Tidal Marshes of Barnegat Bay: Nutrient History and Ecosystem Services

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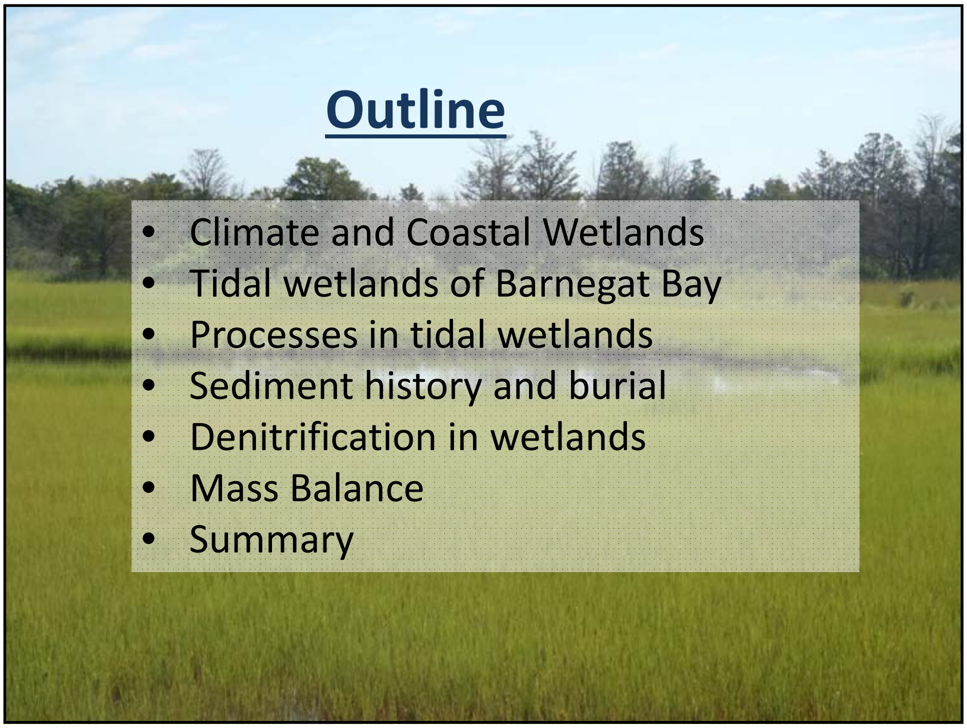


Wetlands Research at the Academy of Natural Sciences

1965 - Dr. Ruth Patrick in 1965 showed that wetlands can remove nutrients and looked at the extent of wetlands in the Delaware Estuary

1996 – Dr. David Velinsky revisited earlier study and modeled oxygen dynamics in Delaware Estuary: tidal freshwater region

1998-2002 – Dr. Jeff Ashley explored how PCBs and other contaminants cycle in a urban tidal marsh and accumulate in fish tissue

2007-2012 – Drs. David Velinsky and Jeff Ashley studied the sediment accumulation of chemical contaminants, nutrients and ecological indicators such as diatoms throughout the Delaware and Barnegat Bays

2011-2014+ – Drs. Tracy Quirk and David Velinsky are investigating the factors that maintain marsh elevation (MACWA)

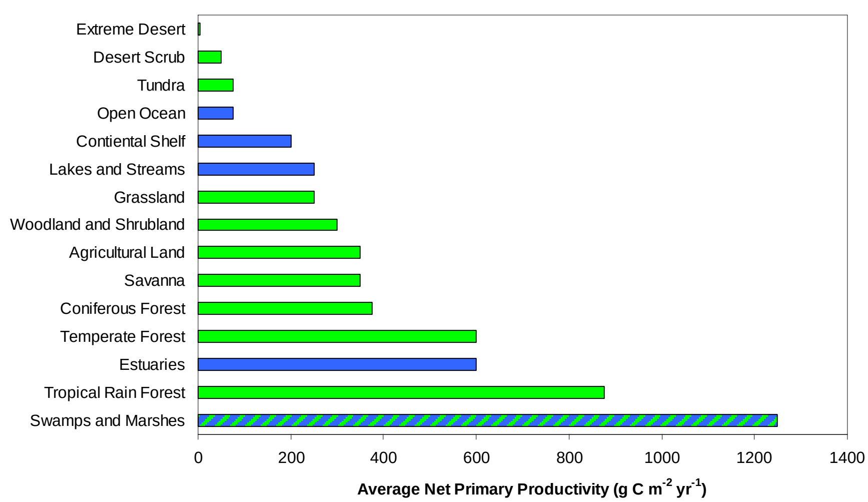
2011-2016 - Drs. David Velinsky and Tracy Quirk explored ecosystem services of tidal wetlands in tidal freshwater wetlands of DE and marshes in Barnegat Bay

2014 - Present Dr. Beth Watson continues to study marsh function in Delaware and Barnegat Bays (MACWA and Carbon Sequestration)

Tidal Marshes: Questions

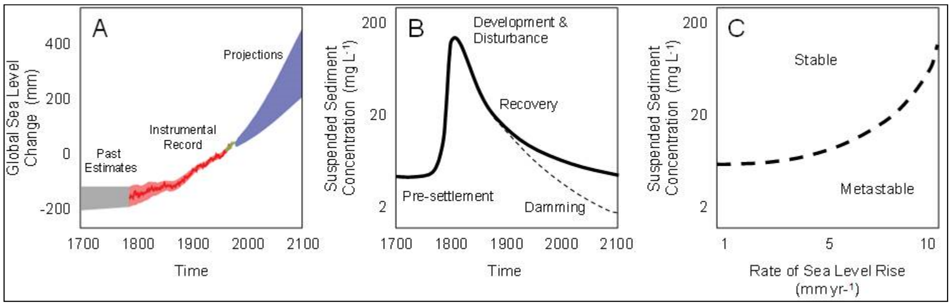
- Ecosystem Services
  - "Nutrient, contaminants and carbon cycling and storage in marshes along an estuarine salinity gradient"
- Climate Change
  - "Response of marshes to sea-level rise and salt-water intrusion"
- Land Use Change
  - "Changing sediments inputs: An unfortunate convergence for tidal marshes"

Ecosystem Productivity

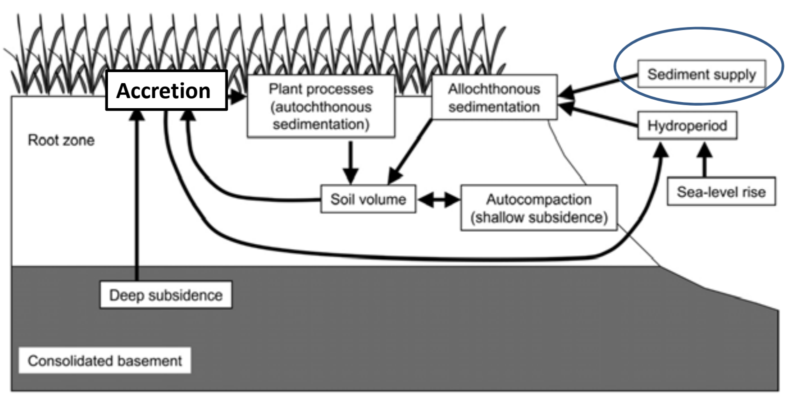


Total area in US = 1.6 x 10^{11} m^2 (loss is about 0.003 X 10^{11} m^2/yr)

Marsh Response to Sea Level Rise and Sediment Availability

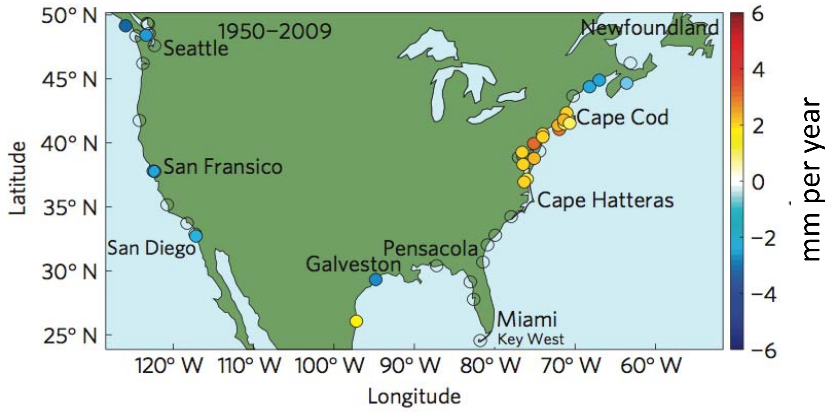


Wetland accretion and erosion



- Local accretion = mass accumulation ÷ soil bulk density
  cm/y g/cm2/y g/cm3
- Absolute accretion = local accretion + subsidence

SLRDs for 60-yr time series at gauge locations across North America

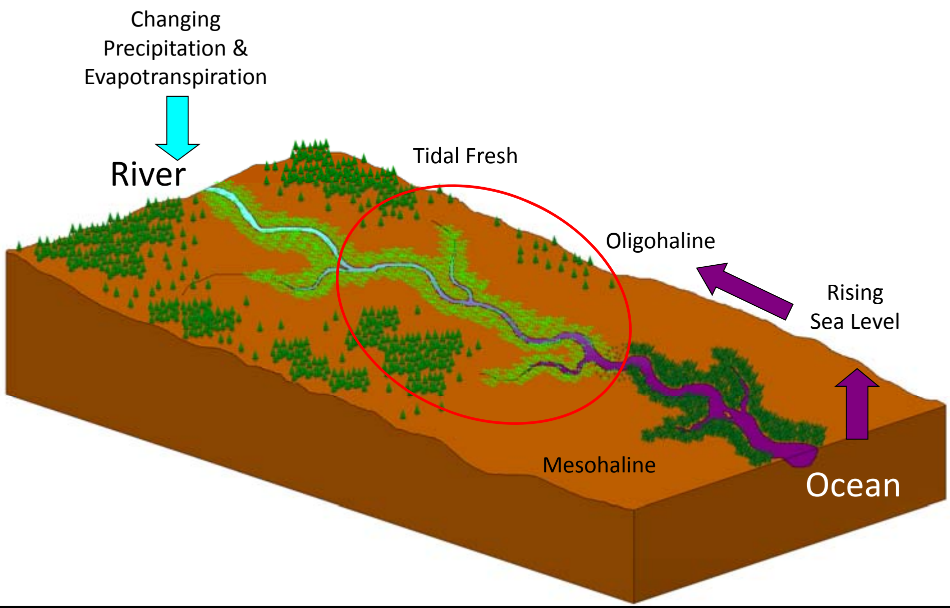


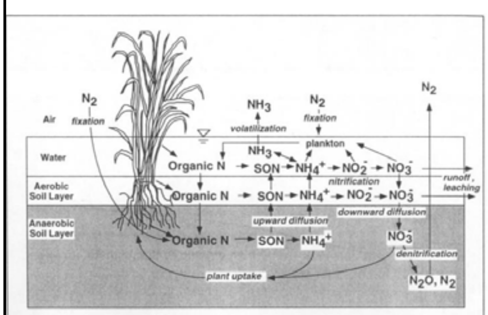
Delaware Bay
2.8 – 4.1 mm yr^{-1}

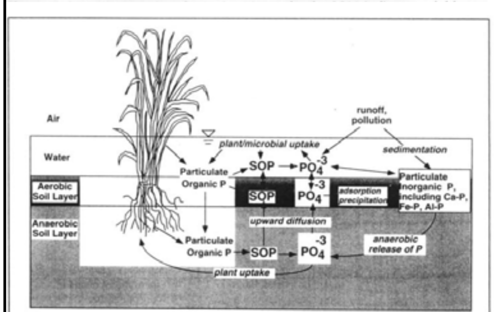
Sallenger, A.H. et al. 2012; Nature Climate Change

Consequences of Coastal Shoreline Development and Marsh Removal

Salt-Water Intrusion







Generalized schematic of nitrogen and phosphorus cycling in wetlands

With salt-water intrusion

- Plants and microbial activity are a key component of N and P transformations
- In marine sediments, high levels of sulfide from sulfate reduction, bind Fe and allow for greater release of dissolved P
- Result in the potential alteration of the amount of N and P buried relative to loadings (unlike PCBs or some trace metals)

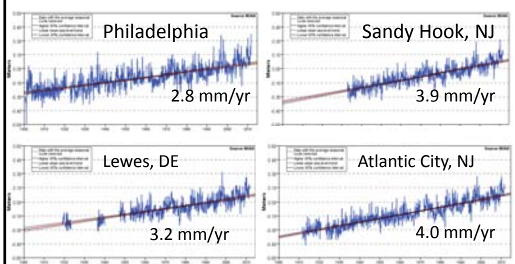
Causes for concern

1. ALTERED LANDSCAPE

- Coastal development
- Altered sediment load
- Increased nutrient load
- Direct human alterations

2. RELATIVE SEA LEVEL RISE

- Salinity, tide range increase



Wetlands provide valuable ecosystem services!

- Water quality improvement
  (e.g. chemical transformation)
- Floodwater retention and protection
- Biodiversity islands and corridors
- Carbon, nitrogen, phosphorus
  (i.e., chemical) sequestration
- Locations for human relaxation and
  nature observation/education

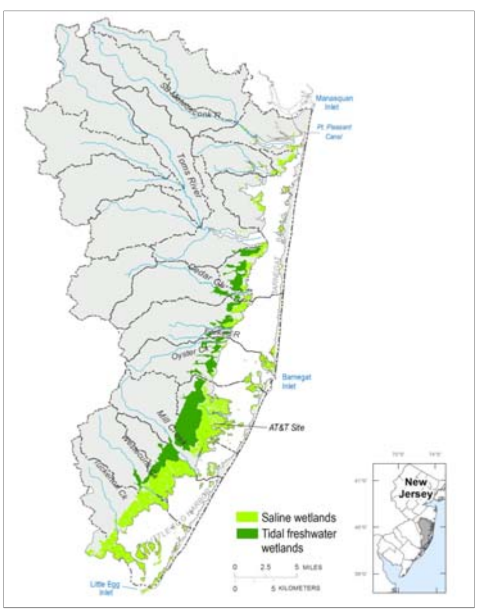
NJDEP Barnegat Bay Comprehensive Research

<u>Objectives of Projects:</u>

1. Evaluate <u>permanent</u> nitrogen (N) removal services provided by Barnegat Bay coastal wetlands:
   - Sediment burial of nitrogen, carbon and phosphorus (Yr 0)
   - *Bay-wide* seasonal denitrification rates in salt marshes (Yr 1)
   - Mosquito control (OMWM) ponds impact on denitrification (Yr 2)
     - How do OMWMs impact ecosystem services?
2. Combine data to obtain an overall estimate of N removal services provided by Barnegat Bay wetlands.

Q: What are the fates of nitrogen and other nutrients in the Bay?

Wetlands of Barnegat Bay



Areal Extent: 26,900 acres

Saline Wetlands: 21,800 acres

Tidal Freshwater: 5,100 acres

Data from V. Depaul (USGS)

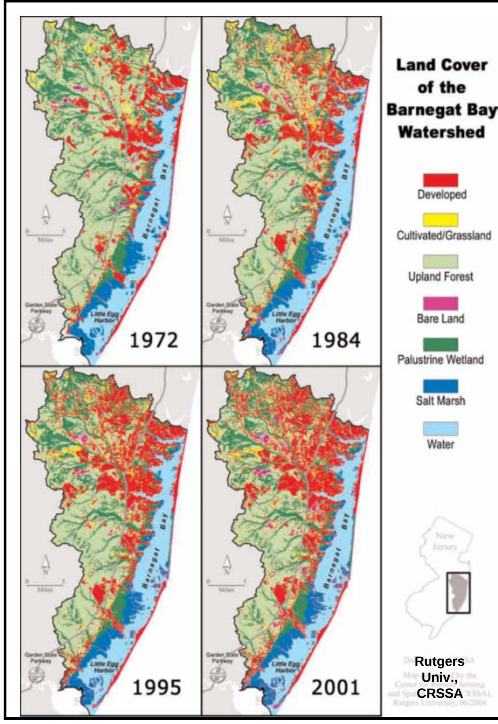
Barnegat Bay

Watershed N load: 4.6 to 8.6 x 10^5 kg N yr^{-1}

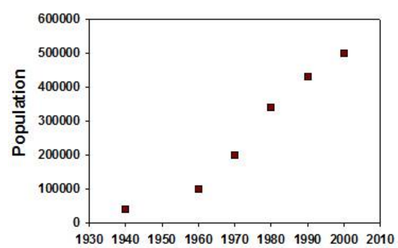
(from 1998 to 2011; Baker et al. 2014)

Symptoms of Eutrophication

- phytoplankton and macroalgae blooms
- brown tide and HABs
- alteration of benthic communities
- loss of seagrass and shellfish beds



Barnegat Bay



TN Load = ~ 5 - 9 X10^5 kg N/yr

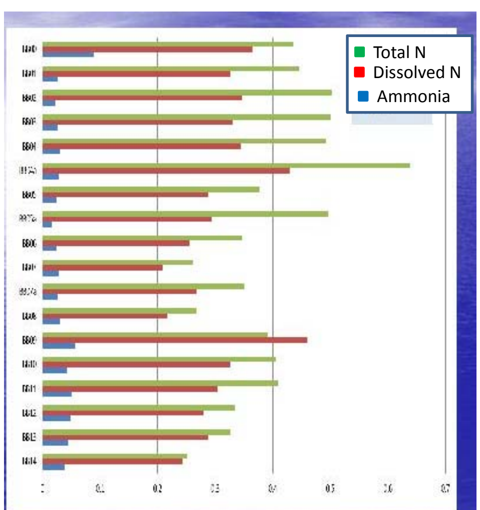
Sources
34% > Direct Atmospheric Dep.
12% > Groundwater Discharge
54% > Surface Water
(Hunchak-Kariouk and Nicholson, 2001)

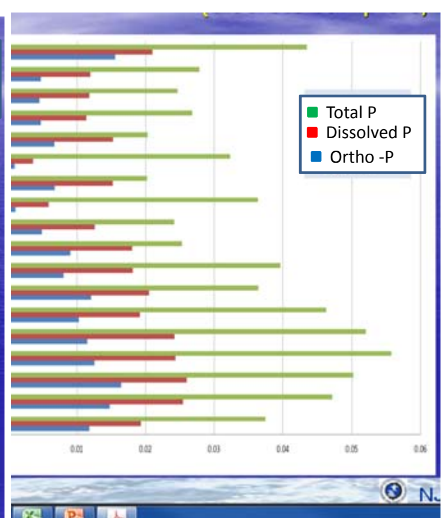
Load is estimated to be 5X above "background" (Kennish et. al. 2007).

NJ DEP Monitoring Data

Taken from H. Pang (NJ DEP)

Nitrogen and Phosporus NJ DEP Monitoring Data





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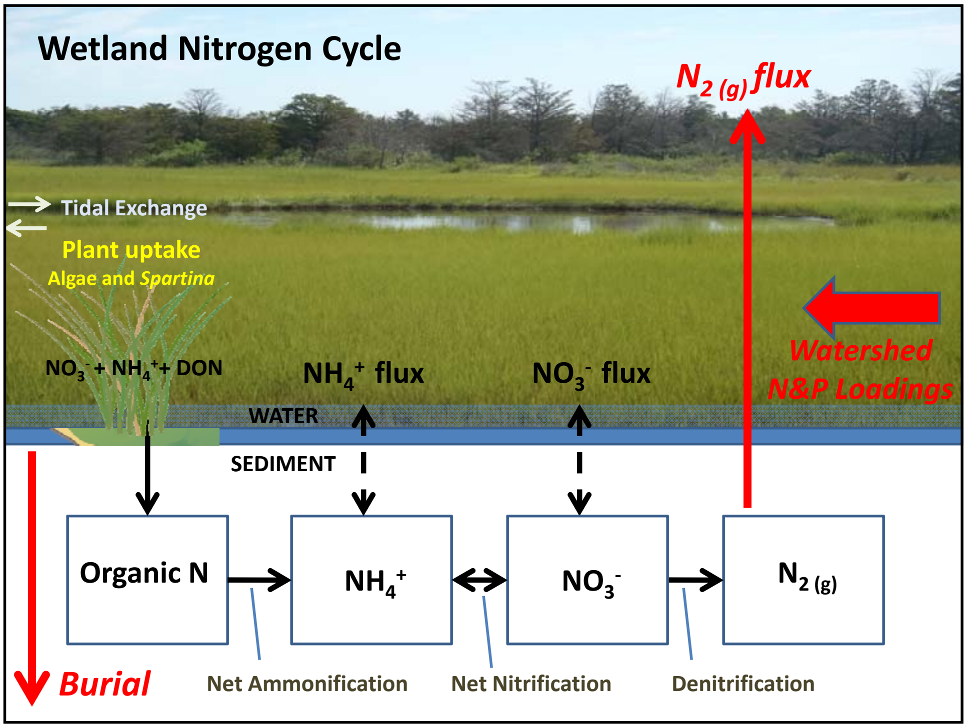
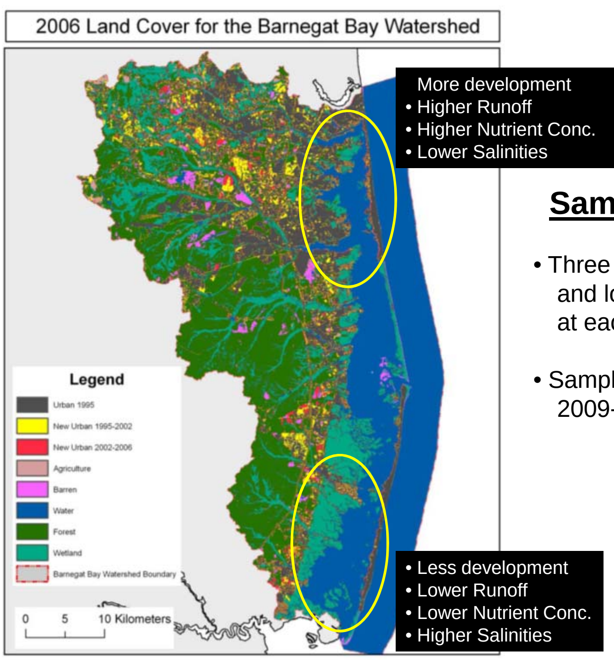
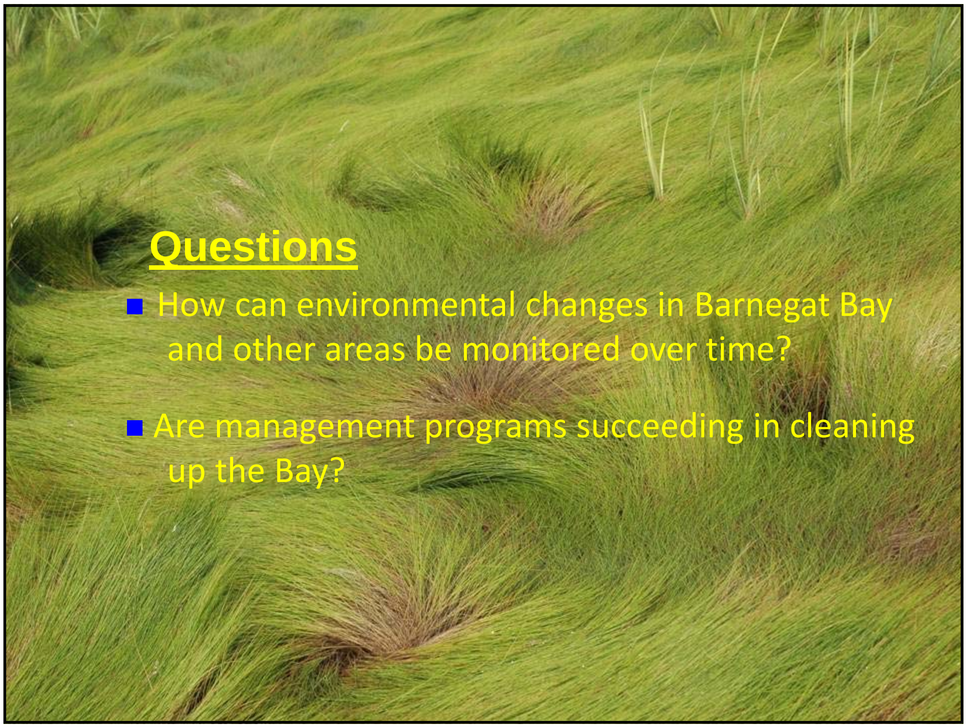




Sampling Program

- Three core locations: upper, mid, and lower reaches. Two cores at each location.
- Sampling in Spring/Summer of 2009-13

•Taken from Lathrop and Haag (2007)

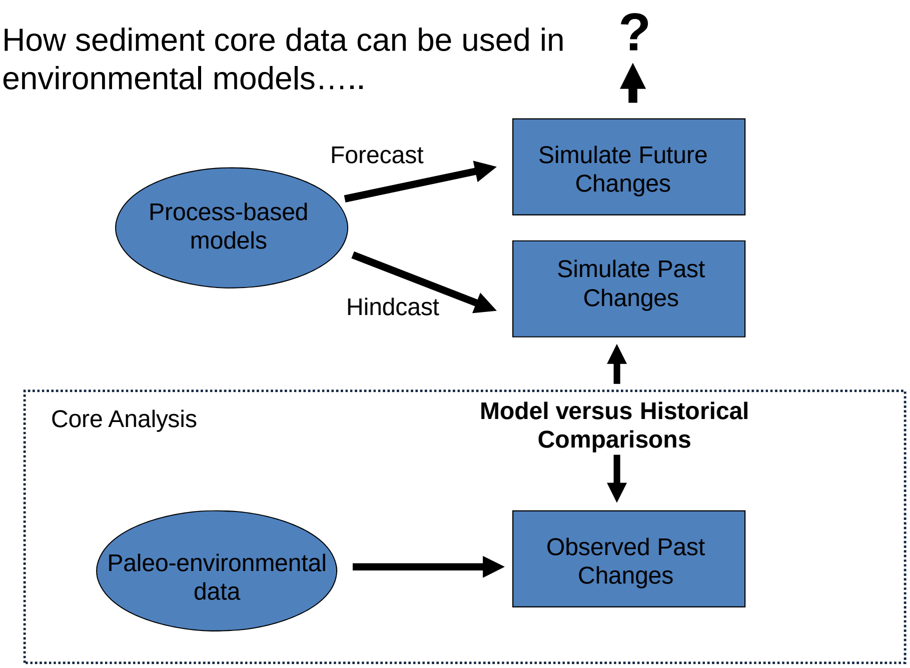


Sediment Cores: An ecosystem's memory

Changes related to:	Are reflected by changes in:
land-use	pollen, stable isotopes (SI), metals
aquatic ecology	diatoms, shells, SI, CNP, Fe-S
pollution sources	chemicals (phosphorus, lead, DDT)

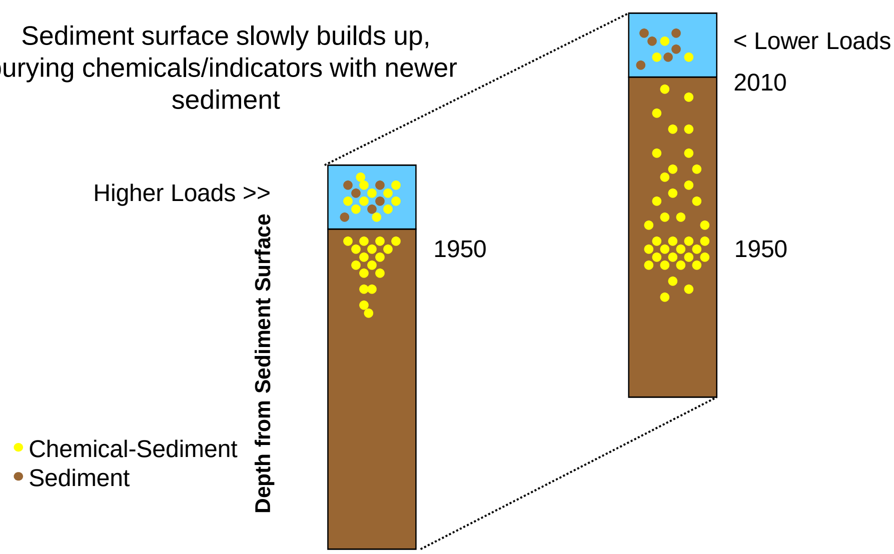
Importance: climate change, pollution control strategies, response time for change…

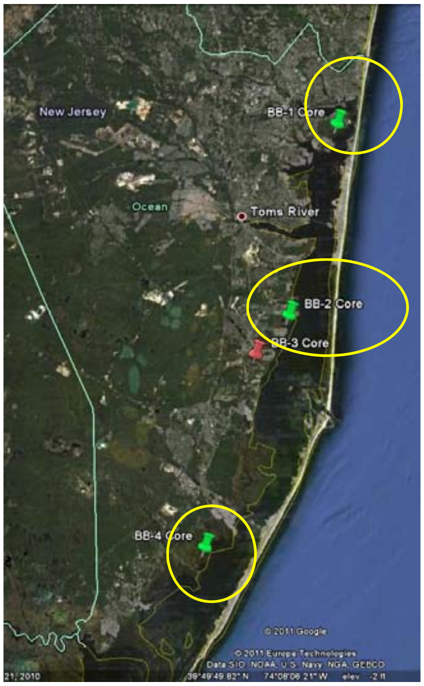
How sediment core data can be used in environmental models…..



Sediments: an ecosystem's memory

Sediment surface slowly builds up, burying chemicals/indicators with newer sediment





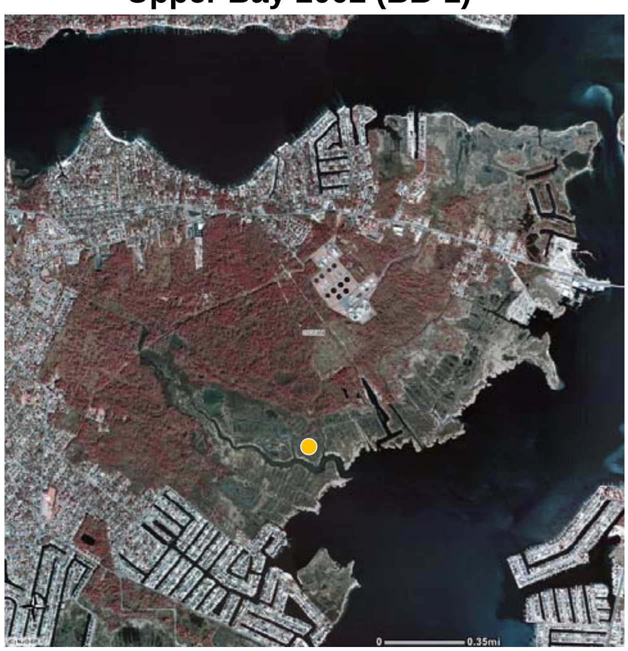
Sampling Locations

- Reedy Creek (BB-1)
- Mid Bay-Wire Pond (BB-2)
- Oyster Creek (BB-3)
  - discharge canal
- West Creek (BB-4)

Analytical Parameters

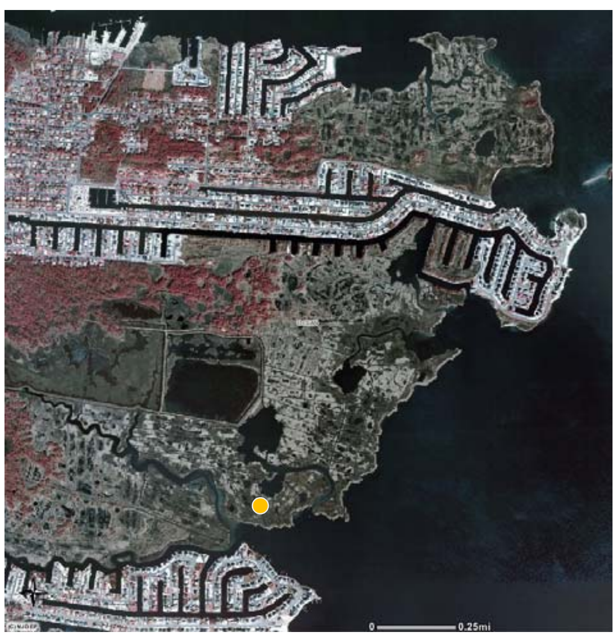
– Organic Carbon, Total Nitrogen and Total Phosphorus
– Diatom Species Composition
– Stable Isotopes of Carbon ($\delta^{13}C$) and Nitrogen ($\delta^{15}N$)
– Grain size (< 63 μm; clay+silt)
– Radioactive Isotopes: ^{210}Pb and ^{137}Cs

Upper Bay 2002 (BB-1)

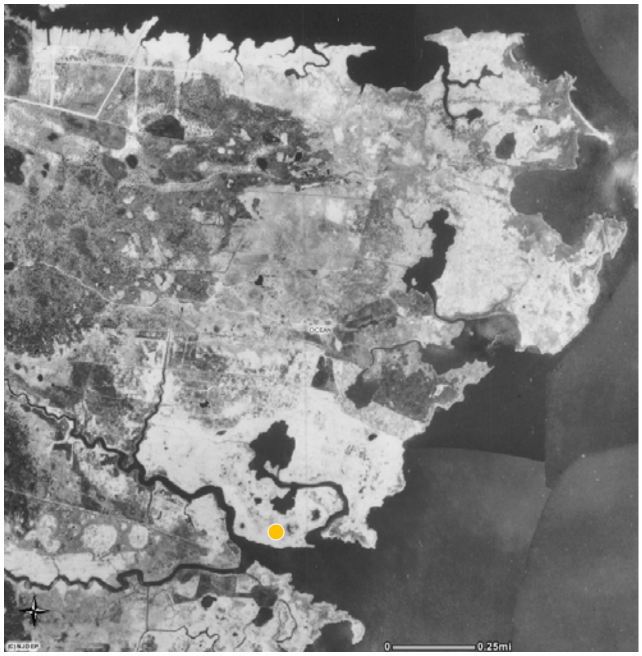


Upper Bay 1930 (BB-1)

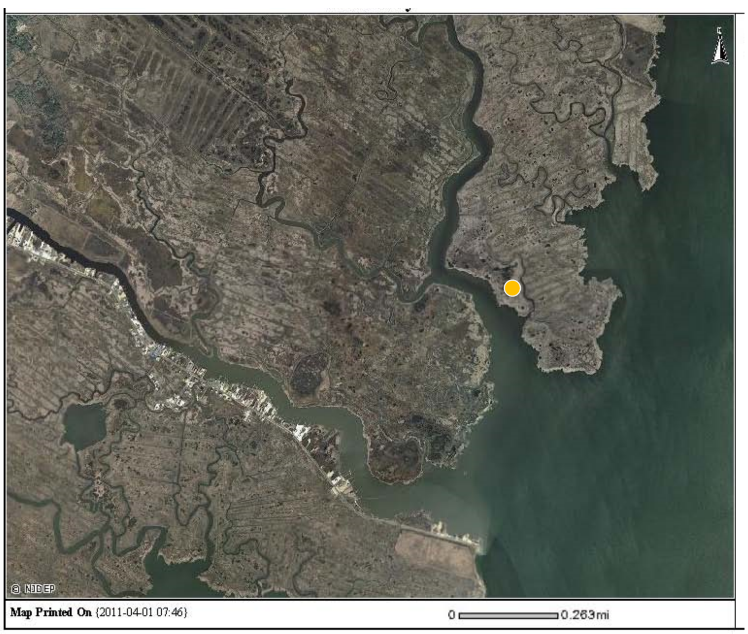
Middle Bay 2002 (BB-2)



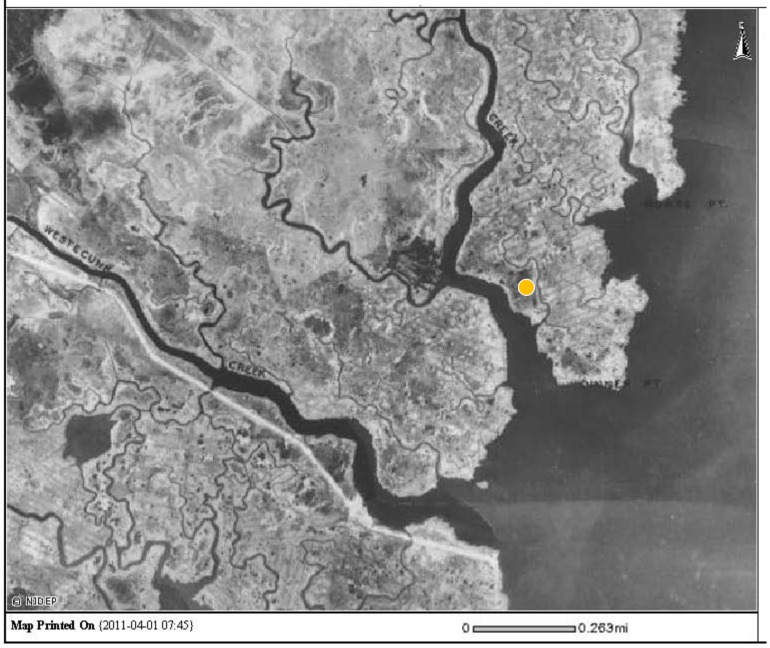
Middle Bay 1930 (BB-2)



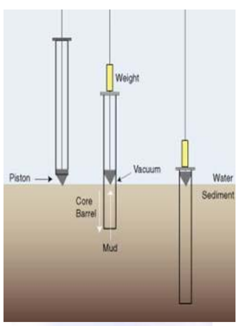
Lower Bay (BB-4)



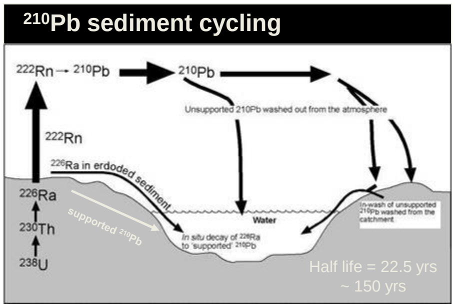
Lower Bay 1930 (BB-4)

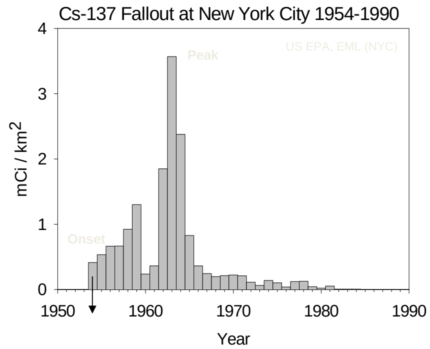


Push-Piston Core: One of many methods for taking a marsh core



Sedimentation rates: ^{210}Pb and ^{137}Cs analysis

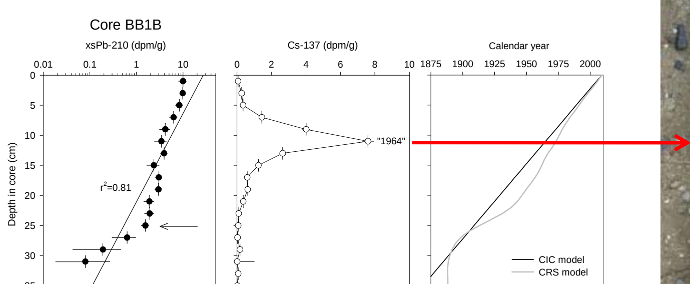




- Particle-reactive
- Pb dating: 100 to 150 yrs
- Supported ^{210}Pb produced by radioactive decay within sediments
- Unsupported ^{210}Pb transported to water from watershed runoff

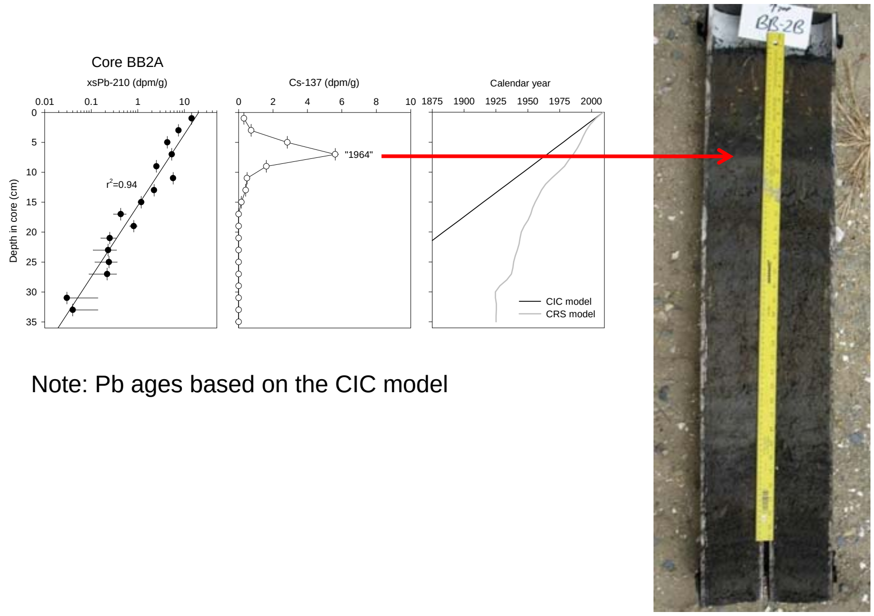
- ^{137}Cs: atomic weapons or power plants
- Onset and peak are used to mark age-depth
- Assume linear rates between dates
- Particle-reactive; can desorb in marine waters

Profiles of excess ^{210}Pb and ^{137}Cs activity for core BB-1



Note: Pb ages based on the CIC model

Profiles of excess ^{210}Pb and ^{137}Cs activity for core BB-2



Note: Pb ages based on the CIC model

Comparison between Delaware and Barnegat Bays: Accretion Rates

Tidal fresh and salt marsh accretion rates in Delaware Estuary:

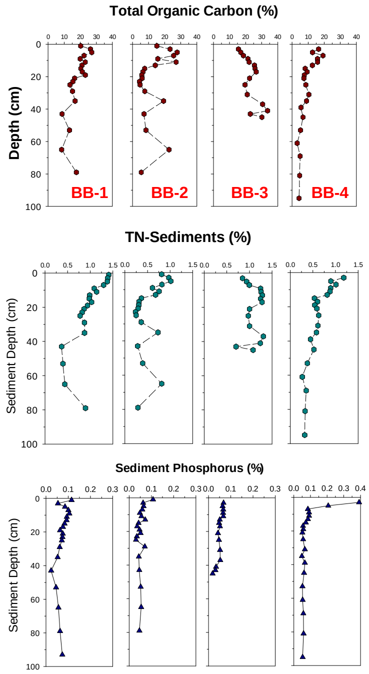
All Sites
Mean 0.72 ± 0.21 cm/yr, n=29
Max 1.1 cm/yr
Min 0.39 cm/yr

Salt Marshes
Mean 0.65 ± 0.17 cm/yr, n=17
Max 1.0 cm/yr
Min 0.39 cm/yr

Tidal Freshwater Marshes
Mean 0.85 ± 0.24 cm/yr, n=12
Max 1.1 cm/yr
Min 0.60 cm/yr

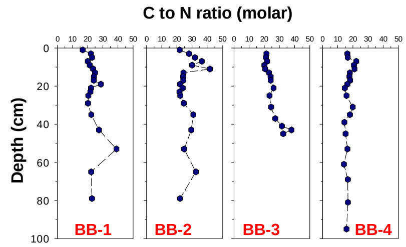
Barnegat Bay Sites:

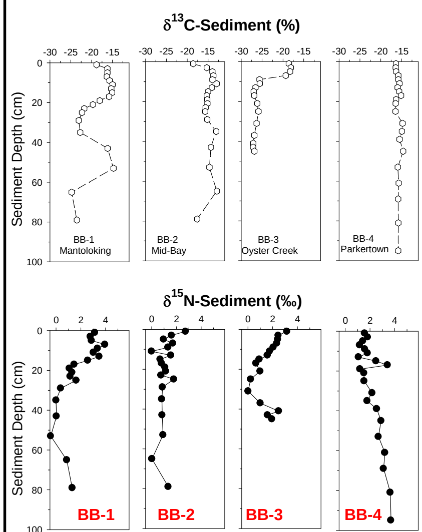
All Sites
Mean 0.25 ± 0.06 cm/yr, n= 4
Max 0.29 cm/yr
Min 0.16 cm/yr



Distribution of CNP with Depth

- Robust levels of CNP in BB marsh sediments
- Generally higher concentrations in the upper sections, with more constant levels at depth
- Very high P level observed at the surface of BB-4
- The C to N ratio is fairly constant in the upper 40 cm, except for Core BB-2



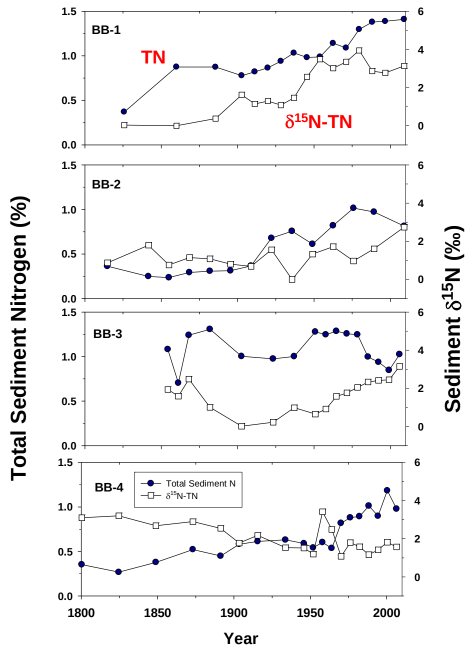


Stable Isotopes of C and N: Indicators of sources and cycling

- *Spartina sp* are C4 plants and would yield $\delta^{13}C$ of OC at ~ -15 to -12 ‰
- Terrestrial plants in this area, as well as algae, are C3 plants and would yield $\delta^{13}C$ of OC at ~ -30 to - 18 ‰ (algae are more enriched in ^{13}C)
- The $\delta^{15}N$ of TN can reflect biogeochemical processes (e.g., denitrification) as well as changes in sources to the bay.

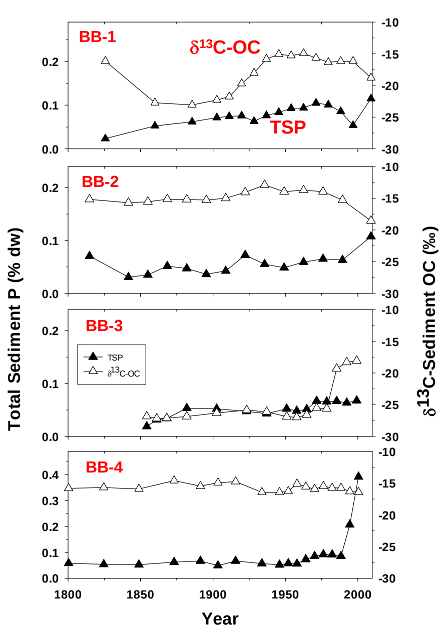
$\delta X = [(R_{sample}/R_{std}) – 1] \times 1000$ (‰)

where is X is either ^{13}C or ^{15}N and $R_{sample} = {}^{13}C/{}^{12}C$ or $^{15}N/^{14}N$



Changes in N with Time

- Increase N concentrations starting around the 1940s
- The δ^{15}N-TN increases from 0-1 per mill to ~ 4 per mill at the surface
- Suggest more sewage-derived N was/is being introduced to the bay (..has it changed?)

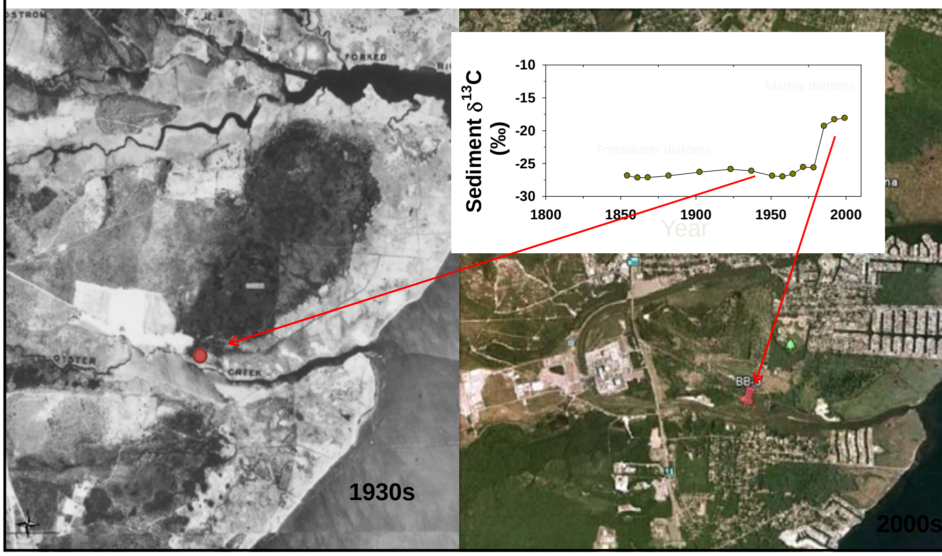


Changes in P with Time

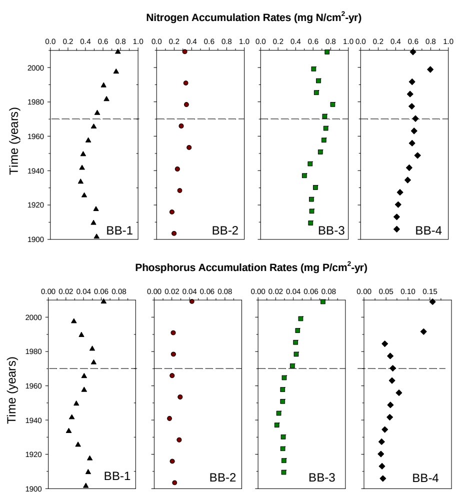
- Slight increase in P concentrations with time
- The δ^{13}C-OC does not change substantially with time (past 50 yrs) except at BB-3
- Lack of relationship between P and δ^{13}C-OC suggest that P is not controlling system wide productivity as shown in other aquatic environments
- Large shift at BB-3 reflects changes in vegetation type over time

Changes at BB -3

Potential Changes in:
- Vegetation type (C3 versus C4)
- C speciation (either source changes or related to temperature increase)



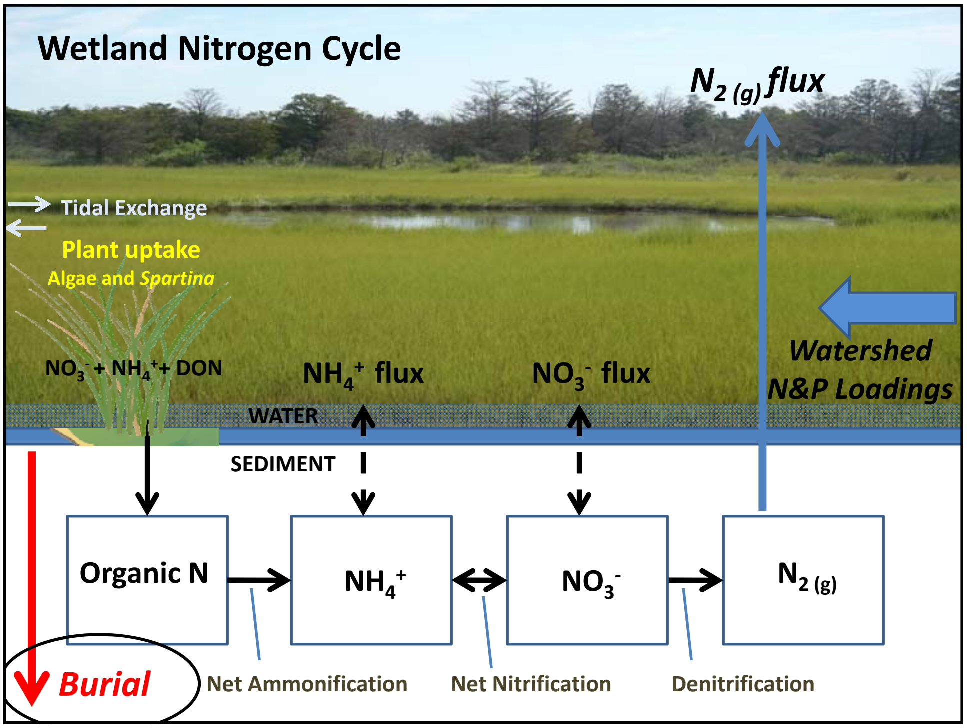
How much N and P are Buried in the Marshes of Barnegat Bay?



Accumulation of N&P over Time

- Using [N or P], sediment mass, and accretion rates to calculate accumulation rates over time
- Rates change with time, with a general increase in most cores starting in the ~1950s/1960s
- No distinct north-south gradient in rates (highest rate for P at BB-4)
- Can use rates at the surface and over time to estimate sequestration of N and P from wetland sediments

Burial rate = 5.2 ± 0.7 g N m^{-2} yr^{-1} (n = 4)



Comparison of Barnegat Bay marsh nitrogen and phosphorus burial rates measured in this study to rates of nitrogen and phosphorus inputs to the Barnegat Bay.

	Nitrogen (kg/yr X10^5)	Phosphorus (kg/yr X10^5)
Inputs	6.9	1.0
Marsh Burial:		
Avg Concentration (50yrs)	5.48	0.54
Burial as % of Inputs		
Avg. Concentration (50yrs)	79±11%	54±34%

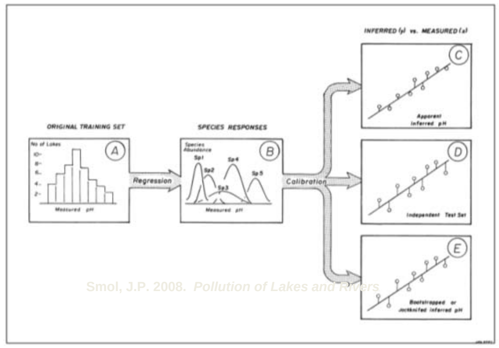
Nitrogen inputs ranged from 6.5 to 7.65 X10^5 kg/yr (Hunchak, 2001; Wieben and Baker, 2009; Kennish et al., 2007) while phosphorus input is derived from the Barnegat Bay Characterization Report. Wetland area (26,000 acres, 1.1 X10^8 m^2) are obtained from www.crssa.rutgers.edu/projects/lc/.

Barnegat Bay wetlands can sequester a substantial amount of N and P

Diatoms as Indicators of Ecological Change

Indicators of Many Different Variables

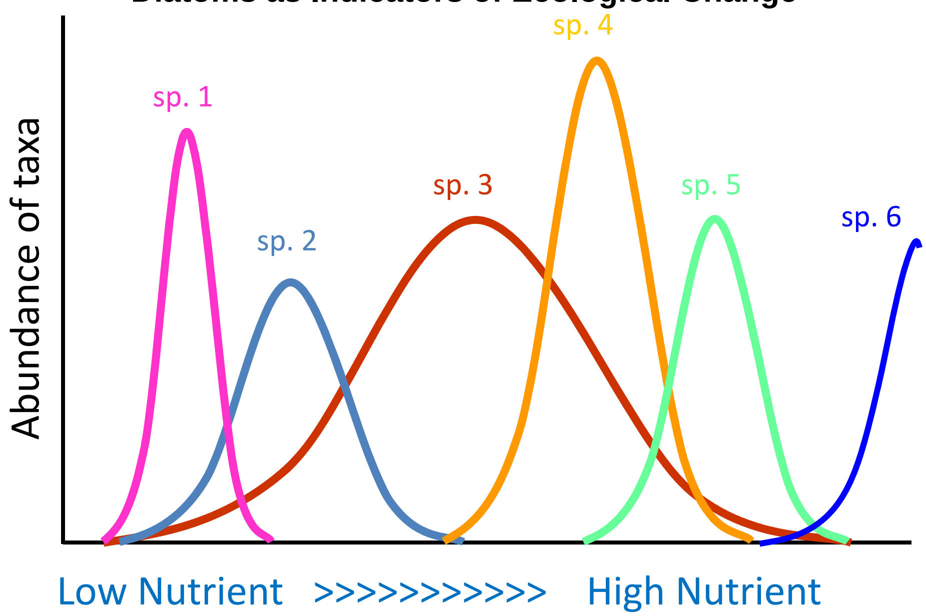
- Nutrient Levels
- Salinity-Conductivity
- pH
- Benthic/Planktonic
- Water Level
- Water Clarity



Sample and Data Needs:

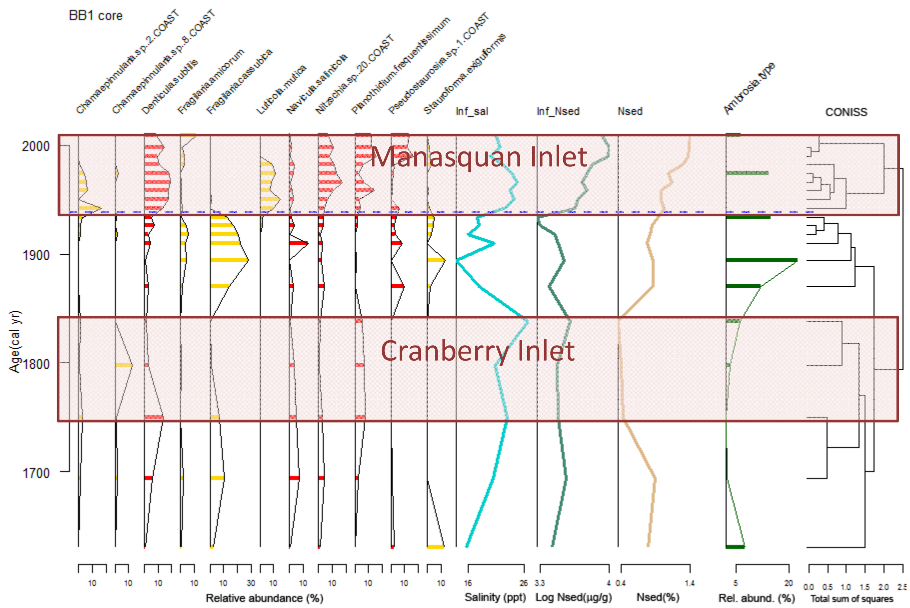
- Well preserved samples
- Calibration set (diatom species versus stressor)
- Adequate separation of the different groups
- Robust change in environmental parameter

Diatoms as Indicators of Ecological Change

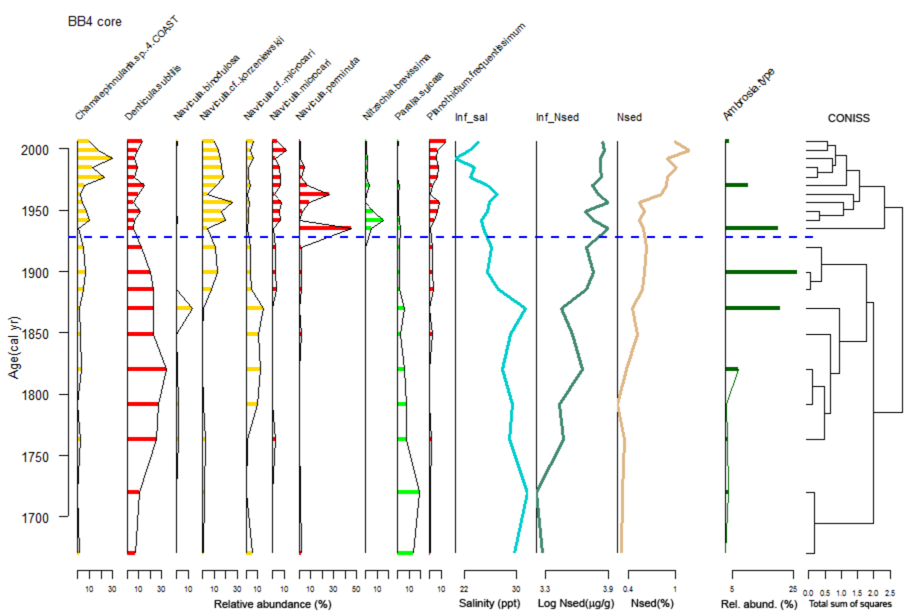


Various species of diatoms have variable tolerances for environmental parameters

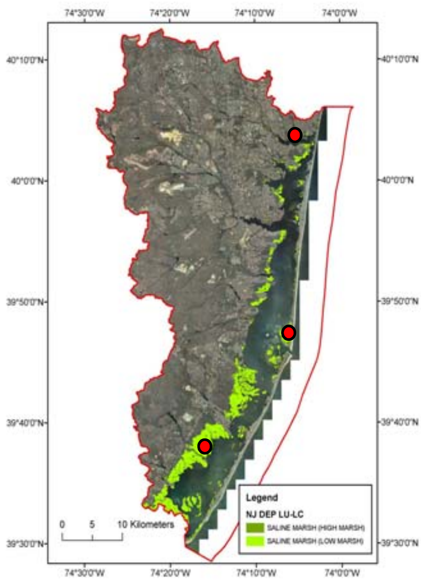
Core BB1: diatom-based inference shows strong N enrichment starting from 1940s



Core BB4: some N increase starting from 1800s

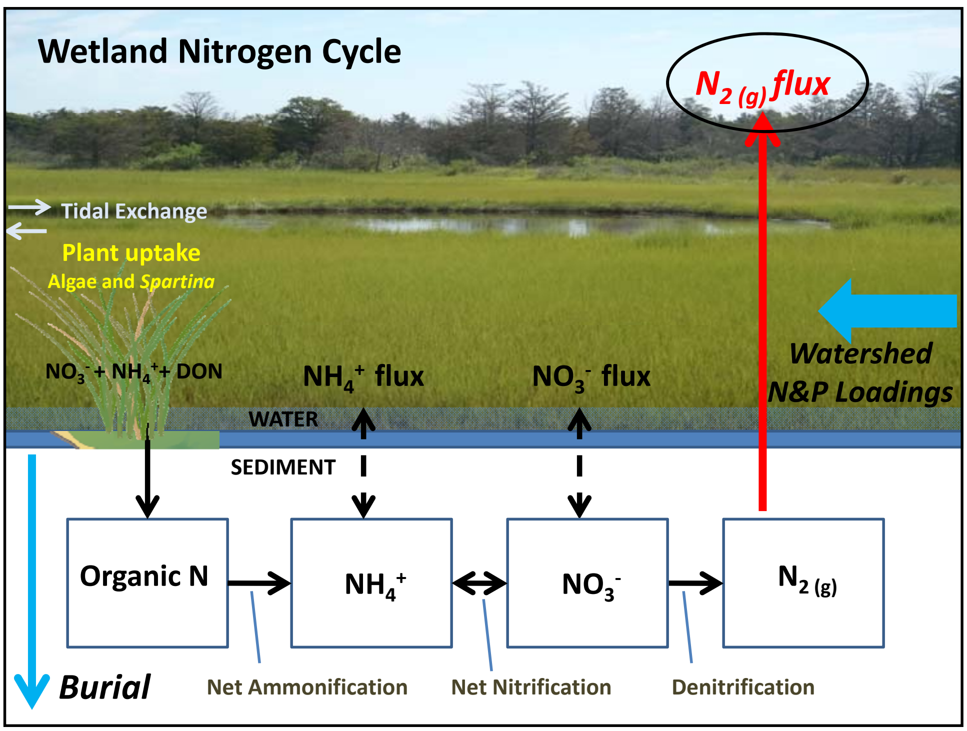


Barnegat Bay Marshes: Denitrification



Seasonal denitrification rates

- 3 salt marshes in north, mid-, and south bay
- 6 cores per marsh
- 3 times per year (May, July, October)
- Analyze cores for N- fluxes, oxygen demand, sediment carbon and nitrogen
- Determine average bay-wide flux rates (g N m^{-2} d^{-1})



Factors that can Limit Denitrification in Sediments

- Dissolved oxygen
- Hydrogen sulfide
- Lower pH
- Amt of labile carbon (i.e., easily degradable OC)
- Available nitrate (coupling of nitrification-denitrification)

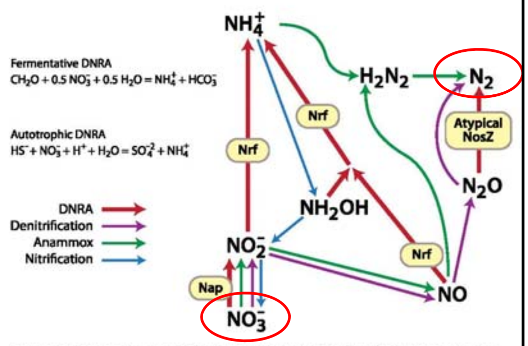
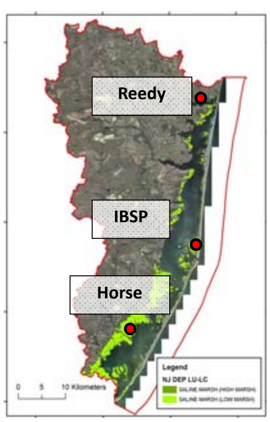


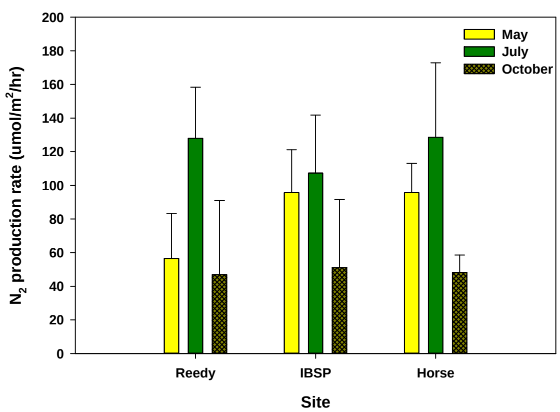
Figure 1. Some important aspects of the nitrogen cycle emphasizing the pathways important to dissimilatory nitrate to ammonium (DNRA). Some of the enzymes known to be involved in the DNRA process, or known to be associated with organisms carrying out DNRA, are shown in yellow. Nap = Periplasmic nitrate reductase. Nrf = Cytochrome C nitrite reductase. NosZ = Nitrous oxide reductase.

- **Question:** Importance of Anammox[1] and DNRA pathways?

[1] ammonium was being converted to N_2 (gas)

Denitrification Rates in Three Salt Marshes in Barnegat Bay





Other salt marshes
12 – 290 µmol/m²/hr
(Valiela et al. 2000)

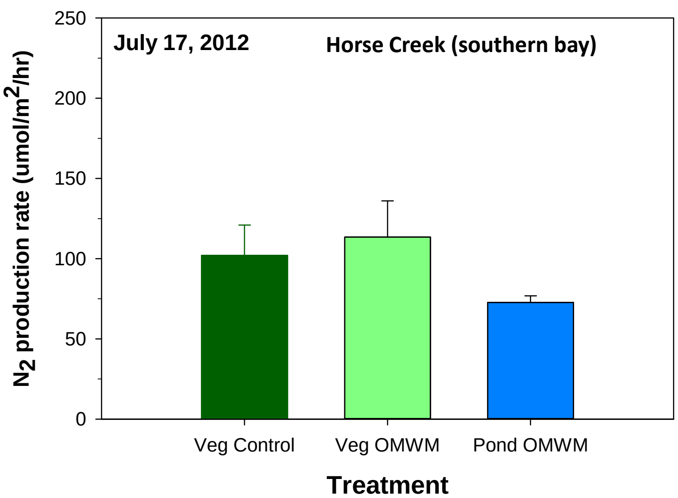
MONTH	N_2 Production (µmol/m²/hr)
May	83 ± 14[ab]
July	121 ± 20[a]
October	49 ± 19[b]

What are Open Marsh Water Management (OMWM) Systems?

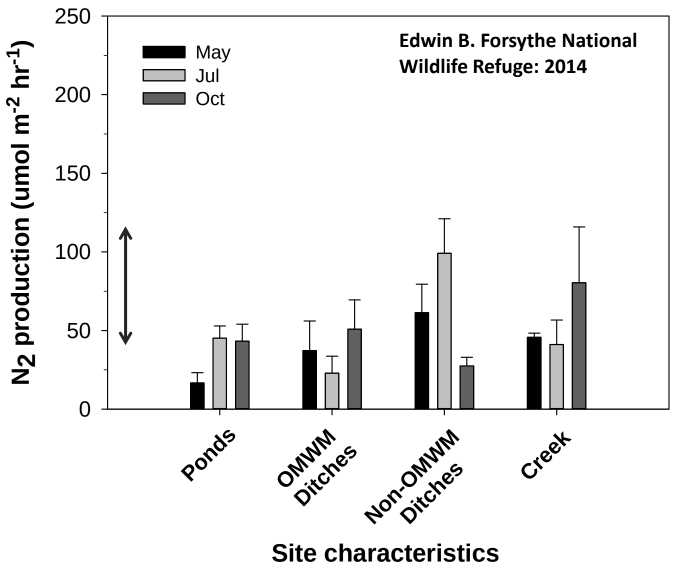
Mosquito control: since the 1970's the Ocean County Mosquito Extermination Commission has created over 9,000 ponds across 12,000 acres of salt marsh in Barnegat Bay, NJ.

- **Limited amount of information about how it affects marsh accretion and ecosystem services**
- **How much is enough?: balance between human health and ecosystem health**

Variation in Vegetated Sediments: Limited Ability to Detect Differences



Comparison of N_2 Production Among Study Sites

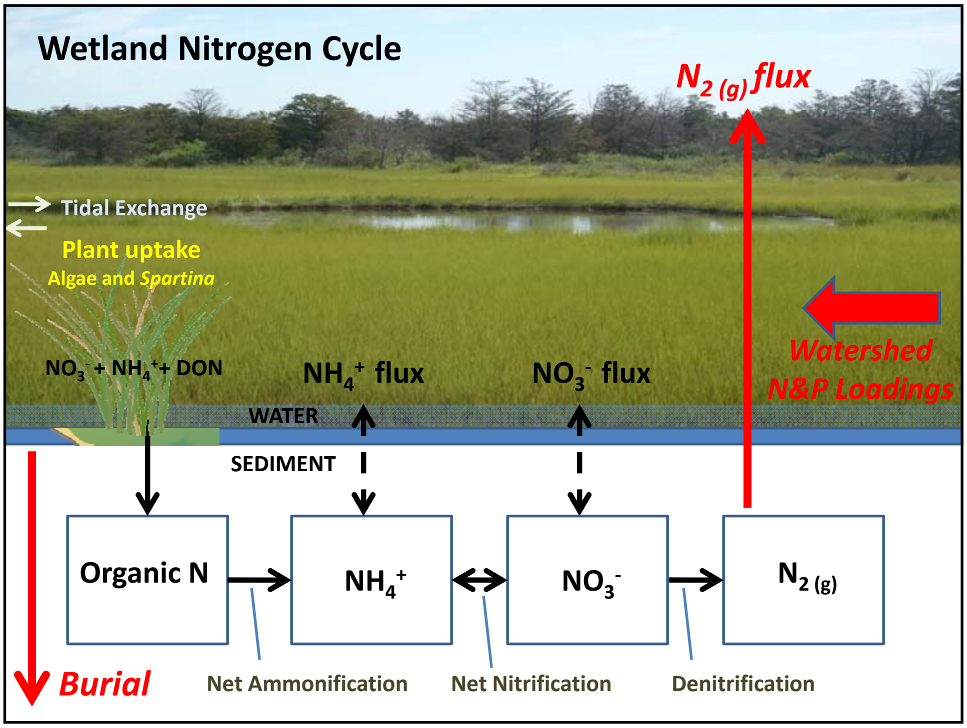


Summary of Denitrification Study

<u>Open water (OMWM) vs Vegetated marsh</u>

- Denitrification variable in vegetated marsh
- Much less variable in open water interior marsh sites
- No substantial difference between marsh open water and vegetated sites
- No relationship between porewater sulfide and N_2 production

Open Marsh Water Management (*OMWM*)



Comparison of Barnegat Bay Marsh Nitrogen Removal Rates Measured to Rates of Nitrogen Inputs to Barnegat Bay

	Nitrogen (kg/yr X10^5)
Inputs (1989-2011; Median)	6.73
Marsh Burial:	
Avg Concentrations (50yrs)	5.2 ± 0.71
Burial as % of Inputs	
Avg. Concentrations (50yrs)	77%
Marsh Denitrification:	
May	0.47
July	0.70
Oct	0.30
Avg ± SD	0.49 ± 0.20
Denitrification as % of Inputs	7.30%
Total Removal	84-98%

Nitrogen inputs ranged from 4.6 to 8.6 X10^5 kg/yr (1989-2011; Baker et al., 2014) Wetland area (26,900 acres, 1.1 X10^8 m^2) are obtained from www.crssa.rutgers.edu/ projects/lc/ and V. Depaul (USGS)

Summary and Conclusions

- Remaining wetlands play important role in nutrient cycles in Bay
- Plant uptake-sediment burial can sequester carbon, nitrogen and phosphorus (nutrient trading?)
- Denitrification is an important process for nitrogen removal in wetlands
- OMWM sites have similar rates in whole marsh
- Studies showcase the importance of BB wetlands and maintaining and increasing area

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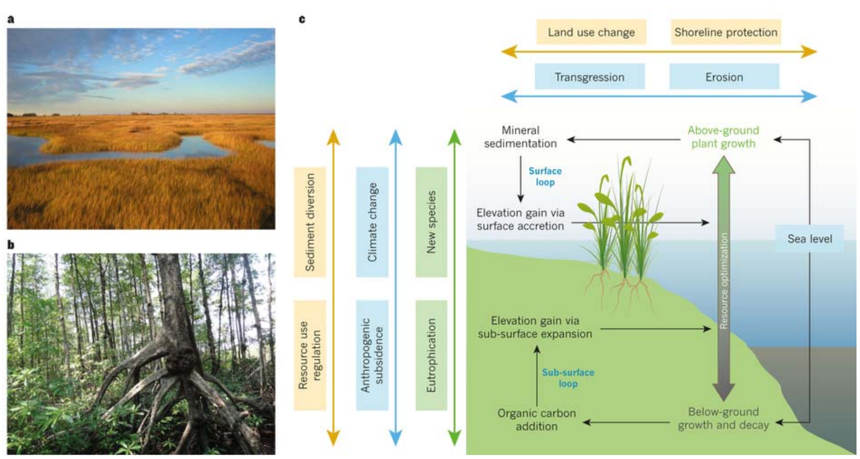
Barnegat Bay's
West Creek in
2013
Google earth



a
b
c
Land use change
Shoreline protection
Transgression
Erosion
Sediment diversion
Resource use regulation
Climate change
Anthropogenic subsidence
New species
Eutrophication
Mineral sedimentation
Surface loop
Elevation gain via surface accretion
Above-ground plant growth
Sea level
Resource optimization
Elevation gain via sub-surface expansion
Sub-surface loop
Organic carbon addition
Below-ground growth and decay