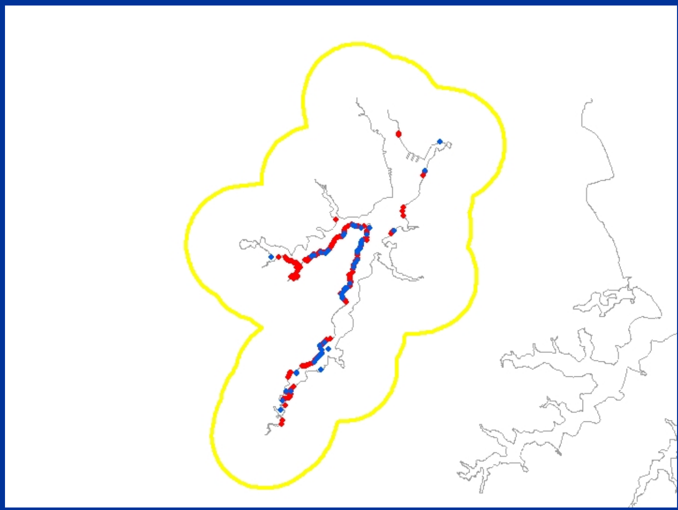




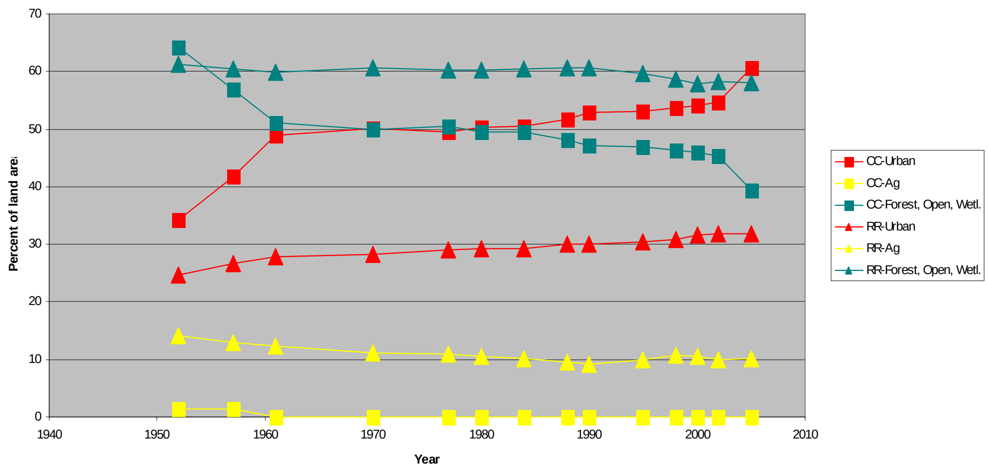
Number of Shoreline Structures: 1943-2005
Curtis Bay Sub-estuary
No. of shoreline structure
0
50
100
150
200
250
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year

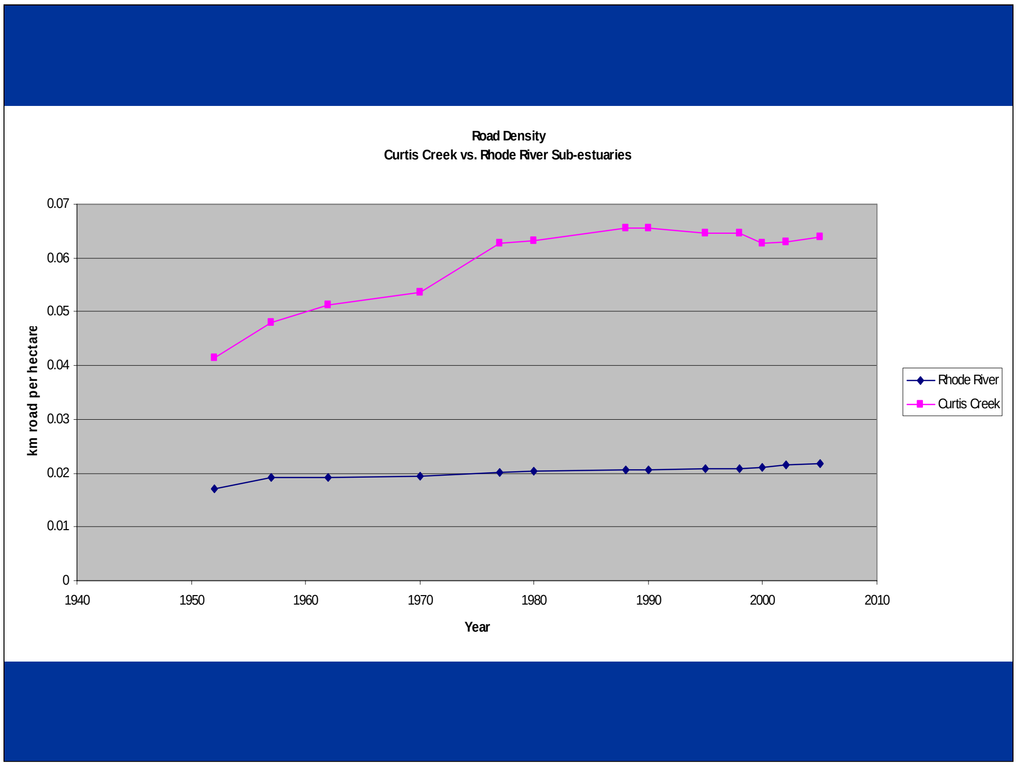
Shoreline Structures: 1952 vs. 2005

Blue structures were present in 1952; red structures have been constructed since that time

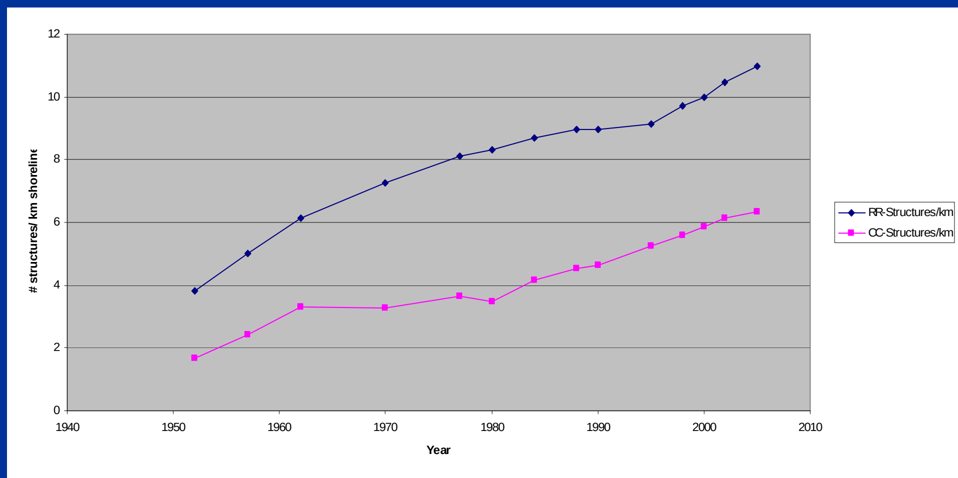


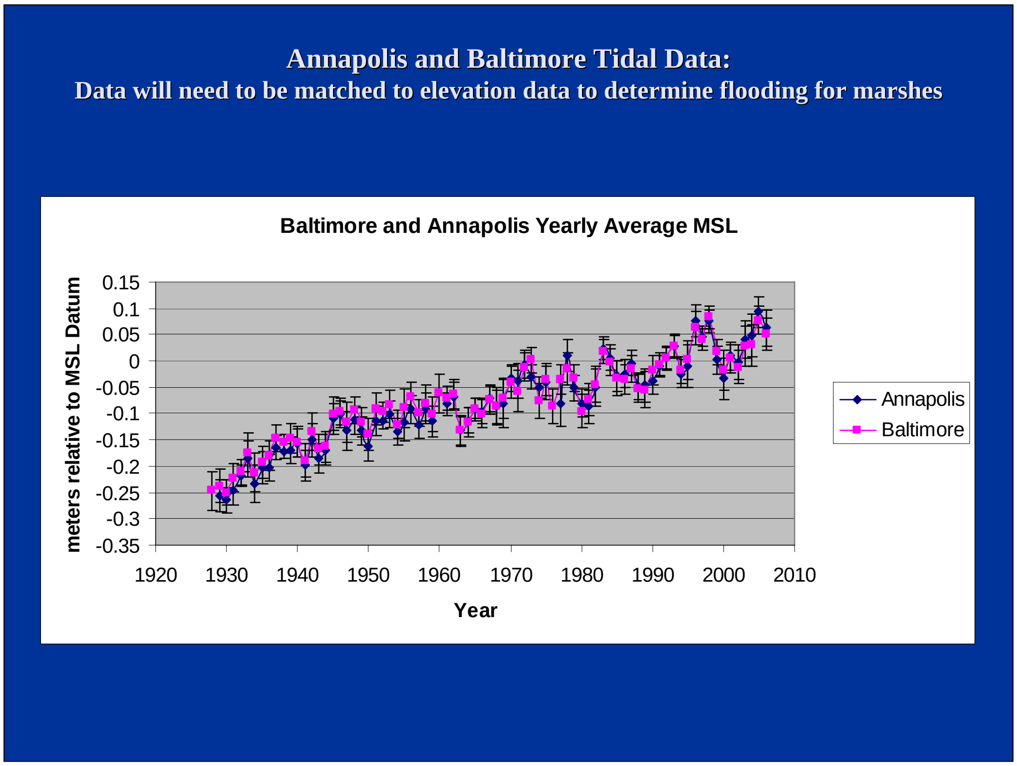
Land Use Comparison: Rhode River vs. Curtis Creek




Road Density
Curtis Creek vs. Rhode River Sub-estuaries
km road per hectare
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1940
1950
1960
1970
1980
1990
2000
2010
Year
Rhode River
Curtis Creek

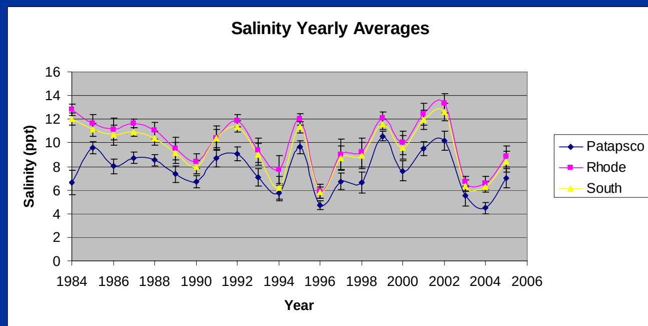
Shoreline Structures: Rhode River vs. Curtis Creek

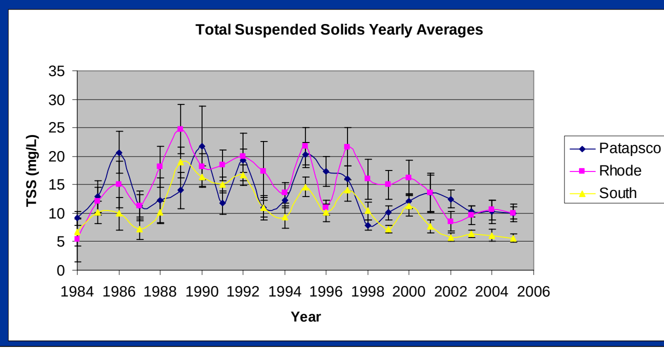




MSL = mean sea level

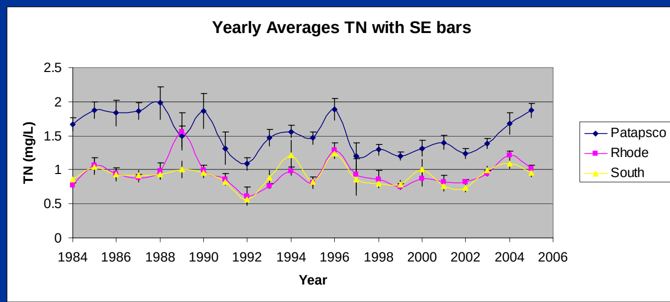
Historic Water Quality Data, Yearly Averages:
Salinity and Sedimentation for Curtis Bay (Patapsco River), Rhode and South River

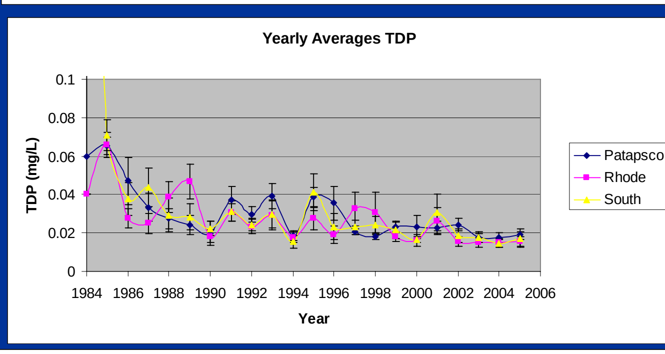




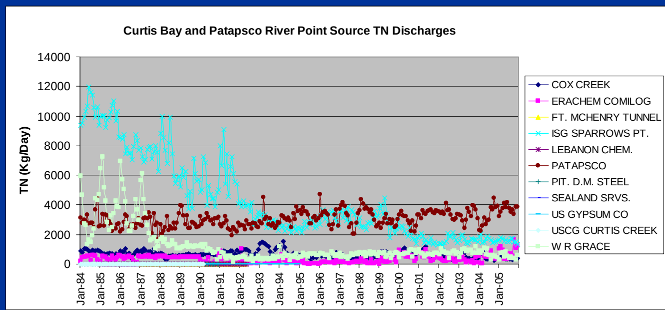
Historic Water Quality Data, Yearly Averages:

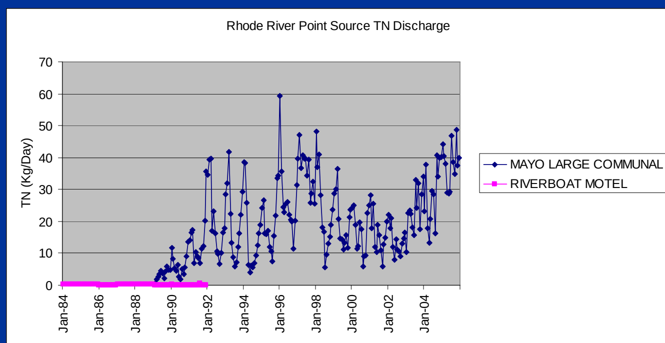
Total nitrogen and total dissolved phosphorus for Curtis Bay (Patapsco River), Rhode and South River

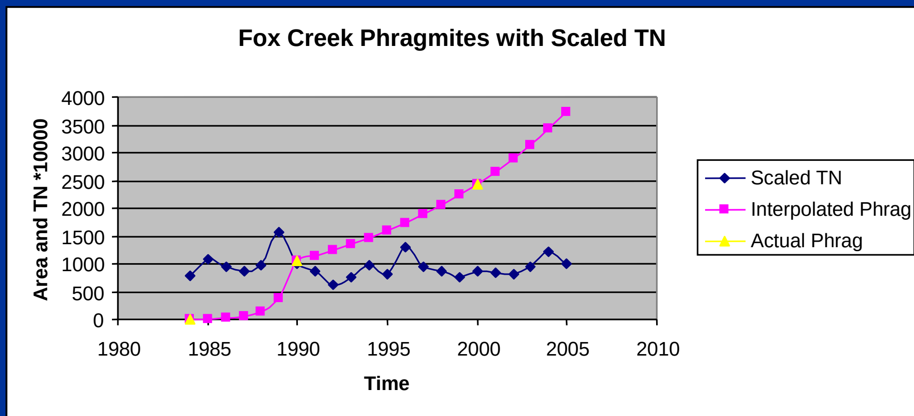




Nitrogen Additions from Point Source Data

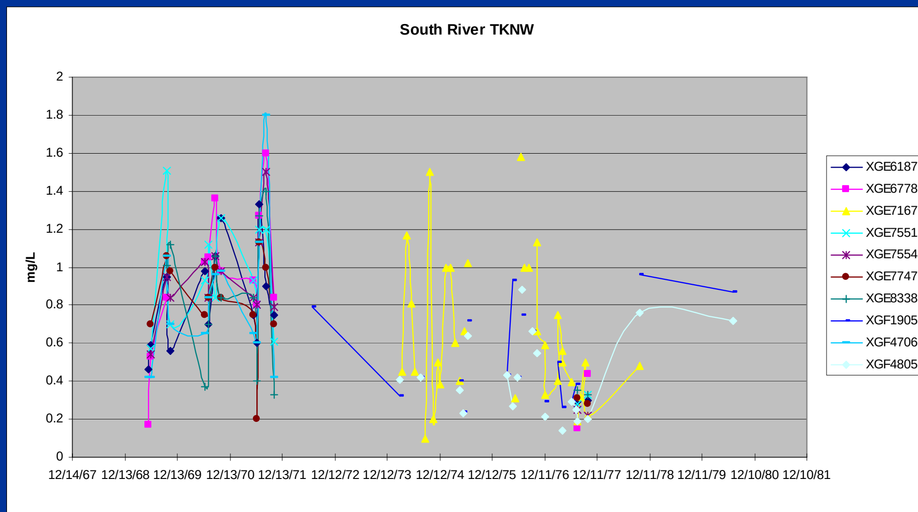




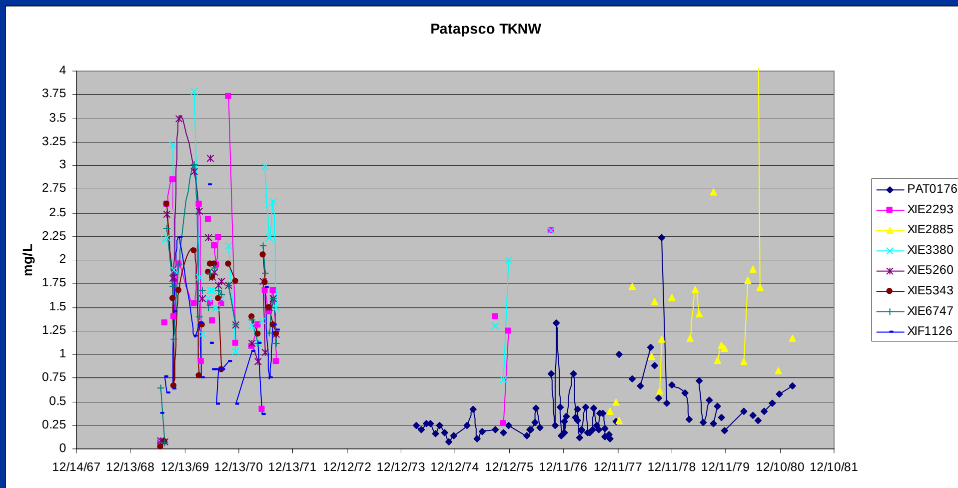


The area (m^2) of Phragmites at Rhode River site # 10 (Fox Creek). The logarithmic growth equation is used to interpolate between points. The points in yellow are actual data points, with the annual averages for TN for Rhode River (*1000).

South River Graphs TKNW: All Stations

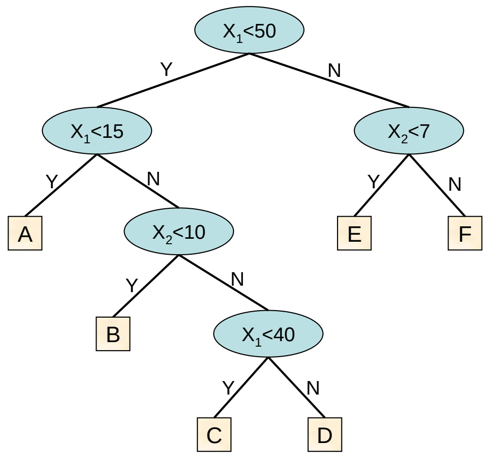


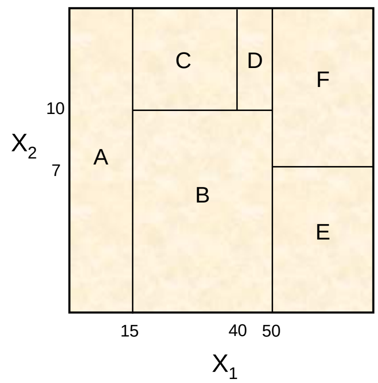
Patapsco River Graphs TKNW: All Stations



Nitrogen load is higher than in the South River area; Still no continuous records from any station

CART-based Probability Surface





Susceptibility versus Dispersal

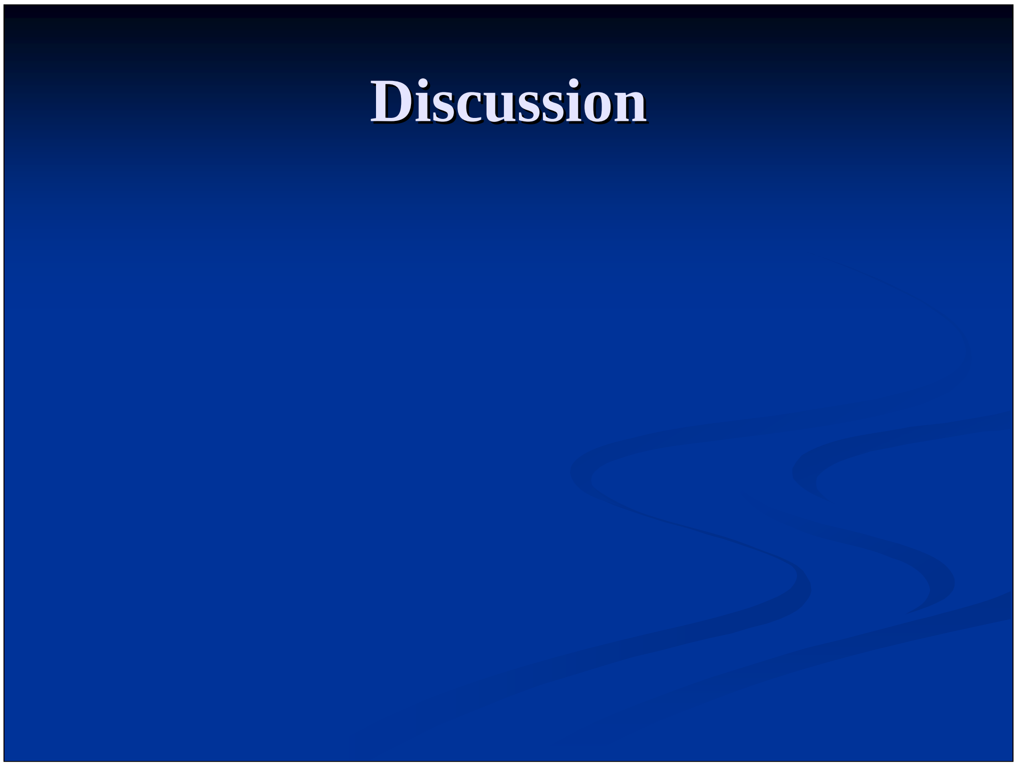
- Statistical model is for susceptibility
- Assumed dispersal was not limiting
- Dispersal and spread mechanisms investigated separately
  - Karin Kettering; CO2 and nutrient enrichment, seed production and viability
  - Melissa McCormick, genetic fingerprinting of populations

Preliminary observations

- Land cover does not adequately describe disturbances relevant to *Phragmites* invasion
- Significant interactions and lag times in a multivariate setting
- Change in susceptibility state may have occurred previously

Future Steps

- Historical photo-interpretation of land cover, roads, and shoreline structures completed by mid-June
- Historical photo-interpretation of *Phragmites* expansion by mid-August
- Statistical modelling through summer, completed by 2008



A participant asked for confirmation that he had correctly interpreted the graph showing a one-third meter rise in sea level over the past few decades. Dr. Whigham confirmed that this was correct.

One participant asked if Dr. Whigham and his colleagues had examined the percent land cover as a potential indicator. In the participant's research, he found that percent land cover was important with respect to the amount of freshwater entering the watershed. Dr. Whigam replied that he and his colleagues have found that the non-native genotype *Phragmites* flourish in brackish conditions; one of the reasons *Phragmites* are becoming established and spreading is that they do not require freshwater.

A participant asked if the *Phragmites* could be eradicated. Dr. Whigham responded that in Maryland there are no restrictions on the eradication of *Phragmites*.

One of the participants asked Dr. Whigham to define metonic cycle. According to Dr. Whigham, a metonic cycle is a drought cycle. It occurs approximately every 10 to 15 years in the area. Dr. Whigham and his colleagues have not yet been able to link this cycle to any of the patterns they have seen.

A participant asked if there was concern about insects as predators in the development and spread of *Phragmites*. Dr. Whigham responded that he did not know how insects might affect *Phragmites* development and spread. He did not know of any research on this topic.

One participant asked if the graphs on the first slides were on a watershed scale or a 1-kilometer scale. Dr. Whigham responded that those slides were on the scale of the entire estuarine segment. The participant asked if the later data shown were on a scale of 1 kilometer by 1 kilometer. Dr. Whigham confirmed that it was and explained that the two are not very different. The strongest predictor the researchers have seen to date is land use within 500 meters of the watershed.